# Data Processing Technology and Economics

Second Edition

Montgomery Phister, Jr.

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*Dedicated*
*to my friends and associates*
*at*
*Thompson-Ramo-Wooldridge Products Co.,*
*Scantlin Electronics, Inc.,*
*and*
*Scientific Data Systems,*
*who taught me most*
*of what I know.*

## Preface

This book is intended to be of value both to those who use, and to those who design data processing systems, software, and services. It contains a quantitative description of the current status of the data processing industry, and shows how that industry has grown, changed, and evolved over the past thirty years. It thus makes it possible for the user to appraise his equipment, procedures, operations, plans, and costs in the light of industry-wide averages and trends. And it gives the designer a fresh look at the marketplace, and suggest new ways for him to evaluate what it costs him to design, produce, market, and maintain his products. The book should also be of interest to general readers curious about the processes by which complex technologies move from the laboratory to the marketplace. And it has served, and is serving as the basis for university-level courses for people who are engaged, or expect to become engaged, in the use, operation, or design of data processing systems. It presupposes that the reader begins having some familiarity with data processing—that he has taken one or more introductory courses in computers and programming, or that he has worked for some time in a job closely related to data processing system design, operation, or applications.

To help the reader understand better the purpose of the book, let me recount how it came to be written.

Between 1955 and 1971 I served as an engineering executive for three companies in the data processing industry: for TRW, where I participated in the development of the computer/process control business; for Scantlin Electronics, Inc., where I helped develop and operate an on-line financial data service; and for Scientific Data Systems (later Xerox Data Systems), where I was responsible for hardware development. I thus have some experience in the three areas of computer applications, operations, and design.

During these years I became convinced that, in general, computer system designers and users are preoccupied with technical matters and pay far too little attention to the economics of computer technology—to the study of the conditions affecting the production, distribution, and employment of data processing goods and services. We are fascinated by new product announcements, and debate the merits of the most-recently-announced systems. We go to seminars to learn about new instruments and techniques for measuring system performance. We study learned papers about structured programming and the Chief Programmer Team concept. We are inundated by articles describing revolutionary new concepts (e.g. voice translators) and technologies (e.g. magnetic bubbles). Much of the enjoyment of our jobs is derived from the fact that the field is in a constant state of engineering and scientific ferment.

But our interest in the way society *uses* data processing equipment is not as well-developed. We examine new-product announcements with too little understanding of the problems a supplier has in developing, manufacturing, and maintaining equipment. We buy instruments to measure what our systems are doing each microsecond, but do not know what functions they perform each week—what applications are most frequently implemented, and how much system time they require. We learn about new programming techniques, but do not really know how a programmer spends his time, or what programming problems contribute most to project delays. We are enthusiastic about new concepts and technologies, but have little feel for the length of time it takes to move even the most promising innovation from the laboratory to the office. And we have little or no appreciation of the costs of running a computer center or writing a program or maintaining a remote terminal.

These economic matters are, in practice, as important to the data processing practitioner as are the technical matters. The applications programmer who has studied nothing but his COBOL manual will not write as satisfactory a program as one who is aware of the costs of program maintenance, and of the expenses incurred when programs are run. The engineer who designs a new peripheral equipment controller knowing only electronics and logic will be less successful than a colleague who has examined the cost of maintenance, and is aware of the importance of preventive maintenance and of diagnostic features which can reduce maintenance time.

It therefore seemed to me that a book which collected together available facts on the economics of data processing would be useful to people working in the field, and could form the basis for a valuable course in Computer Science and Engineering, or in Business or Management. Because the field is continually changing, it seemed important that the book should present a history, which would show how rapidly (or slowly, depending on ones viewpoint) changes take place. Accordingly, I started collecting data and making notes in the late sixties, and in early 1972 started working on the book full time. A preliminary version was published and distributed in 1974 and 1975, when I taught a course based on the material, first at Harvard University, and then at the University of Sydney, in Australia. The first edition, covering the period 1950 to 1974, was published in 1976. This, the second edition, contains the first edition essentially unchanged (pages 1 to 514), and includes a Supplement (pages 516 to 666) which covers the years 1975-1978 and which revises some of the 1950-1974 data.

### A PERSONAL NOTE

The task of assembling a quantitative history of data processing has proven to be as difficult as it has been fascinating. I will not pretend that the result portrays the past with great precision. The reader will observe that the Supplement contains major revisions to some of the data in the first edition, and will rightly conclude that my 1975-1976 estimates are different from my 1978-1979 estimates, and that my 1981-1982 estimates may be changed once again. He will also observe, if he studies the tables and their accompanying notes, that there are wide variations of opinion between authorities on many basic facts. I present what is, as best I can determine, a balanced and consistent set of data describing industry history up to 1978-1979. But the reader should be forewarned:

1. Much of the data is from secondary or tertiary sources, based on surveys and samples or on informed estimates by individuals or organizations. Data from such sources is not always accurate.

2. Where authorities provide conflicting data, or where no data is available, I have made estimates of my own. The reasoning and calculations behind such estimates is given, but my estimates may of course be wrong.

3. At many points I provide interpretations and analyses of available data. Such interpretations are subject to errors in judgement, and errors of this kind are best detected in peer reviews of a work before publication. I have not been uniformly successful in obtaining reviews of this material—some sections have been read and criticized, others have not. The distribution of the preliminary edition, and the process

of teaching from that edition, resulted in the detection and correction of many errors. Publication of the first edition led to the discovery of others, which are corrected here. But there are likely to be still more, both in the first edition's material and in the Supplement.

Several friends have pointed out the danger inherent in publishing a book which attempts to provide data but which acknowledges that many sources are in disagreement with one another, and that much of the data was developed by means of tenuous inferences, extrapolations, and interpolations. They predict that numbers and charts will be used by others out of context as if they were undisputable facts, and that my warnings about the reliability of the data will be overlooked or ignored. I admit the likelihood of such misuse of information. But I am convinced that an imprecise history is better than no history at all, and that many organizations and individuals will be able to make intelligent use of this information to help understand the past in order to plan for the future. Furthermore, I hope publication of the book will lead to corrections and amendments which can be incorporated into later editions, and will encourage and stimulate the collection and publication elsewhere of better data in the future. Readers having comments and corrections should send them to me care of the publisher.

Finally, I hesitatingly comment on writing style. The book has provided entertainment as well as education for its author. If its style, including its use of the personal pronoun, is far from conventional, I hope the reader will not be offended, and will attribute the idiosyncrasies to the author's eccentric high spirits. Perhaps some later edition will be more dignified.

## ACKNOWLEDGEMENTS

The five year period 1972-1976 was a long time to be engaged in a writing project, and especially on a project which attempted something so new—something whose value and usefulness had yet to be determined. To a large extent, my confidence in the viability of this book was encouraged and sustained by the interest shown by a number of old and new friends, who helped me in a variety of ways—by supplying information, by putting me in contact with other sources of information, by pointing out relevant articles and books, and by giving me a push when my feet began to drag. Since publication of the first edition the circle of friends has grown, and in the following paragraphs I would like to acknowledge and thank everyone who has been so generous in providing help and encouragement.

Some of the computer companies have been cordial and interested. James B. O'Connell of IBM and J. Bradley Stroup of Honeywell answered many of my questions. Robert S. Arthur of the Control Data Corporation and Dr. Robert R. Johnson of Burroughs let me make use of their company libraries. C. Gordon Bell of Digital Equipment Corporation let me look into the DEC library, and has consistently been cheerfully encouraging.

Other friends in the industry were also very helpful. Pat McGovern, of the International Data Corporation has been extremely kind in making IDC data available, and in giving me permission to use it. His associates, James Peacock, John Rehfeld, and Paul Arabasz, have gone out of their way to help me understand and interpret that data. Isaac Auerbach of the Auerbach Corporation lent me copies of old issues of his company's reports. Dr. Walter F. Bauer, the President of Informatics, Lester Kilpatrick, the President of California Computer Products, Dr. Robert N. Noyce, Chairman of the Board of Intel Corp., Trude Taylor, the President of Electronic Memories and Magnetics, and Erwin Tomash, the Chairman, along with Graham Tyson, the President of Data Products all were most helpful and encouraging. Jean Sammett of IBM provided some very useful input on software. The late Dr. Robert Seeds of Fairchild and Gene Potter of Silicon Systems Inc., helped educate me on semiconductor economics. Viktor Sell of Ampex Corp. and Royce Fletcher, formerly of EM & M were extraordinarily kind in helping me put together the story about magnetic core memory developments. Dr. Clark Weissman made it possible for me to use the comprehensive System Development Corp. library. John V. Blankenbaker of International Communications Sciences and Sei Shohara of the Xerox Corporation read and commented on the material on electronic technology. Tom Gilb, a consultant whose home base is in Norway, supplied me with a number of leads to useful data. John W. Kitzmiller of the Electronic Industries Association gave me access to the EIA Market Data Book. Ken W. Kolence, of the Institute for Software Engineering, shared his organization's study results with me and was most helpful in answering questions. John Navas of Memorex helped me find some new sources of data. Glen Madland of Integrated Circuit Engineering let me make use of his organization's remarkable publications.

Several university friends have encouraged me, although some have reservations about the viability of a computer science course on data processing technology and economics. Prof. John Bennett of the University of Sydney, Prof. A.S. Douglas of the London School for Economics, Prof. Donald Dunn of Stanford, Professors Gerry Estrin, Walter Karplus, and Mike Melkanoff of UCLA, Prof. Jack Munushian of USC, Prof. Allen Newell of Carnegie-Mellon, and Prof. Tony Oettinger of Harvard must all be mentioned. I am especially grateful to Tony for making it possible for me to teach the seminar at Harvard in the Fall of 1974, and to John for inviting me to teach at the University of Sydney in the winter of 1975. I must also express my admiration for Prof. Melkanoff, who has made use of the book as the basis for a Computer Science course at UCLA. Finally, I want to thank Dr. Michael C. Mulder and Prof. Gerald L. Engel, who encouraged me to comment on the revised IEEE and ACM Computer Science curricula and who, with their colleagues, listened courteously and patiently while I presented the case for a course on the subject-matter of this book.

Some friends in government circles were also very kind. Dr. Ruth M. Davis, formerly of the National Bureau of Standards, let me make use of her organization's library and reference materials, and encouraged some very useful discussions with members of her staff. Mr. Sol Padwo of the Department of Commerce helped me interpret government statistics on the computer industry, and continually encouraged me to go forward. Richard S. Cook and S. Schechter of the General Services Administration answered my various questions and provided me with helpful data. Len Smith, of the Department of Commerce, showed me how to locate data on tabulating card sales.

A variety of other friends have helped in ways too numerous to mention. I hope they will forgive me if I fail to include them here. But I must close with a final note of thanks to three good personal friends who have advised me since the beginning of the project. Their help and enthusiasm has been most welcome and appreciated—Lowell Amdahl, Dan McGurk, and Keith Uncapher.

# INTRODUCTION

"That, Sir, is the good of counting. It brings every thing to a certainty, which before floated in the mind indefinitely."

—Samuel Johnson

# MARKETPLACE

"Three women and a goose make a market."

—(Italian Proverb)

# PRODUCTS

"There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy."

—Hamlet (Act 1, Scene 5, Line 166)

# APPLICATIONS

"Be not the first by whom the new are tried, / Nor yet the last to lay the old aside."

—Alexander Pope

# COSTS

"For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it?"

—Luke 14:28

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## LIST OF TABLES

# Part I

# Introduction

## PURPOSE OF THE BOOK

The collection of enterprises which is known as the Computer Business has had a remarkable history in the years since World War II (when the first modern machines were developed) and particularly since the mid 1950's (when the first commercial machines were sold). Entrepeneurs have made and lost fortunes, companies have blossomed and died, ingenious inventions have succeeded and failed, and in a wonderfully short time the computer has begun to play a part in everyones life. We see it first hand, so to speak, in such functions as printing and processing our bills and bank statements, handling our reservations for air journeys and sporting events, computing our pay and printing our paychecks, calculating our mortgage payments, and reviewing our credit when we cash checks. And we're also aware of its use behind the scenes, controlling portions of chemical or petroleum plants, helping astronauts land on the moon, calculating stresses in the design of new aircraft, bridges, and skyscrapers, assisting doctors in interpreting the results of electrocardiagram tests, processing census data, searching for characteristic word patterns in Shakespearean texts, checking our income tax returns, and analyzing the data from experiments in university laboratories.

Although we call it the Computer Business, and although it all started because the United States government wanted a rapid and accurate method for carrying out complex calculations, we shall see that the real heart of the business is the storage, retrieval, transmission, sorting, and analysis of all sorts of data, numerical and alphabetic. For that reason, the business is also, and more accurately, known as the Data Processing Industry, and the heart of any equipment installation is a Central Processing Unit (CPU), not a "computer".

The scientist and the bookkeeper, the inventor and the businessman, and the tax collector whose business is everyones—all these gentlemen have been customers for data processing services ever since numbers and letters were invented. The early Egyptians who calculated the radius of the earth have their counterparts in NASA Scientists planning a route to Saturn. The ancient Babylonian who recorded on papyrus the value of his ship's cargo was probably as frustrated as a modern corporation president who is trying in October to find out what his costs were in August. Data processing is an ancient and generally honorable profession. But in the milleniums which have passed since the first byte was processed, there has never been a period in any way comparable to the computer revolution of the past 20 years. The scientist, bookkeeper, engineer, businessman, and tax collector who use data processing equipment or services, and the smaller and more turbulent groups which plan, design, manufacture, and market these products need to have an understanding of the magnitude of this revolution and of the forces which shaped it.

To achieve this understanding, we must distinguish three aspects of the study of technology:

1. The **Science of Technology** tells us how to design, fabricate, and analyze products, services, and activities. It tells us, for example, that we can store information in superconducting circuits or in magnetic films, and that we can program computers to translate languages or to access large files of data.

2. The **Economics of Technology** examines the production, distribution, and consumption of technology-based goods and services. It tells us, for example, that magnetic films are cheaper than superconductors for data storage; and it evaluates language translation and file processing in terms of their operating costs and of the number and nature of potential applications.

3. The **Politics of Technology** deals with the decisions society must make about the uses of technology. It tells us, for example, that citizens have the right to examine and correct certain automated files; and it sets aside public funds to support research on holographic memory technology.

Thus the science of technology tells us what is possible, and can propose and develop a variety of techniques for solving our problems. The economics of technology tells us which of science's possibilities is useful, and why. It can therefore evaluate various solutions in the light of society's habits and interests. And the politics of technology tells us which of science's possibilities is forbidden and which is selected. It represents the complex procedures by which society decides how to deal with its troubles and opportunities.

It is my contention that individuals and organizations interested in data processing and in computer science and engineering pay far too little attention to the economics of technology. Technical books and journals, professional society meetings and conferences, government publications, and computer-oriented trade magazines and newspapers are largely devoted to studies of and news about the science of technology. University courses and curricula in computer science and engineering are, also, typically devoted to science (PhisM76), though the politics of technology has received increasing attention in recent years. There is, of course, some work done and reported on the economics of technology—much of the data in this book comes from such sources. *But our preoccupation with the science of technology causes us all too often to focus our attention on problems which are technically challenging and prevents us from trying to determine what their solutions are really worth.* In support of this statement, let me adduce three examples:

1. In December, 1971, the California Commission For Teachers Preparation and Licensing issued a report (GustG71) on the analysis of an Automated Teacher Credentialing System (ASTEC). The system, which at that time had been in operation for over a year, had been designed with the help of an aerospace firm, an equipment manufacturer, and a national accounting/consulting firm. Its operating cost at that time amounted to $3.60 per document. The report recommended that the computer system be discontinued, and that a manual system whose cost was estimated at $.50 per document be put in operation. *The glamorous computer is applied much too often in situations where the user does not properly consider the economics of various alternative ways of solving problems. The emphasis is placed on "how can I best design a computer system for this application?" rather than, "what is the most economical solution to this problem?"* And if we take into account the natural reluctance of organizations to admit their mistakes, we must conclude that uneconomic systems like ASTEC are probably in widespread use.

2. In a notable paper on FORTRAN Programs, (KnutD71, notable for its clarity and interest, and also because it was apparently the first such study ever carried out on one of the most widely-used computer languages) Knuth presented statistics on the actual use of various FORTRAN

features by working programmers. One conclusion of that study was that typical user FORTRAN programs are remarkably unsophisticated. In reflecting on this surprising discovery, Knuth remembered a paper he prepared some years earlier which showed how the translation of a very complicated FORTRAN statement could be achieved with only 19 machine instructions compared to the 21 required by a previously-published method. He comments, "the fact that (FORTRAN) arithmetic expressions usually have an average length of only two operands, in practice, would have been a great shock to the author at that time." And he further says, *"there has been a long history of optimizing the wrong things, using elaborate mechanisms to produce beautiful code in cases that hardly ever arise in practice, while doing nothing about certain frequently occurring situations."*

3. In an early book on computer logic design (PhisM58), Phister spent a full 50 page chapter describing three methods for simplifying Boolean equations. To justify this extravagant waste of paper, Phister cited the widespread use "today" of diode gates, and the fact that configurations of such gates, "can be made to correspond to a particularly convenient definition of 'minimum' ". *All too frequently we see this unhappy trait of solving today's (or yesterday's) problems without trying to anticipate what tomorrow's will be; and of restating problems in such a way that solutions are possible, though the restated problem may bear little resemblence to real problems.* Judging from papers and correspondence in computer journals, engineers are still working on the Boolean simplification problem, without regard even to today's hardware economics, much less tomorrow's.

These three examples have a common thread. They illustrate situations where an interest in the question of what is technically possible has been the driving force, rather than the question of what is economically important. Only by considering a variety of alternative data processing systems, and by estimating the costs of installing and operating each one, can we make rational decisions in systems planning and design. Only by studying the way programs are actually written, and by identifying the costs of writing, debugging, compiling, and running real FORTRAN programs (and Knuth's article only treats one aspect of running costs, important in programs which will be run time and again), will we be able to write truly efficient compilers. Only by learning which logic systems are in widespread use, and by understanding costs and cost trends in designing and manufacturing logic systems can we determine what aspects of logic design need attention.

Only by studying the economics of technology can we best determine how to use and direct our science. Let me emphasize the point by stating it in the form of a principle: *A study of the science of technology defines what is possible; a study of the economics of technology establishes which of the possibilities is practical and useful.*

I am thus advocating that data processing system designers, users, and managers will all benefit from a very broad view of the economics of the industry. It might be argued that users should study only information on applications; that programmers should only look at data on programming costs and program use; that engineers should concentrate only on hardware development and manufacturing costs; and that officers of hardware companies should only be interested in data on the hardware marketplace. I suggest we can all benefit from a much broader picture of the industry. Specifically, I contend that:

—Users will make better decisions in planning for the future if they appreciate what has happened in the marketplace, and understand better the changes which are taking place in product price and performance.

—Applications programmers and systems analysts are likely to plan and write better programs if they are aware of the costs of both program maintenance, and of operating a computer center.

—Systems programmers may design better operating systems if they recognize the cost of system down time and of its relationship to software design; and they will design better compilers if they take into account the practices of compiler users.

—Hardware designers are likely to make better design decisions if they are conscious of the concept of Life Cycle Costs, and if they perceive the many cost ramifications of a new component or assembly.

—Managers at all levels, in all disciplines, will benefit from a broad view of all aspects of data processing system design, manufacture, distribution, and use.

I hope, then, that this book will help data processing system designers and users:

1. Develop an approach to problem-solving and problem-identifying which is based on an analysis of the economics of data processing system design and use.

2. Formulate their own lists of the most critical and important data processing problems facing the computer industry specifically, and society in general; and use those lists to help direct applied research and product development.

3. Understand better the relationship between different aspects of data processing, and appreciate how a seemingly trivial or routine policy or decision established at one point may have very large economic implications at other times or places.

4. Learn what kind of industry data is generally available, and develop a healthy skepticism regarding the accuracy of such data. Take steps to collect and disseminate better data on all aspects of data processing.

5. Contribute more effectively to discussions regarding the politics of technology, by being better able to evaluate the effect of political decisions on data processing costs and functions.

## ORGANIZATION AND FORMAT OF THIS BOOK

### The Organization: Four Topics

The book is organized in four functional chapters, covering the Marketplace, Products, Applications, and Costs. The first chapter, on the Marketplace, describes the various subdivisions of the industry, shows how each has developed, and how that development compares with that of other industries and of the economy as a whole. The chapter on Products, which comes next, examines the various equipments, services, and materials which have been and are being marketed, and shows how prices and performance have changed over the years. It starts with a discussion of unit performance, and then reviews a number of approaches which have been used to study and characterize system performance and efficiency.

The third chapter, on Applications, attempts to analyze the uses and potential uses of data processing equipment, to provide a basis for understanding why the industry has grown so rapidly. It includes data on alternative, conventional (manual) data processing methods, and compares the costs of manual and automatic computing and data handling.

The final chapter, on industry Costs, attempts to provide a basis for understanding the development, manufacturing, marketing, and maintenance costs which are fundamental to the industry and which provide a floor for the prices the user (the end customer) pays.

Looking at the outline from a gross point of view, the reader may observe my purpose is to *describe* the growth of the data processing industry in the first chapter, and to provide facts and opinions in an attempt to *explain* that growth in subsequent chapters.

**The Format: Two Presentations**

Having outlined the content, let me now indicate the format in which this information is presented. The book contains two presentations at two levels of detail, each divided into four chapters which follow the above functional outline. The first presentation (Part I, pp. 1-236) contains a number of graphs, charts, and drawings accompanied by definitions, explanations, and descriptions. The text and graphs are arranged on facing pages, and these pages are intended to present an objective, factual description and discussion. The reader who wants to gain some understanding of the history and status of modern data processing, or who is simply interested in the interaction of economics with technology in general, should be able to read Part I as an independent document, without reference to the second part.

Part II contains, in tabular form, the graphical information of Part I, along with a great deal of related material not plotted. Each table in Part II is accompanied by various definitions, together with descriptions of the source of the data and of any calculations that were carried out. These notes refer in abbreviated fashion to the annotated bibliography, which, with the indexes, appears at the end of the book.

For readers who wish to use the data for their own analyses, or who want to understand where the data comes from, I supply in Part I references to the tables in Part II and to the bibliography. Most figures are plots of tabular data from Part II, and a citation (usually in the upper left-hand corner of the figure) states the identity of the source table or tables. Furthermore, many of the tables contain a column labeled "Figures", and an entry in that column opposite some specific row of the table tells which figure contains a plot of that row. For example, Figure 1.1.1 references Table II.1.1.1; and the "Figures" column of that table shows that lines 1, 2, and 3 are plotted in the figure.

There are some tables in Part I. Source information for many of them is shown in the table itself. For others, there are notes in Part II describing the sources. These notes appear in Part II in sequence with the Part II tables. For example, the notes for Table 2.23.4 appear in Part II preceeding those for Table II.2.23.4. *Note that Part II tables are distinguished by having a Roman numeral II preceding their number, and that the page headings for Part II are also preceded by that Roman numeral. Figure and table numbers containing no Roman numeral will be found in Part I.*

**The Supplement**

The ideal way to bring the book up to date would be to revise it completely. However, in the interest of reducing the delay between the time year-end 1978 data was available (March to July, 1979) and the time the book is published (end of 1979), we have included the updating information in a Supplement. For purposes of description, let's refer to the first edition's material (pages 1-514) as DPT&E, standing for *Data Processing Technology and Economics.* The Supplement follows immediately after DPT&E, and has the same organization—four topics—and format—two presentations. However, the Supplement does not cover every topic that is covered in DPT&E.

The best way to use the book is to select a topic, from Table of Contents or Index, and start reading about it in DPT&E—that is, in the first edition portion. This reading will set the stage—define terms, provide background information and comments. If the material is covered in the Supplement, the Section or Table in DPT&E will be marked thus: ●

Having read the DPT&E material, the reader is prepared to look at the update in the supplement. Note that the sections, figures, and tables in the Supplement use the DPT&E numbering system, but append a letter of the alphabet.

For example, suppose you are interested in Data Communications products. You turn to Section 2.14 and read pages 76-81, where you see plots of communication costs versus calendar time and versus usage, and learn what is included in those costs and how breakeven conditions are defined for dialed and private lines. You observe that the section is marked with a dot, and therefore know it is updated in the Supplement. You find Section 2.14a in the Supplement (p. 548) by consulting the Table of Contents or simply by thumbing through the pages looking at the running heads at the top of the page. On page 549 you find Figures 2.14.1a, 2.14.1b, and 2.14.1c along with Figures 2.14.2a and 2.14.3a. The first three are updated versions of Figure 2.14.1, on page 77, and the other two are updates of Figures 2.14.2 and 2.14.3. Because you read the descriptive and defining material in Section 2.14 of DPT&E, you are able to follow the somewhat abbreviated discussion in Section 2.14a of the Supplement. If you are interested in the tabular material and look at Table II.2.14.5, for example, in Part II of DPT&E (p. 399), you find it marked with a dot also, and look for a Table II.2.14.5a in Part II of the Supplement.

**Bibliography and Indexes**

References to the bibliography generally appear in parentheses. The abbreviation for a reference is normally created by taking the first four letters of the author's last name, adding the first letter of his first name, and finally adding the last two numerals of the year the reference was published. The bibliography is organized first by subject matter (as identified by a section number from Part I), and within subject is alphabetical by the abbreviated bibliographical reference—which is very nearly alphabetical by the author's last name. In addition, the citations are indexed at the end of the book, and the reader can look up a citation in that index to discover which section of the bibliography contains it.

The indexes cover both DPT&E *and* the Supplement.

## THE SOURCES AND ACCURACY OF THE DATA

The bibliography begins with a detailed discussion and commentary on the organizations which collect, and the publications which disseminate information of interest to the data processing industry. In the next few paragraphs, I will comment on the reliability of this public information, and of the data contained in this book.

In a fascinating book "On the Accuracy of Economic Observations", Oskar Morgenstern lists a host of reasons for errors in economic statistics. The principal difficulties regarding statistics about the computer industry seem to be:

1. Manufacturers, service organizations, and even users are very secretive and do not generally publish statistics about their own operations. They presumably are driven to withhold data by a desire to hide successes from their competitors, failures from their stockholders, and anti-trust evidence from the government. Contrast the data processing with the automotive industry, where every week or so the *Wall Street Journal* publishes the precise number of cars of each model manufactured during the previous week.

2. Private organizations attempting to keep track of the marketplace are handicapped by the industry's phenomenal rate of growth. The estimated number of systems in place at the end of a given year, for example, is based on an estimate for the end of the previous year plus an estimated shipment rate minus an estimated return rate. In a dynamic situation, none of the numbers is easy to guess. A typical result is shown in Table 0.1, which compares estimates of the number of systems of various kinds in use in the United States at two specific dates, as estimated by *DP Focus*, by International Data Corporation, the publisher of *EDP/IR*, and by John Diebold, the publisher of *ADP/N*. In each case, the numbers shown are for precisely the same group of computers. Note that the numbers not only differ wildly (Diebold estimating 47% more 360's than *Focus*, and 18% more than IDC), but that it is not uncommon for one authority to report an increase in installations for a period of time in which another authority reports a decrease.

3. Inconsistent definitions or classifications introduce another cause of error. Part of the differences in Table 0.1 might be explained by differing definitions of the word "install". Is a system installed when it is shipped by the manufacturer? When it arrives at the installation site? When it is accepted by the customer? When the manufacturer sends an invoice? When the customer pays that invoice? Should the manufacturer's use of his own computers be included in the statistics? There is no standard answer to any of these questions, and in fact each manufacturer may use a different definition in his own internal statistics on installations—but it is unlikely that these matters of definition can be the cause of the startling discrepancies in Table 0.1. Table 0.2, on the other hand, recording the opinions of different authorities as to data processing dollar shipments in 1960, 1965, and 1970, clearly reflects problems having to do with a definition of what is included in "shipments". The Electronic Industries Association, the International Data Corp., Arthur D. Little, Inc., and the U.S. Department of Commerce are all represented. Each provides data, and generally the definitions given for the data are imprecise enough that they may account for much of the discrepency shown. Thus, for example, the EIA figures include analog computers and minicomputers; EDP/IR and Arthur D. Little include shipments by the nine major system manufacturers, but the former includes an additional four to six manufacturers, while the latter excludes systems returned and reinstalled—which would lead one to expect the Arthur D. Little figure would always be less than the EDP/IR figure. (This data, along with other comparable figures, is discussed in Part II.)

There are undoubtably other sources of error, difficult or impossible to identify. Manufacturers may disseminate misleading figures; questionnaires, which are frequently used to obtain data from users, may be filled out carelessly or may be misinterpreted by the respondant or by the analyst; and keypunching or data processing errors may occur in the course of forming or processing a data base of industry statistics.

Morgenstern quotes with approval Norbert Wiener's remark, "Economics is a one or two digit science". My experience in collecting material for this book has convinced me that many aspects of the economics of data processing are one digit sciences. (It may even be argued that the one digit is binary, not decimal. It would perhaps be appropriate that we count shipments, installations, and other intractable figures to the nearest power of two.) Nevertheless, the reader will find that I have taken extravagent steps to present data having a precision of five or six decimal places. In Table II.1.20, line 11, for example, I report that the total domestic revenue for U.S. data processing companies was $7,096,000,-000 in 1968. The "6" in the millions position of that number seems to imply somehow that I believe the revenue was between $7.0955B and $7.0965B. Let me immediately and loudly deny that I believe any such thing. I have tried to be consistent in supplying data having much more precision than it has accuracy simply because premature "rounding off" leads to a loss of information. If I had rounded off the components which add to $7.096B *before* performing the addition, the sum would have been $7.3B. By keeping five decimal digits in my Table, I mean to imply that actual 1968 revenue from the sources given lies somewhere in a range surrounding $7.096B—not $7.3B. Most important, the tables are intended to supply data for other calculations by the user; and the value of the information is greatly reduced when precision is lost.

At one time I contemplated supplying estimates of accuracy along with the data. I dropped the idea because of the impossibility of estimating accuracy with any accuracy. I have settled simply for recording, as faithfully as possible, my sources and my assumptions. I thus pass off to the reader the burden of deciding how accurately the data describes the facts.

The reader is therefore forewarned. It is unwise to make use of data in this book, or from other hopefully more reliable sources, without thoroughly understanding what the data means and how it was derived. Whenever any action is being taken based on economic data, the user must be careful to figure out how sensitive his expected results are to errors in that data.

The scarcity of accurate data is certainly discouraging to the scientist, the engineer, or the businessman who is trying to figure out "which of the possibilities is important". With the data so unreliable, is it even worthwhile collecting and studying it? The answer is, unquestionably, that it is worthwhile. Although we don't know exactly how many IBM 360's were shipped nor what their average sales price was, our estimates and approximations can tell us relatively which of the models contributed the greatest revenue to IBM, and how that revenue compared with that of similar products by other manufacturers. Though we don't know exactly what it costs to manufacture a $500,000 system, or to maintain that system for a year, we can formulate estimates which tell us the relative importance of different elements, and which show how and why these proportions have changed with time. Although we can't know exactly how the population of programmers or magnetic tape reels or line printers or memory bytes or data service companies has changed, year by year, since 1950, we can find enough data to formulate an estimate of each of these and can gain some understanding of the relationship between them.

It is quite likely, in a field where data is so staggeringly unreliable, that I will in the following pages draw wrong conclusions or mistake cause for effect or confuse the trivial with the vital. But the advantages to be gained far outweigh the risks of error. It is, I believe, much more important that the reader finish this book with a new understanding of the relevance and importance of economic data to his work than it is that the data presented here be flawless. It is also to be hoped that errors and inconsistencies in my data will stimulate various public and private organizations to collect or to finance the collection of better data—an activity which will benefit us all.

**TABLE 0.1 NUMBER OF SYSTEMS INSTALLED IN THE U.S., AS REPORTED BY DIFFERENT AUTHORITIES**

| Date of Census | | 6/30/70 | | 6/30/71 | |
|---|---|---|---|---|---|
| Authority | DPFocus | EDP/IR | ADP/N | EDP/IR | ADP/N |
| Computer System | | | | | |
| 360/20 | 7161 | 7750 | 8600 | 8600 | 8500 |
| 360/30 | 5487 | 7650 | 8900 | 6600 | 8600 |
| 360/40 | 2453 | 3320 | 3900 | 3200 | 3400 |
| All 360's | 18189 | 22593 | 26715 | 22811 | 25232 |
| All IBM | | 32079 | 38300 | 33864 | 38629 |
| All NCR | | 3590 | 2988 | 3663 | 3755 |
| All Univac | | 4672 | 4703 | 4730 | 4740 |
| All Manufact'rs | | 47053 | 54050 | 48652 | 55466 |

**TABLE 0.2 VALUE OF SHIPMENTS BY U.S. COMPUTER MANUFACTURERS, AS REPORTED BY DIFFERENT AUTHORITIES. (In $ Billions)**

| | Worldwide Shipments | | | Domestic Shipments | | |
|---|---|---|---|---|---|---|
| Calendar Year: | 1960 | 1965 | 1970 | 1960 | 1965 | 1970 |
| Authority | | | | | | |
| EIA | .630 | 2.830 | 5.162 | | 2.574 | 3.958 |
| EDP/IR | .72 | 2.40 | 7.29 | .59 | 1.77 | 4.37 |
| ADL | | | 7.27 | .53 | 2.10 | 4.94 |
| U.S. Dept. of Commerce | | 2.6 | | | | |

## 1.1 Background ●

We all know that the 20th century has been a period of unprecedented innovation. A variety of political, social, economic, and technical revolutions have changed both the face of the earth and the way we look at it. In order to see the data processing revolution in proper perspective, we will take a very brief look at some measures of the world's growth and change.

**Gross National Product (GNP).** The GNP has generally been adopted by world government and business as a measure of the size of a country's economy. It is defined as the sum of four components: personal expenditures for goods and services; government purchases of goods and services; gross investment in machinery and inventories; and net export of goods and services. The American GNP is plotted in Figure 1.1.1, and has grown from $20B at the turn of the century to over $1,000B today. However, those numbers, generally referred to as "GNP at current prices", do not take into account the effects of inflation; and a price deflator is therefore shown in the figure. The deflator is referenced to the year 1958, and Figure 1.1.1 shows that something which cost $1 in 1958 cost about $1.50 in 1970 and only $.25 in 1900. The GNP at 1958 prices, then, is computed by dividing GNP at current prices by the price deflator, and gives a measure of the "real" change in the country's economy. Comments:

1. The years 1915-1920, 1940-1948, and 1965-1975 were periods of substantial inflation.

2. A recession is defined as a period during which there occurs a decline in real GNP. Major depressions occurred in 1919-1920 and 1929-1933, and there were recessions in 1949, 1953, 1957, 1960, 1969, and 1974. The combination of recession and inflation which occurred in 1970-1975 was unusual.

3. The period from 1947 to 1969, during which the data processing industry was created and began to grow, was a relatively stable period during which the country's real output more than doubled in value.

The U.S. computer industry, led by IBM, has played a dominant role in world data processing and we therefore must look at economic growth abroad as well as at home. Figure 1.1.2 shows the growth in GNP for four of the world's major industrial countries, chosen because of their interest in, and widespread use of, data processing equipment. Note particularly the phenomenal rate of growth of the Japanese, West German, and French economies in the years since World War II. Figure 1.1.3 shows how GNP per capita has developed since the war for these four countries and for the United States. Japan's vitality in closing the gap between itself and Europe, the United Kingdom's fading prosperity, and the traditional Franco-German competition are all illustrated.

Returning to the American economy, let us look at the relative size of various industrial subdivisions. Figure 1.1.4 shows how U.S. National Income (which is the sum of earnings by labor and property—wages, rents, and interest—and which is directly related to and less than GNP) has shifted during the twentieth century. Note the growth of manufacturing and government share of National Income, and the decline in that claimed by agriculture. Note also the relative sizes of these different components of the economy, all of which are customers for data processing equipment and services. If the total market for data processing products were proportional to an industry's share in national income, manufacturing would be the biggest user, followed by wholesale and retail trade, government, the service industry, and finance (including insurance and real estate). Mining, construction, transportation, communications, and public utilities—the other major industrial subdivisions—together accounted for less than 15% of total national income in 1970.

**Industry Sales.** Next let's look at three major segments of American industry, and begin to get some feeling for the relative importance and impact of the computer business. Figures 1.1.5 and 1.1.6 show the growth which has taken place in automobile sales, electronic sales (which will be defined in a moment), and telephone revenues since the beginning of the century, both in current dollars, and per capita in 1958 dollars. The erratic fluctuations in new car sales, which are tied to the whims and pocketbooks of the consumer; the contrasting smooth growth in telephone revenues, arising from a service we have come to regard as a necessity; and the most recent explosive growth of the heterogeneous electronics industry—all are clearly illustrated here.

Electronic industry statistics shown in Figure 1.1.7 are provided by the Electronic Industries Association (EIA), which distinguishes four categories of sales: government products, mostly procurement, research, and operations for the Department of Defense, but also including NASA expenditures; communications and industrial products, comprising computer and data processing equipment, communications and broadcast products, and measurement and control instruments of various kinds; consumer products including T.V. and radio receivers, recording equipment, musical instruments, etc.; and that portion of electronic component sales which accounts for replacement parts. In the early 1950's, government business outran the booming T.V. industry as electronic equipment was developed and manufactured for the control of aircraft and missile systems. In the mid and late sixties, our Space Program also contributed to the growth in electronic sales. In the meantime, electronic equipment of all kinds was increasingly adopted by industry, mostly in new applications of communication, measurement, and control products. And the data processing industry has expanded from nothing to the point where its shipments account for nearly half of all industrial and communication product sales. (The break in the graph at 1966-1967 denotes the time when the EIA began including telephone equipment in the Industrial Products category.)

Finally, Figure 1.1.8 shows EIA figures for total component dollar sales, and indicates how those sales are distributed between vacuum tube, discrete semiconductor, integrated circuit, and other components. Though the EIA figures exclude some very large and very important component producers—notably Western Electric Corporation and IBM—they nevertheless serve to give us some idea of the size of the business. Note that component dollar sales are larger than the sale of electronic consumer products; and that, somewhat surprisingly, discrete semiconductor shipments have never exceeded vacuum tube shipments—though in 1969, for the first time, semiconductor shipments including integrated circuits did exceed vacuum tube shipments.

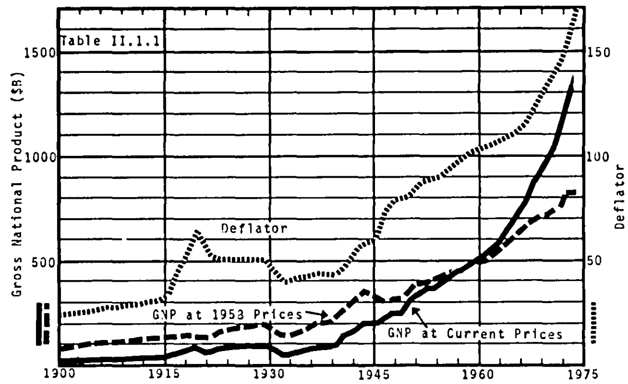



FIGURE 1.1.1 GROSS NATIONAL PRODUCT AND DEFLATOR

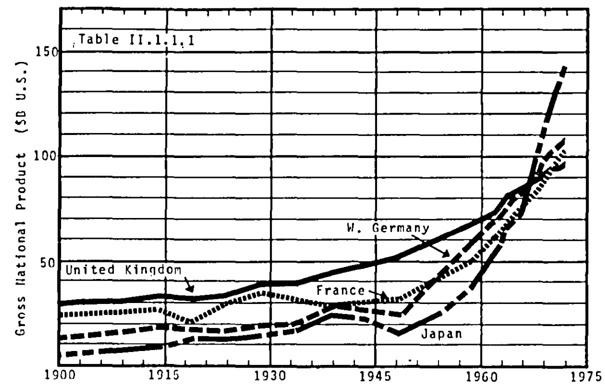



FIGURE 1.1.2 GNP FOR FOUR COUNTRIES
(1958 PRICES)

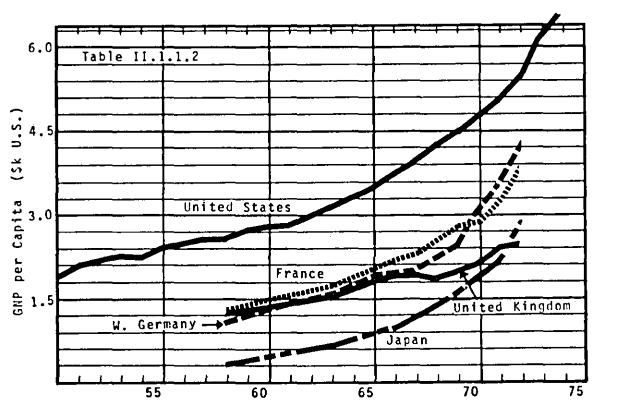



FIGURE 1.1.3 GNP PER CAPITA FOR FIVE COUNTRIES (CURRENT PRICES)

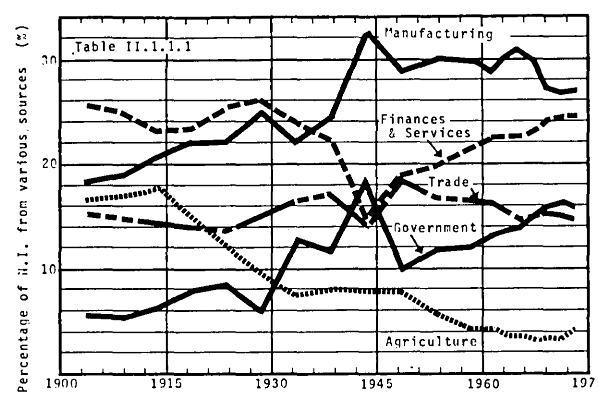



FIGURE 1.1.4 DISTRIBUTION OF NATIONAL INCOME

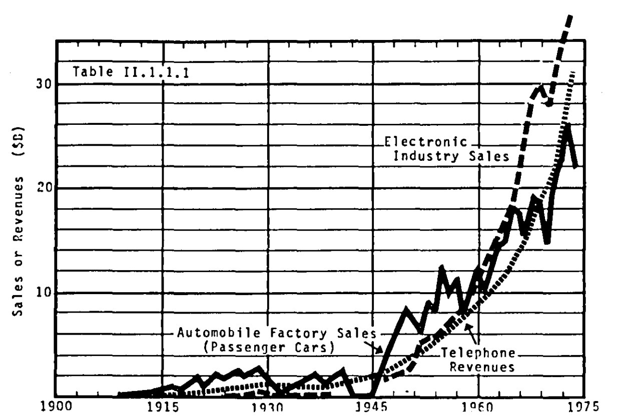



FIGURE 1.1.5 SELECTED INDUSTRIES SALES

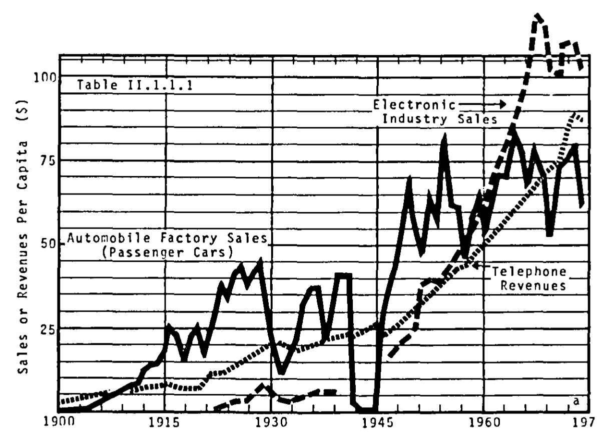



FIGURE 1.1.6 SELECTED INDUSTRIES PER CAPITA SALES IN 1958 DOLLARS

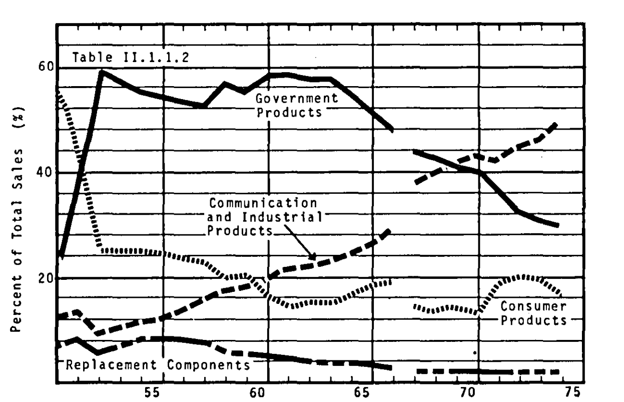



FIGURE 1.1.7 DISTRIBUTION OF ELECTRONIC INDUSTRY SALES

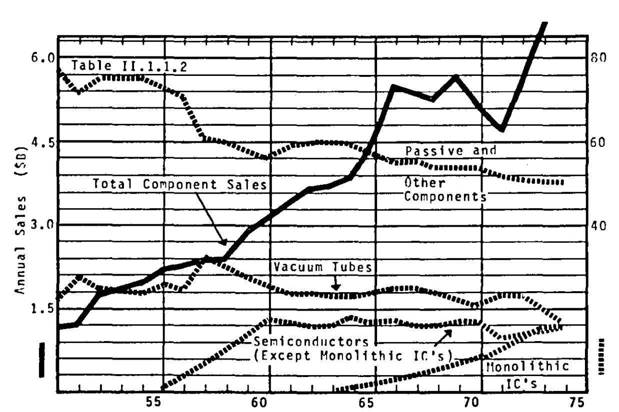



FIGURE 1.1.8 COMPONENT SALES BY U.S. MANUFACTURERS

## 1.2 Data Processing Industry Sales ●

On this and the following pages we will review the progress, growth, and status of the data processing industry from a phenomenological point of view, much as a zoologist might review the evolution of mammals. We'll try to identify the important segments of the industry, and will show how each has grown and changed. In subsequent parts of the book, we will attempt to analyze, understand, and explain in some detail the various economic forces, exerted both by the user and by the supplier, which have led to the explosive growth of the industry. However, in these initial pages, we will concentrate simply on describing what has happened.

### 1.20 OVERVIEW ●

In the last section, we had a look at the growth of the automobile, telephone, and electronic industries since the beginning of this century. Figure 1.20.1 provides another look at some of this same information, with TV sales and data processing equipment (i.e. "system") shipments shown in place of electronic industry sales, of which they are of course a part. This time we show expenditures as a percent of GNP. The enormous growth in TV sales just after World War II, and the renewed growth in the mid sixties with the introduction of color TV show up clearly on the chart. Data processing equipment shipments took ten years to reach the point TV sales reached in five; and we further see that, spectacular as has been the growth of the computer industry, it doesn't compare with the growth and impact of the automotive industry during its first twenty years, starting in 1900. The customer base for the two industries is, of course, entirely different. The eight million automobiles registered in 1920 had a when-new value of perhaps one thousand dollars each and were largely owned by private citizens; as we shall see, the 75,000 computers in use in the United States in 1970 had an average value of perhaps $300,000 each, and were largely in the hands of corporations.

Computer system shipments are the largest but not the only measure of the size of the data processing industry. The total dollar impact of this industry is shown in Figure 1.20.2 and in the next few paragraphs we will discuss and describe the major components of that total figure, which includes revenue earned by software, service, communications and supplies firms, as well as shipments of hardware. Note that only U.S. firms are included so that the "worldwide" figures do not pretend to include all worldwide data processing industry revenues and shipments.

The various component parts included in the totals of Figure 1.20.2 are detailed in the next four figures. System shipments—the shipment of central processing units and their associated memories, peripherals, and terminals—are the largest items in the total, and are plotted in Figure 1.20.3. Note the increasing importance of overseas sales to American manufacturers. Domestic shipments these days account for only about 65% of the total, and the effect of the 1969-1971 recession, which caused a 15% drop in domestic shipments, was softened by the fact that overseas shipments continued to grow during this period.

**Hardware Shipments.** In Figures 1.20.4 to 1.20.6 I have subtracted out overseas system shipments, and show the various components of shipments and revenue as a percentage of total domestic shipments and revenue. Figure 1.20.4 makes it clear that hardware shipments have been and continue to be the most important part of the industry. Total hardware shipments are broken down into their major parts in Figure 1.20.5; and the "other" segments of the industry—services, software, supplies and data communications—are described by Figure 1.20.6.

In interpreting these figures, we must of course begin with some understanding of the terms used. (In much of this analysis, we use International Data Corporation data and definitions. See the beginning of Section 1.2 of the Bibliography for a discussion of sources.) *General purpose (GP)* and *minicomputer (mini)* shipments represent the dollar value of complete systems shipped by computer manufacturers in each year. The figures therefore include central processors, internal memories, peripherals and peripheral controllers of all kinds, and terminal equipment shipped by such manufacturers as IBM, Univac, DEC, and Hewlett-Packard. Both complete systems and add-on equipment for existing systems are included. The difference between GP and mini systems is precisely defined by listing computer model numbers, and that listing is published by IDC in its *EDP Industry Report.* (A partial listing of the more important machines will be found in Section 2.10 below.) Generally speaking, the GP systems are the larger machines, mostly used for business data processing and scientific calculations, often byte or character oriented, and more often leased than purchased. The minis are generally dedicated application computers, normally purchased, and used where some single, special program is run time and time again, often in association with some real-time activity. Analog computing equipment, tabulating machines, accounting machines, and data entry keyboard equipment are not included. *Independent peripheral shipments* are shipments of terminals, data entry equipment, and peripherals by manufacturers who don't manufacture central processer products. Some of this equipment is shipped to the end user, but much of it is shipped to system manufacturers who themselves ship to the end user. To the extent that these original equipment manufacturer (OEM) sales are included, we are inflating total hardware shipments by double counting.

The general features of hardware shipments are apparent from Figures 1.20.3 to 1.20.5. The shipment rate from 1955 to 1960 grew rather slowly as first generation machines were delivered and manufacturers and users began to understand the marketplace. From 1960 to 1965 shipments accelerated as the second generation of equipment was delivered and users learned how to take advantage of improved processing power. The introduction of the third generation, starting in 1965, gave rise to an additional spurt in sales which was brought to a close in the recession of 1969-1971, when computer users were forced to economize and began to look critically at their total data processing expenditures. In 1972 the growth in system shipments continued, although *real* growth has fallen off—using the GNP deflator to correct shipments figures, we find that real growth from 1972 to 1974 was only 7.4% compared with 35.2% in the 1966-1968 period. Mini shipments have always been a small proportion of the total dollar volume, even though, as we shall see, they represent a much larger proportion of the *number* of systems shipped.

The Independent peripheral equipment business started strong, as various companies developed magnetic tape equipment, magnetic drums, printers, etc. for delivery to system manufacturers. As time went on and it became apparent that peripheral shipments were going to represent a growing portion of the total system business, the various system manufacturers developed their own peripherals and the Independents' business fell off, as a percentage of total revenue. With the delivery of third generation systems starting in 1965, however, the peripheral manufacturers developed a family of "plug-compatible" products which could be sold to the end-user as direct replacements for IBM products. The success of these products—magnetic tape units, moving head files, and magnetic core memories—and of the key-to-tape and key-to-desk data entry products which were developed at about the same time explains the upturn in peripheral shipments between 1965 and 1970.

**Non-Hardware Revenues.** Let us now look at the "other" parts of the industry, as shown in Figure 1.20.6—the software, service, supplies, and data communications segments.

As the total industry grew, it became clearer and clearer that the expense and time required to write programs was going to represent an increasingly serious problem. The development budgets of manufacturers and the operating budgets of users began to include more and more funds for software planning and development. As a result, a new industry evolved to design programs both for manufacturers and for users. This software industry, whose growth is shown in Figure 1.20.6, initially was strictly a service business, writing special and unique programs under individual contracts. More recently, software firms have used their own funds to develop and market program products, mostly for end users.

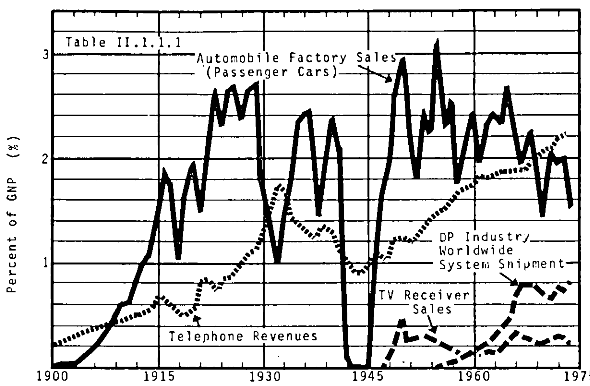



FIGURE 1.20.1 SELECTED INDUSTRIES--SALES AS PERCENT OF GROSS NATIONAL PRODUCT

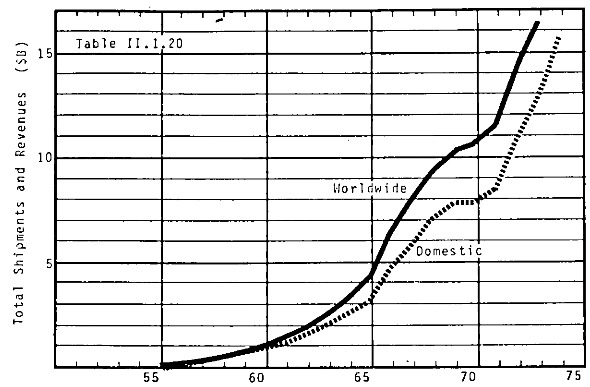



FIGURE 1.20.2 DATA PROCESSING INDUSTRY--DOMESTIC & WORLDWIDE TOTAL SHIPMENTS AND REVENUES BY U.S. FIRMS

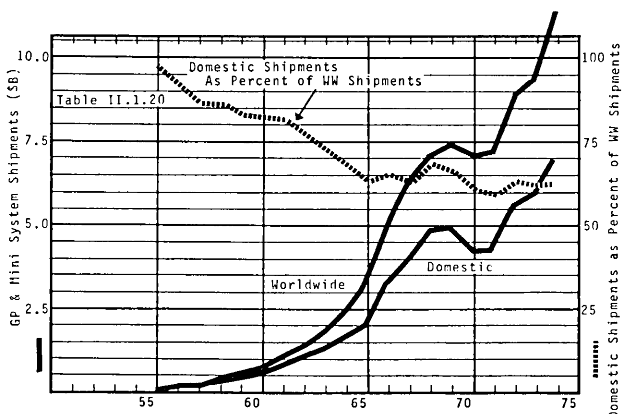



FIGURE 1.20.3 DATA PROCESSING SYSTEM SHIPMENTS DOMESTIC AND WORLDWIDE SHIPMENTS OF GP & MINI SYSTEMS

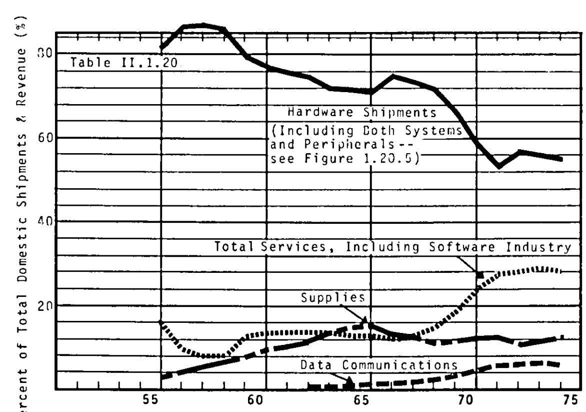



FIGURE 1.20.4 D.P. INDUSTRY DOMESTIC SHIPMENTS & REVENUES I PROPORTIONS OF PRINCIPAL COMPONENTS TO TOTAL

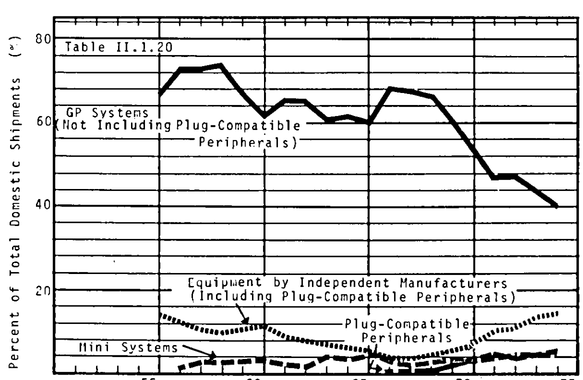



FIGURE 1.20.5 DATA PROCESSING INDUSTRY DOMESTIC SHIPMENTS II. PROPORTIONS OF HARDWARE SHIPMENTS TO TOTAL

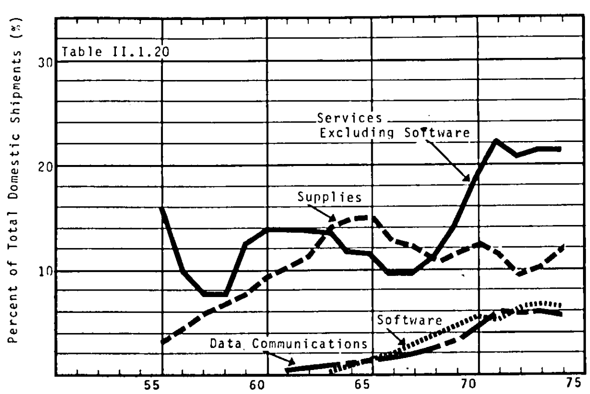



FIGURE 1.20.6 DATA PROCESSING INDUSTRY DOMESTIC SHIPMENTS III. PROPORTIONS OF OTHER REVENUES TO TOTAL

Although all big firms and many small ones find it economical and convenient to operate their own data processing equipment, many firms turn to outside service organizations either to provide total computing services or to supplement internally-provided service. In addition, the past few years have seen the formation of new firms providing specialized services such as training computer programmers and operators, installing and operating computer systems, and supplying computer maintenance. As a result, the service industry has been the fastest growing segment of the data processing marketplace as is shown in Figure 1.20.6.

Data processing system users spend money for supplies and for data communications facilities, and these final two segments of the industry are included in the same figure. The major supplies expenditures are for media, which are defined (ANSI) as "the material, or configuration thereof, on which data are recorded". The principal media are continuous printing forms, punched cards, magnetic tape, and disk packs. Punched cards and continuous paper were used (and are still used) by tabulating equipment and accounting machine installations long before the stored program computer was invented—but the figures shown do *not* include supplies shipped for such equipment. Expenditures for supplies grew very rapidly in the period 1955 to 1965 primarily because of the development and improvement of magnetic tape units, and of applications where large files were stored on tape. The 1974-1975 spurt was mostly caused by increases in the prices for paper products.

The requirement for on-line access to a common data base (in airline reservation systems, for example), the hope that the power of a very large and expensive system could be shared by a number of individuals simultaneously working at remote terminals, and the need for large companies to improve internal communications between widely separated offices—these factors and others led the Communication Common Carriers to introduce a variety of data services. These facilities were first offered in the early 1960's, and there was an immediate period of growth as the requirements for several special applications were satisfied. The third generation systems shipped since 1965 have included a growing number of communication options which encouraged more and more data processing users to transfer data, messages, requests, and replies by wire directly to their central computers from distant plants and offices.

Expenditures for supplies, services, communications, and software (or at least the software product portion of software revenues) are related more to the value of computers in use than to the value shipped each year. Figure 1.20.7 plots these components as a percent of the installed value of general purpose computers. To the extent that the data processing industry ever settles down and reaches some steady-state condition, these curves will presumably become horizontal lines.

We have so far discussed the dollar value of hardware shipments, and the revenues earned by companies which supply goods and services directly related to the data processing industry. There are, of course, other ways of measuring the industry's impact. In section 1.30, for example, we will look at the revenue derived from system shipments—shipment dollars are not the same as revenue dollars because so many GP systems are leased. Figure 1.20.8 provides another measure: the total value of GP systems, minicomputer systems, and keyboard data entry equipment in use in the United States reached \$30B in 1972. GP and minisystems have already been discussed. Keyboard data entry equipment is the hardware used to convert data manually from written, printed, or verbal sources into computer-readable media. (Optical- and Magnetic-Ink-Character-Recognition equipment is included with GP system value in use.) Keypunches, which produce punched card records, and key-to-tape and key-to-disk systems make up the keyboard data entry system population. Note that the value of data entry equipment has for some years represented 5% of all hardware in use, and has only recently been surpassed by the value of the much more widely discussed minicomputer system population.

In the next few pages, we will look in more detail at the constituent parts of the computer hardware business, which is of course the basis for the entire industry and accounts for the largest dollar portion of that business (Figure 1.20.4). We will begin by discussing systems, and will continue with reviews of peripherals, terminals, memory, and data entry equipment. As usual, I must introduce a word of caution about the figures. The notes accompanying the tables in Part II discuss sources and make it clear how sandy and swampy is the ground on which this structure of purported quantitative history is built. In general, the figures represent the author's best judgment regarding authoritative but conflicting numbers, together with extrapolations and interpolations of various kinds in those periods for which he could find no data.

## 1.21 SYSTEMS ●

**Shipments and Installations.** The number of computer systems in use in the United States at the end of each calendar year is plotted in Figure 1.21.1, and the corresponding value of those computers is shown in Figure 1.21.2. The "systems" counted in the first figure are central processing units (CPU's). The dollar values shown in the second figure include not only the CPU's, but also memory, peripherals, and terminals. Furthermore—and here the economist and accountant will shudder at our bookkeeping—the dollar figures represent valuations made as if all the installed equipment were new. For example, included with the 107,000 machines installed at the end of 1972 are five first generation IBM 705's valued at their original cost of about \$1.5 M each. Obviously those five machines were not "worth" \$7.5 M in 1972: their paper value on the books of the companies which own them was undoubtably zero; and they probably would not sell for more than a few thousand dollars if offered on the open market. So the "installed value" shown in Figure 1.21.2 and in other figures on this page and later in the book are in a sense fictional and inflated.

Figures 1.21.3 and 1.21.4 show the number and value of computer systems shipped in the United States each year. Once again the number of systems shipped refers to the shipment of CPU's. The dollar value of equipment shipped includes shipments to end customers by the system companies, and shipments of plug-compatible peripherals by independent peripheral manufacturers. It includes not only equipment shipped with new CPU's, but also peripherals, memory, and other hardware products shipped to augment already-existing installations.

The four figures taken together make it possible for us to understand a little better the development and growth of the minicomputer business, and its relative importance compared with the general purpose portion of the market. Obviously, the GP systems have always accounted for much the largest share of hardware shipments and installed value—GP machines accounted for 95% of the installed value in 1965, and 90% in 1974. But shipments of GP systems seem to be levelling off. And the minicomputer market, which developed in the 1965 to 1970 period as powerful systems were marketed at prices under $100,000, as manufacturers realized there was a potentially very large and very price-sensitive market for such systems, and as electronic technology (and particularly the advent of integrated circuits) made it possible to sell processors for prices under $20,000 and then under $10,000, has had an enormous impact in number of computers in use, a much smaller one, so far, on installed value. Note that it only took about five years for the number of minis shipped annually to overtake the annual number of GP's shipped, once the market was identified and the products proliferated.

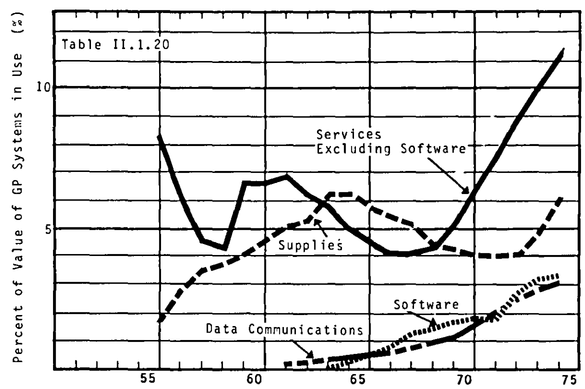



FIGURE 1.20.7 DATA PROCESSING INDUSTRY DOMESTIC SHIPMENTS IV. EXPENSE ITEMS AS PERCENT OF VALUE OF GP SYSTEMS IN USE

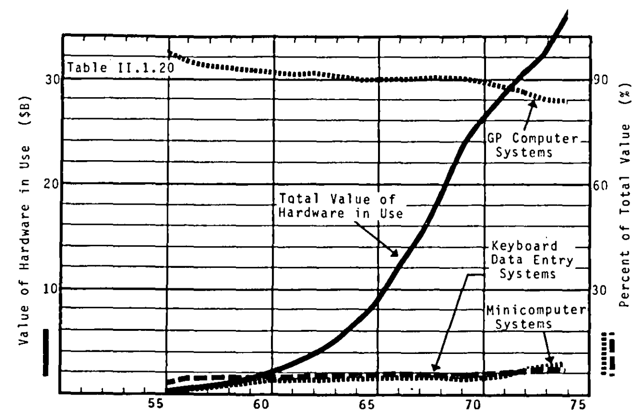



FIGURE 1.20.8 TOTAL D.P. HARDWARE IN USE IN THE U.S. GP SYSTEMS, MINI SYSTEMS, AND DATA ENTRY EQUIPMENT

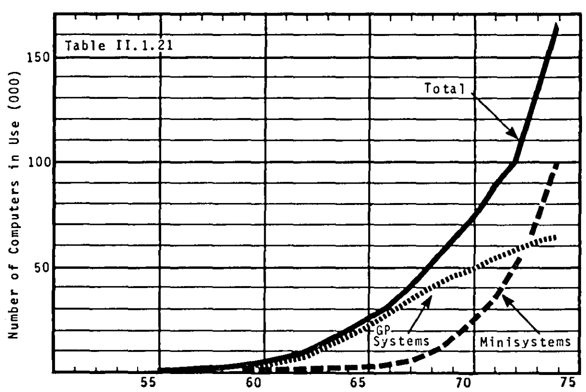



FIGURE 1.21.1 TOTAL NUMBER OF COMPUTERS IN USE IN THE U.S.

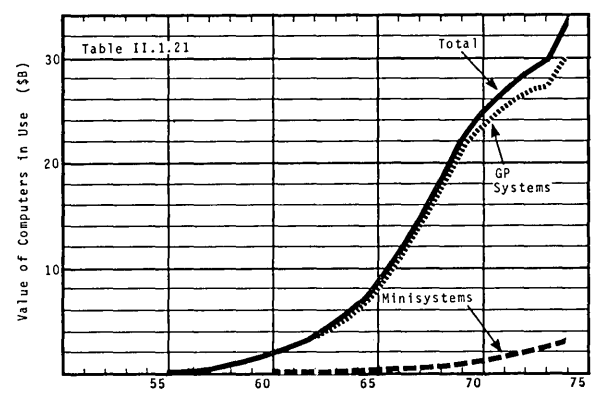



FIGURE 1.21.2 TOTAL VALUE OF COMPUTERS IN USE IN THE U.S.

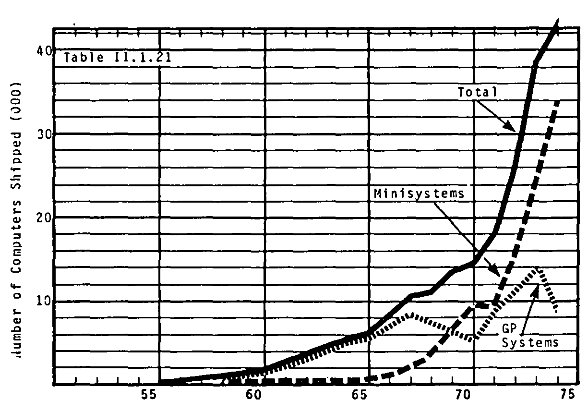



FIGURE 1.21.3 TOTAL NUMBER OF COMPUTERS SHIPPED IN THE U.S.

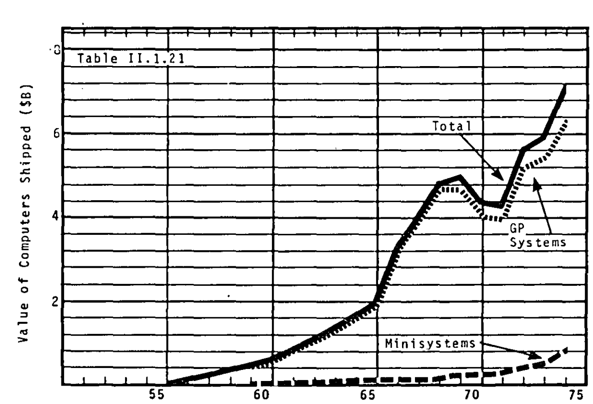



FIGURE 1.21.4 TOTAL VALUE OF COMPUTERS SHIPPED IN THE U.S.

**Average System Price.** A review of the trends in average system price is shown in Figure 1.21.5, where we see the average price of installations and of shipments for both GP and mini systems. (The relationship between average shipment price and average installed price is not as straightforward as one might think because of the effect of returns and removals, whose number and average value vary substantially from year to year, as we shall see.) Looking at the GP curves first, we see that first generation systems wound up with an average price around $400,000; that second generation equipment, shipped between 1960 and 1965, included machines like the IBM 1401 which sold well and reduced average installed value to considerably under $400,000; and that the shipment of the third generation systems has led to a substantial rise in average installed price, partly because the development of the minicomputer market cut into the sales of low-cost GP systems, and partly because the recession of 1969-1971 both reduced spending on new processors and encouraged system owners to increase capacity by adding peripherals and memory to their existing system. In particular, the 1970 peak in average shipped value must *not* be interpreted as a surge in shipments of very large systems; rather, it comes about when we divide shipment dollars which include a great deal of add-on equipment by a number of processors shipped which is relatively low because of the recession.

Looking now at the minicomputers, we find average system prices around $100,000, and relatively modest sales during the fifties and very early sixties. Several machines with prices between $50,000 and $100,000 sold well during this period: the Bendix G15, the LGP30, the Recomp II, and the Control Data 160 were notable examples. Starting in about 1962, a variety of second generation machines were shipped with prices over $100,000, and the average system price rose somewhat. These new machines–the Control Data 160A and 160G, and the XDS 920 and 930 are examples–were on the whole successful and profitable, though both in numbers and in dollar value they were unimportant compared to the general purpose systems.

Meanwhile, DEC had been exploring and developing the market for small machines. Their PDP-1, PDP-4, and PDP-5 introduced in 1960, 1962, and 1963, respectively, were modestly successful and seemed to confirm the existence of a potential market for even smaller machines. In 1965, DEC shipped the first PDP-8, a machine with a system price around $20,000, and its remarkable success stimulated the development of other small machines (along with the formation of a number of new companies). The result has been a year by year reduction in the average price of a minisystem shipment from over $150,000 in 1965 to under $30,000 in the early 70's.

Why didn't minicomputer sales accelerate earlier, with the small, cheap first generation machines? Why weren't the $50,000 G-15 and LGP-30 even more successful? There are a variety of explanations. As we shall see, the earlier machines were substantially slower and less reliable than their successors. They generally lacked features like a powerful interrupt system and a flexible, buffered input-output capability, both of which are essential in many of the specialized real-time applications which are the basis for the dedicated-application, minicomputer market. However, the fact that early computers lacked important capabilities is only part of the story. The minicomputer boom required not only the right combination of price and performance, but also suitable sophistication on the part of potential users. Scientists, engineers, and managers had to be aware of the capabilties of computer power. Applications had to develop and mature. Qualified programmers and system designers had to be available in suitable numbers. And in many situations, where the minisystem supplies data to or receives data from a general purpose system, applications were dependent on the existence of a sufficiently large population of GP systems.

**System Size.** A rough measure of the trends in the distribution of total GP system value across various price ranges is shown in Figure 1.21.6. We must be careful not to attribute too much significance to this graph, for the boundary lines between one system size and another are set quite arbitrarily, and the data comes from different sources which are not altogether comparable. However, we can perhaps make a couple of observations. The first is that, since 1965, there has been a significant increase in the proportionate value of large and very large systems. There are, and presumably always will be, some problems whose solutions require a computational power which can only be obtained from systems designed to push current technology to its ultimate limits. Such large systems (E.G. LARC, STRETCH, CDC-6600, 360/195, Burroughs 7700, ILLIAC IV) have often encountered technical difficulties during development, and have not always been commercial successes. However, their high price and value has made them a significantly growing factor in the marketplace despite the fact that relatively few are installed compared to the whole computer population. And while the value of these giant systems has been growing, so also has the value of the smaller "large" systems–those with prices over $1.0M.

The other remark to be made is a relatively innocuous one: in the early days the success of a few individual products tended to concentrate installed value within narrow price ranges; but as time passed, total value became much more evenly distributed over the logarithmic scale of system prices shown. The community of users is large enough, and the variety of data processing requirements is disparate enough, that manufacturers have been encouraged to develop and promote a broad range of system offerings.

**System Life.** As time passes, a computer user installs new applications on his system and expands its capacity by buying new peripherals and additional memory. Ultimately he reaches a point where his system is saturated, or where he finds some different system which will handle his applications more economically; and he sells the old system or returns it to the manufacturer (depending on whether he had purchased or was leasing it). The old system may or may not be put back into service, depending on its age and marketability. The annual value of these "retirements" can be computed if we know the value of each year's shipments and the value of the systems in use at the end of each year: net retirements for a period are found by adding together the value in use at the beginning of the period to the value shipped during the period, and then subtracting the value in use at the end of the period. Since we are looking at a small difference between relatively large numbers, and since the numbers themselves have large probable errors, we must regard the results of the computation with a certain degree of suspicion. Nevertheless, general purpose system retirements for computers installed in the United States are shown in Figure 1.21.7. Obviously, retirements are cyclical in nature, peaking in periods when new systems are introduced, or when a recession causes users to tighten their belts.

We can also calculate average system life from data on shipments and on the value of systems in use. The average life of all U.S. GP systems ever shipped, shown in Figure 1.21.7, has generally been increasing, as one would expect in a relatively new industry. It will stabilize when the ratio of annual shipment value to annual value in use levels off—and that ratio has consistently been dropping. The life of the last system retired in each year is also shown in Figure 1.21.7, and was computed assuming that the oldest systems in use are always *retired* first. As retirements increase, their average life naturally tends to decrease. Average system life is an important parameter to the data processing industry because so much equipment is leased by users. The two measures shown in Figure 1.21.7 are worth studying, and would converge if annual shipments and retirements remained equal and constant over a number of years.

**Computer Models.** Finally, Figure 1.21.8 gives us some idea of the product variety which has created and sustained industry growth. Here we have plotted the number of new computer system model numbers introduced each year. Special one-of-a-kind machines, built by universities or designed under special contracts, are not included—we have only counted commercially available machines. In the twenty-year period ending in 1970, about 400 different processors were designed and marketed, half of them general purpose and half minisystems. Since 1950, there have been an average of about 15 new GP systems introduced per year; and the fantastic boom in the minisystem marketplace is reflected in the large number of new mini models introduced since 1967—between January 1967 and January 1972 over forty new companies each introduced one or more minicomputer systems.

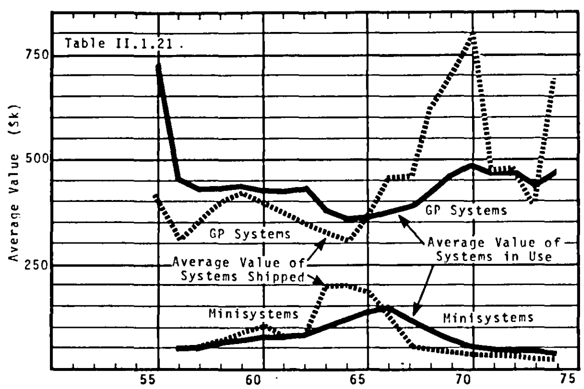



FIGURE 1.21.5 AVERAGE VALUE OF COMPUTERS INSTALLED IN THE U.S.

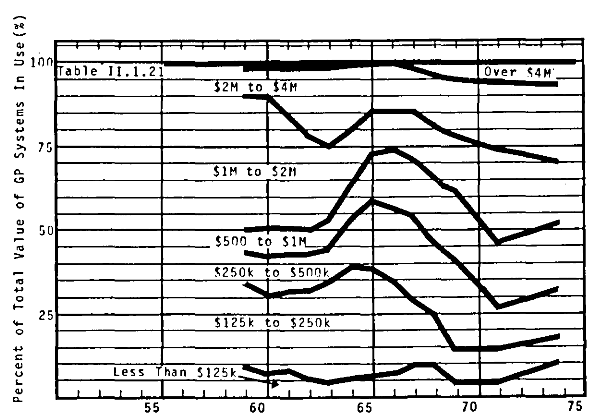



FIGURE 1.21.6 DISTRIBUTION OF TOTAL VALUE OF GP SYSTEMS IN USE, BY SYSTEM SELLING PRICE

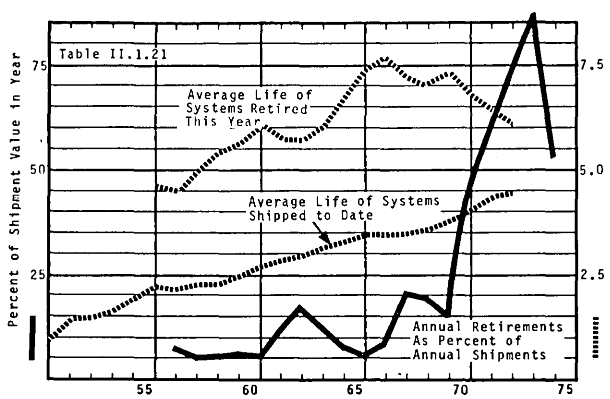



FIGURE 1.21.7 GP SYSTEM LIFE
ANNUAL RETIREMENTS, AND AVERAGE SYSTEM LIFE

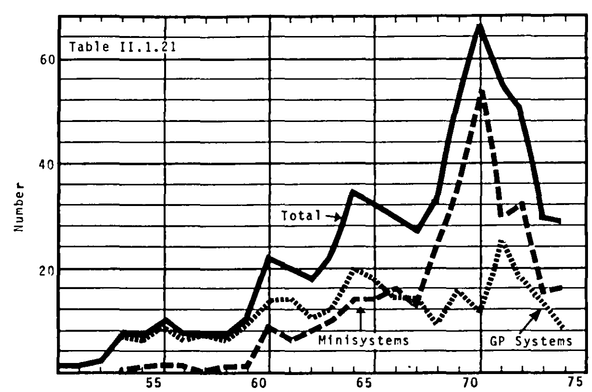



FIGURE 1.21.8 NUMBER OF COMMERCIAL COMPUTER MODELS INTRODUCED EACH YEAR

## 1.22 GP SYSTEM COMPONENTS ●

**Summary.** Having had a look at the general size and growth rate of the hardware portion of the data processing industry, let's now examine the principal system components which contributed to that growth, and see how the importance of various elements has changed with time.

We begin by looking at the component parts of GP systems installed in the United States. We limit discussion to these systems, and omit analysis of mini and foreign systems, not because the latter are unimportant, but rather because it has proven difficult to acquire pertinent data.

The four most important components are processors, internal memory, peripherals, and terminals. A processor is a device which performs or controls a sequence of operations on data, and I include in this category CPU's, input-output processors, and a large variety of processor options such as floating point arithmetic units. Internal memory is that part of system memory from which instructions are directly executed. Peripherals are the input-output and auxiliary memory units designed to provide the processors with data, and connected to them via high-data-rate cables. Magnetic tape units, line printers, punched card equipment, moving-head and head-per-track disks and drums, are the principal peripherals; and their controllers are also included in this category. Terminals are input-output devices connected to the processor by common-carrier communication lines or their equivalent. Lumped with terminals I have included communications interfaces to the processor, along with modems and multiplexers.

The installed value of each of these four parts of the market is shown in Figures 1.22.1 and 1.22.2, both in absolute dollars and as a percentage of total GP installed value. The industry changes which have taken place in the past twenty years are evident in these figures. In early systems the emphasis was on the processor, including its internal memory. As time passed, and systems were used more and more for storing and processing data as compared to carrying out computations, peripheral devices grew in importance, and quickly surpassed the processor in dollar volume. Meanwhile, as we have seen, AT&T and the other common-carriers made data communication facilities available, and the terminal market began to grow. That growth came at a time when the magnetic tape unit and the head-per-track memory markets were flattening out, and booming internal memory sales were helping to sustain the processor market. Furthermore, terminals began to be used for data input and output and thus began to encroach on the peripherals market. The result was that the peripheral proportion of total installed value peaked between 1965 and 1970, and that terminals have become correspondingly more important in recent years.

The next figures provide a detailed look at the important peripherals. It is convenient to distinguish memory peripherals from the others, and Figures 1.22.3, 1.22.5, and 1.22.7 show memory peripherals installed value in absolute dollars and as percentages of the installed value of all peripherals and of GP systems. Figures 1.22.4, 1.22.6, and 1.22.8 provide the same information for line printers, punched card equipment, and "other" peripherals. The "other" category contains a host of devices of relatively small dollar volume, including keyboard printers, punched tape equipment, plotters, audio output devices, analog-to-digital and digital-to-analog converters, etc.

**Unit Record Devices.** Examining these figures all together we can get a fair picture of how the peripheral marketplace has developed. In the early years, line printers and card equipment accounted for over eighty percent of the total value of installed peripherals. And though the market for these devices has grown, it has not grown as rapidly as that of peripherals generally, so these unit record devices by 1970 accounted for only thirty percent of total peripheral value. The installed value of various units collectively identified as "other" is difficult to quantify, and was fairly arbitrarily set at the value shown—see the discussion in Part II.

**Memory Peripherals.** Between 1955 and 1960 the head-per-track magnetic drum was the leading technology for internal memory (to be discussed later), and was also used as auxiliary (peripheral) memory for large systems having magnetic core or electrostatic internal memories. Magnetic tape memories in exotic variety were marketed in this period, but by 1960 IBM's dominant position in the market had been established, and the importance of compatibility between their first generation 727 tapes and second generation 729's was apparent. Other manufacturers increasingly adopted the IBM standards; and as more and more users developed applications based on large, machine-readable files, a new standard medium, the magnetic tape, was available and was widely used. By 1960 the magnetic tape unit was the dominant peripheral.

Some applications, however, demanded faster access to data than was possible with magnetic tape, and lower cost per bit than the head-per-track drum could deliver. IBM's solution was the 350, a rotating magnetic disk memory with a movable set of heads which could be positioned opposite any data track on any disk surface. In the next few years, other manufacturers developed similar moving-head-file products, generally aiming at large capacity and low cost per bit. But in 1962 IBM introduced a disk memory, the 1311, with a removable medium which, like the magnetic tape, could be used for off-line storage of data. Installations of this unit and its improved successors grew nearly as rapidly in the latter half of the 1960's as magnetic tape units had in the first half; and by 1970 moving-head files and magnetic tape units were very nearly equal in installed value.

In the early 1960's, the importance of head-per-track peripheral memories diminished as tape and moving-head technology improved. In the last half of the 1960's, however, some manufacturers (Burroughs, Scientific Data Systems) developed operating systems which made effective use of new and economical head-per-track memories. Their success, plus the availability and use of large capacity data cells (such as the NCR CRAM and the IBM 2321) is indicated in the figures.

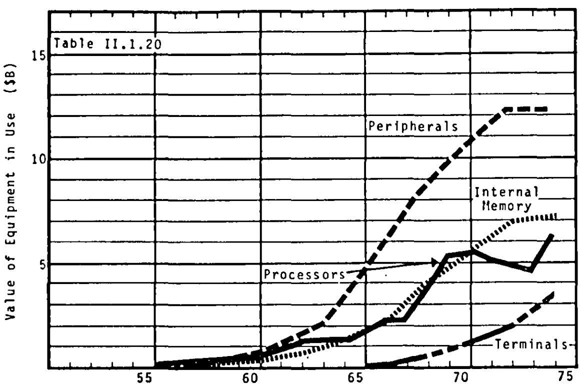



FIGURE 1.22.1 GP SYSTEM VALUE IN USE IN THE U.S. I. VALUE OF MAJOR EQUIPMENT CATEGORIES

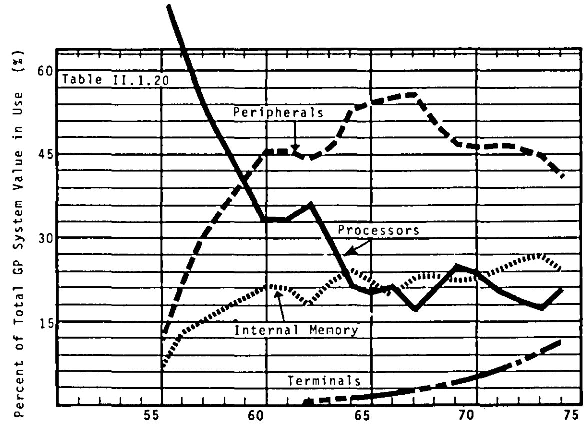



FIGURE 1.22.2 GP SYSTEM VALUE IN USE IN THE U.S. II. PROPORTIONS OF MAJOR EQUIPMENT CATEGORIES

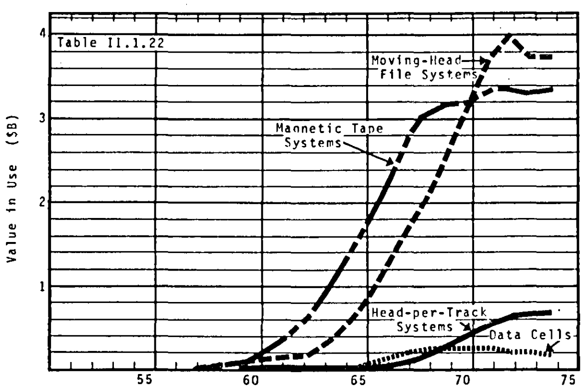



FIGURE 1.22.3 INSTALLED VALUE OF PERIPHERALS I. MEMORY EQUIPMENT

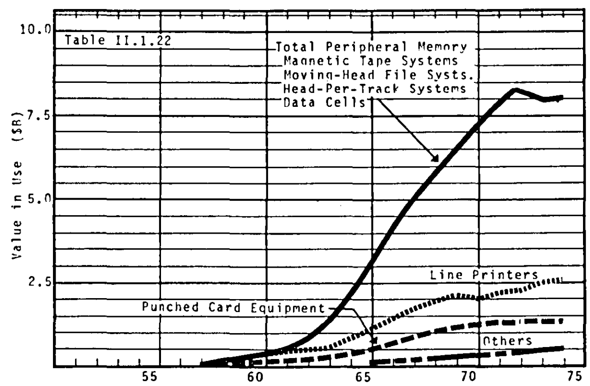



FIGURE 1.22.4 INSTALLED VALUE OF PERIPHERALS II.

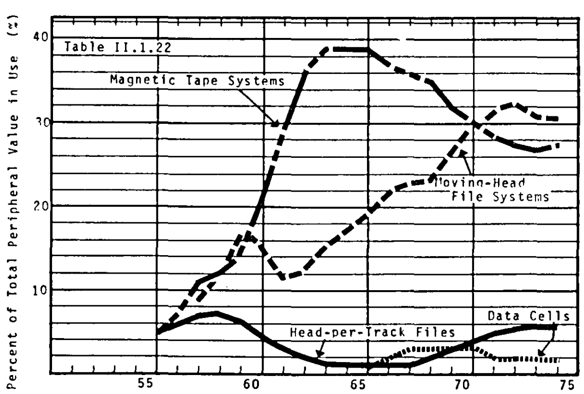



FIGURE 1.22.5 INSTALLED VALUE OF PERIPHERALS III. MEMORY EQUIPMENT AS PROPORTION OF ALL PERIPHERALS

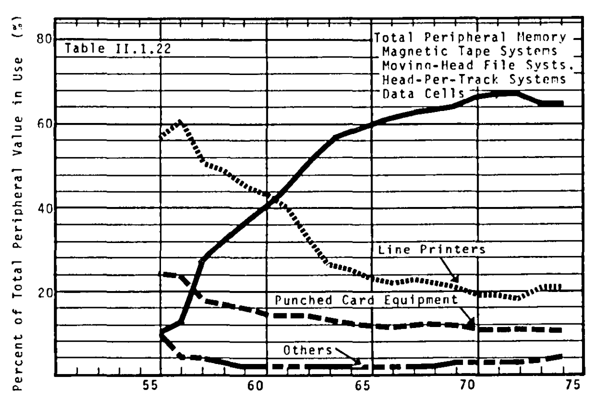



FIGURE 1.22.6 INSTALLED VALUE OF PERIPHERALS IV. AS PROPORTION OF ALL PERIPHERALS

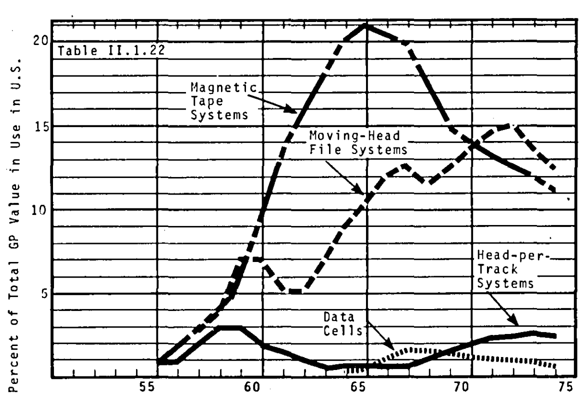



FIGURE 1.22.7 INSTALLED VALUE OF PERIPHERALS MEMORY EQUIPMENT AS PROPORTION OF ALL U.S. GP VALUE IN USE

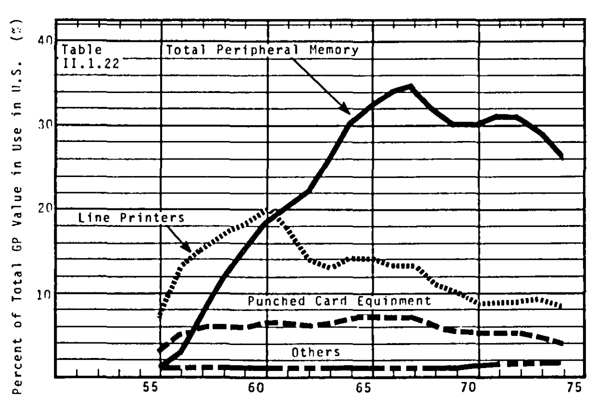



FIGURE 1.22.8 INSTALLED VALUE OF PERIPHERALS VI. AS PROPORTION OF ALL U.S. GP VALUE IN USE

The next eight figures, 1.22.9 to 1.22.16, show the number of peripheral units installed, the average price, and the average number of units per installed computer, for each of the major peripherals. Comments:

1. A system having a line printer or a card reader/punch usually includes only one unit; a system having tapes or disks usually contains multiple units, to provide ample on-line storage and to facilitate operations like sorting and file updating, which are carried out faster and more efficiently as more devices are added. This is the prime reason for the fact that there are many more tapes and disks than line printers and card units.

2. The removable disk pack and the low-cost high-performance moving-head files which became available in the mid sixties, have caused a remarkable change in average systems configuration. In 1965 there were only one-fourth as many disk spindles as tape drives; in 1971 the populations were the same. Since the average price of a spindle and drive are nearly the same, and the disk spindles have greater on-line capacity and much lower access time than the tape drives, one might ask why the tape drives survived at all. The answer is, of course, that they survive primarily because the off-line storage cost of tape is much less than that of disks. (See discussion of Supplies in Section 1.27 below.)

3. Figures 1.22.9 and 1.22.11 show on-line storage capacity of tapes and disks as well as the number of units installed. Note that disk capacity exceeded tape in about 1970, and appears to be increasing at a faster rate while tape capacity is levelling off or falling.

4. Looking at the average prices of units in use, we see that disk file and line printer prices have declined substantially more than have magnetic tape and punched card equipment prices. (Tape unit prices were actually higher in 1974 than in 1958, when the IBM 727 at $18,200 was the pace-setter.) The price changes shown reflect improvements in manufacturing productivity and technology; and in general prices have been reduced despite improvements in device performance.

In summary: the increasing variety of file-based as contrasted to computation-based applications, and the magnetic tape and moving-head-file technologies developed by the industry and especially by IBM, helped the peripheral market to grow much faster than other segments of the hardware business between 1955 and 1967.

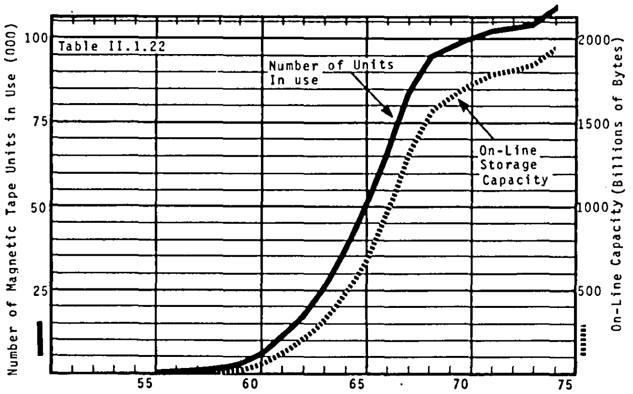



FIGURE 1.22.9 MAGNETIC TAPE UNITS IN USE I.
NUMBER OF UNITS AND TOTAL ON-LINE CAPACITY

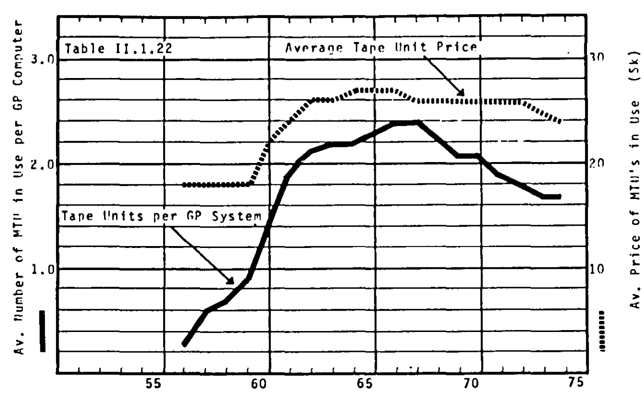



FIGURE 1.22.10 MAGNETIC TAPE UNITS IN USE II.
AVERAGE NUMBER OF UNITS PER GP COMPUTER AND AVERAGE PRICE

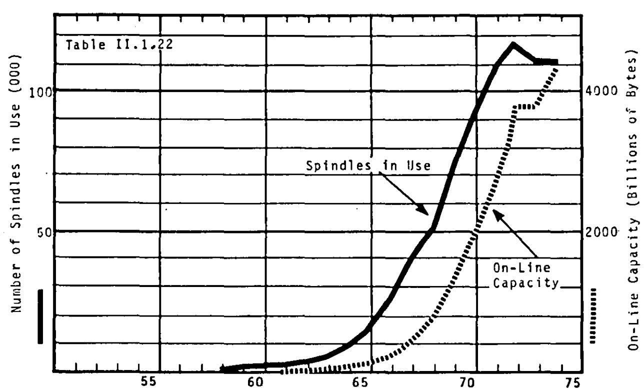



FIGURE 1.22.11 MOVING-HEAD FILES IN USE I
NUMBER OF UNITS AND TOTAL ON-LINE CAPACITY

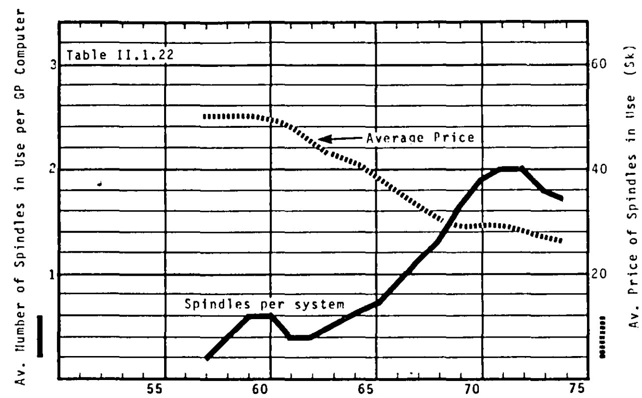



FIGURE 1.22.12 MOVING-HEAD FILES IN USE II.
AVERAGE NUMBER OF UNITS PER GP COMPUTER AND AVERAGE PRICE

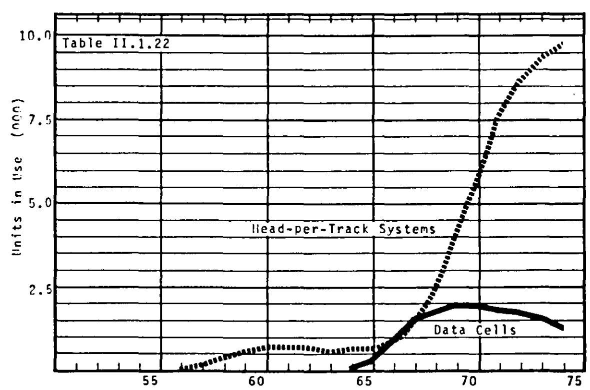



FIGURE 1.22.13 HEAD-PER-TRACK SYSTEMS AND DATA CELLS
NUMBER OF UNITS IN USE

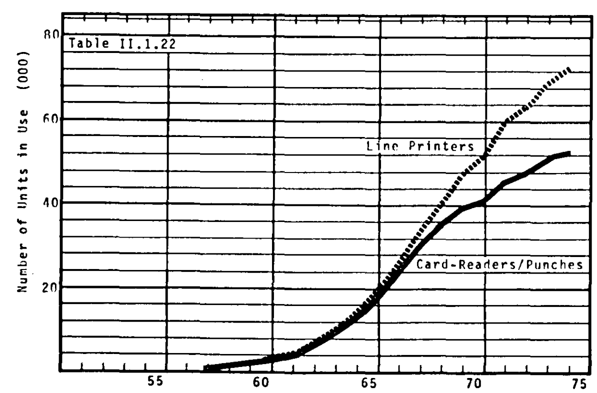



FIGURE 1.22.14 UNIT RECORD DEVICES IN USE
NUMBER OF PUNCHED-CARD UNITS AND LINE PRINTERS

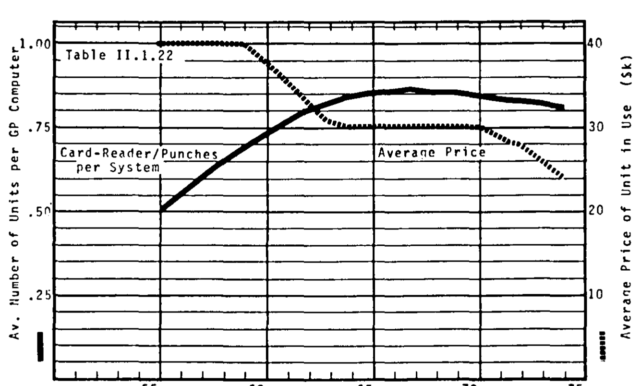



FIGURE 1.22.15 CARD-READER/PUNCHES IN USE
AVERAGE NUMBER OF UNITS PER GP COMPUTER AND AVERAGE PRICE

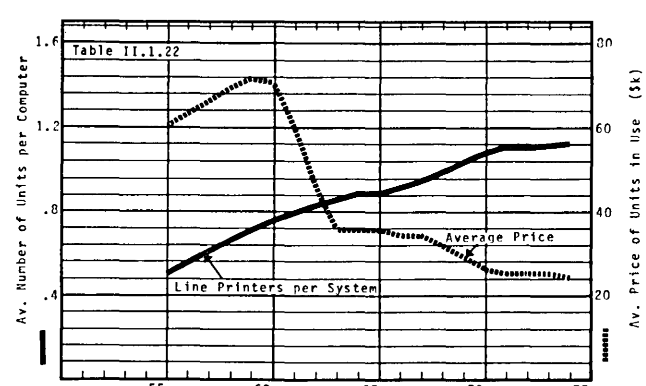



FIGURE 1.22.16 LINE PRINTERS IN USE
AVERAGE NUMBER OF UNITS PER GP COMPUTER AND AVERAGE PRICE

**Internal Memory.** The spectacular growth of two peripherals—the magnetic tape unit and the moving-head file—is recorded in the previous graphs. In Figures 1.22.17 to 1.22.20, we show the equally spectacular growth of another system component. Internal memory is the high-speed memory from which the processor extracts the commands it is required to carry out, along with the data referred to by those commands. In compiling these figures, I determined a memory capacity in bytes by multiplying its capacity in words by its word-length in bits, and dividing the result by eight. And I determined the price of a byte by dividing the price of a complete memory by the number of bytes it contains. (Where manufacturers do not price memories separately, an incremental price is computed by dividing the incremental price of adding memory to some processor by the number of bytes added for that price.) Comparing Figure 1.22.17 with 1.22.3, we see that the value of internal memory in use has always been greater than that of either magnetic tape units or moving-head files. By 1974 there were over 18 billion bytes of internal memory in use on all American made GP computers, worldwide, and they were worth about $12B.

During the first years of computer development, engineers invented and manufacturers shipped a variety of memory technologies. Magnetic drums were widely used on small machines, and electrostatic memories, which stored bits as electric charges on the inside surfaces of vacuum tubes, were used for high performance systems. Other technologies were attempted in the laboratory, and some (e.g. magnetostrictive delay lines) were shipped by commercial manufacturers. The slowness of the drum, the unreliability of the electrostatic memory, and the invention of the coincident-current magnetic core memory resulted in the latter becoming almost universally adopted for internal memory technology, starting in the late 1950's. Average price per byte, shown in Figure 1.22.18, increased between 1950 and 1960 as an increasing portion of large machines with high-cost, first-generation magnetic core memories were shipped, and as owners of such machines added memory to their initial installations. The incremental cost of core memory in those early days ranged from $6 to $10 per byte. Between 1960 and 1965, as second generation machines were shipped in volume, the average installed price per byte stabilized at around $5 per byte.

In introducing its third generation System 360, IBM recognized the improvements which had been taking place in core memory technology, and announced substantial reductions in incremental memory prices. Where it cost $6 to $7.50 per byte to increase memory capacity of the popular second-generation 1401, it cost only $1.70 to $2.70 to add memory to a 360/30. Furthermore, where the price for very large, high-performance second-generation memories was comparable to the price of 1401 memory ($5.50 to $6.50 per byte for the 707x family, for example), large third-generation memories were substantially cheaper than smaller ones (memory increments for the 360/65, for example, ranged in price from $.90 to $1.50). The IBM 370 systems introduced in 1971 have contributed a further reduction in average price—370 memory increments are priced at $.40 to $1.40 per byte.

Figure 1.22.18 illustrates another important aspect of memory system design: there was very little difference between average memory capacity of first and second generation systems. It was not until the early Sixties, when engineers began designing third generation systems, that they recognized the importance of internal memory to the user, and took steps to accomodate memories containing hundreds of thousands of bytes. The IBM 650 actually had a larger maximum memory than the 1401—20k bytes compared with 12k bytes. And the 709 and 7090 both had maximum capacities of 144k bytes. In contrast, the 360/30 had a maximum memory size of 32k bytes, and the 360/65 a maximum of 2048k bytes. The 370/168 has an announced maximum capacity of 8,389k bytes.

The resulting growth in average memory size, shown in Figure 1.22.18, is further examined in Figures 1.22.19 and 1.22.20, which show the total amount and total value of IBM memory in use, by generations. (The data on total U.S. and worldwide installations, shown in Figures 1.22.17 and 1.22.18, is based on estimates of the growth of average memory size for IBM systems, and on the assumption that non-IBM installations are comparable in price and capacity to the IBM installations—see notes to Table II.1.22.)

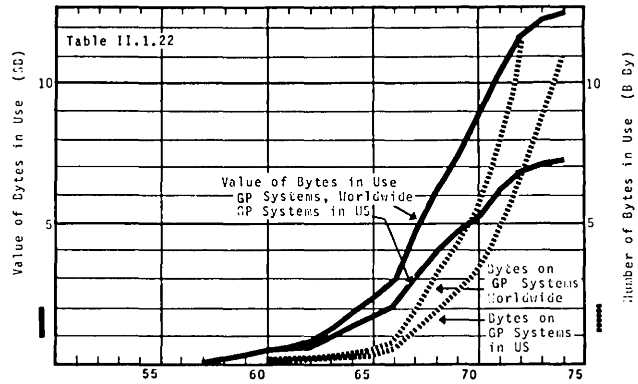



FIGURE 1.22.17 INTERNAL MEMORY I.
NUMBER AND VALUE OF BYTES IN USE

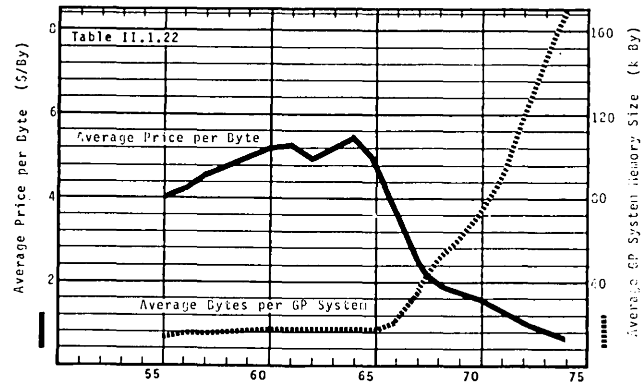



FIGURE 1.22.18 INTERNAL MEMORY II.
AVERAGE PRICE & SIZE OF SYSTEMS IN USE IN U.S.

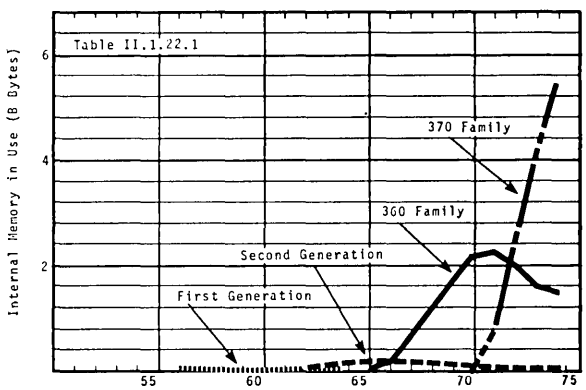



FIGURE 1.22.19 INTERNAL MEMORY III
IBM SYSTEMS --- BYTES IN USE

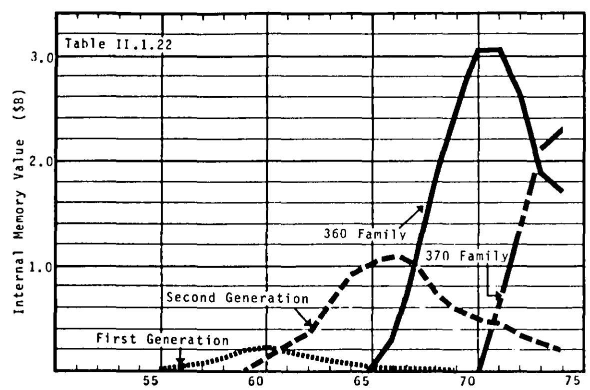



FIGURE 1.22.20 INTERNAL MEMORY IV.
IBM SYSTEMS -- VALUE OF MEMORY IN USE

## 1.23 DATA ENTRY EQUIPMENT ●

A computer cannot process data until that data is available in the form of digital, electrical signals. Data orginates with people, who execute transactions (sales, transfers, orders, cancellations, hirings, etc.), or make plans (budgets, forecasts, etc.), or prepare procedures (manufacturing drawings, computer programs, etc.). It also originates with physical situations (blood pressure of a hospital patient, temperature in a chamical reactor, load on an electric generating plant, etc.). The data entry portion of a data processing system is the set of procedures and equipments which control the data from the location where it originates to the location where it is in electrical, digital form.

Data entry systems employ one of three different techniques. They may require:

1. That a person located at the point of origin transcribe the data on a piece of paper—normally a pre-printed form designed for that purpose. The paper is then transported to a central location, where it is converted into electrical, digital signals through the use of the data entry equipment described below. Or

2. That a person located at the point of origin enter the data on some device which immediately converts it to electrical, digital form. The device may record the data locally on media (magnetic tape, punched tape, printed paper) which can later be read automatically by a computer peripheral or terminal; or it may be immediately transmitted by wire to a central point, transaction by transaction, if the input device is a terminal. Or

3. That special equipment capable of automatically "reading" the data be located at the point of origin. The equipment may record the data on media for later conversion into electrical, digital form; or it may perform the conversion immediately, thus automatically providing an associated computer with timely data.

The second of these alternatives employs either specialized transaction recorders, which are difficult to identify and therefore won't be considered here; or terminals, which will be discussed in the next section. The third alternative includes analog-to-digital converters, which are widely used in real-time process control and monitoring systems to convert physical measurements into numbers. Converters, like transaction recorders, are difficult to enumerate and are therefore not included in the ensuing discussion. (Minicomputer systems employed in process control, data acquisition, and test equipment applications generally make use of these converters. To get some feeling for the size of this market, see Figure 3.12.2.)

**Keyboard Data Entry Equipment.** The first alternative, requiring a written record of the data, is obviously the oldest system and is still by far the most widely used. The equipment employed in converting written records to computer form will be discussed in connection with Figures 1.23.1 to 1.23.4. For the most part, the conversion is accomplished by a keyboard device at which an operator enters the data he or she reads, either from the original written form, or from a specially-prepared copy of that form. The oldest keyboard device is the keypunch, which prepares a punched card for later entry into the computer; and the verifier, with which a second operator can independently check the cards punched by the first. These devices are direct decendants of the keypunches invented by Herman Hollerith and used in the analysis of the 1890 U.S. census. By the early 1950's, the widespread use of tabulating equipment and punched-card accounting machines required a corresponding use of keypunch equipment for data entry; and there existed, therefore, at the outset of the computer revolution, manufacturing and maintenance know-how, reliable products, user experience and acceptance, and a large pool of experienced operators—in 1954, when the U.S. government owned only 10 electronic computers, it employed over 6,000 keypunch operators, and must have operated over 5,000 keypunches to prepare data for its own accounting and tabulating machines.

In the accompanying figures, we count only the keypunches associated with electronic computers. In Figures 1.23.1 and 1.23.2, we see that, by 1970, there were over 270,000 unbuffered keypunches and verifiers in use, with an "if-new" value of almost $1.0B.

The use of some media as an intermediate depository to accumulate data transcribed (slowly) by an operator until it could be read (at high speed) into a computer was a necessity in the early days to disengage the more or less continuous work of the keypunch operator from the intermittent operation of the computer, which processed one job at a time, and was idle between jobs while the operators examined results and loaded programs and data. The choice of the punched card as the intermediate storage media was dictated by the already-mentioned existence of punched-card technology and experience. In the late 1960's, the data entry market had grown to the point where there was a large body of sophisticated users having heavy data-entry requirements, who were interested in reducing their costs. Mohawk Data Sciences exploited this market by offering a data-entry system where the media was IBM-compatible magnetic tape instead of punched cards. The advantages—greater keyboard operator productivity, elimination of cards, higher-speed input to the computer—were at once apparent to the user, with the result that the key-to-tape keyboard population grew rapidly, and the rate of growth of keypunches was slowed. IBM responded to this attack on a very lucrative market (the vast majority of keypunches in use were and are leased from IBM) by offering, in 1970, a buffered version of the keypunch, which improved operator efficiency, if it didn't provide the other advantages of key-to-tape equipment. The success of this product has resulted in a reduction of the unbuffered keypunch population, as shown in Figure 1.23.1. More recently, a third generation of data-entry equipment has been marketed in which a central controller (normally a minicomputer) having a removable-disk memory serves half a dozen or more keyboards. The introduction of these key-to-disk devices has affected shipments of both key-to-tape and keypunch equipment.

As was mentioned above, the existence of intermediate storage was initially required to separate the day-long operations of a keypunch department from the intermittent operation of early computers. Some second- and most third-generation systems function under the control of an operating system which enables the computer to run continuously, and which can respond at any time to an operator request for action. Some such systems have programs able to accept data at any time from any of a number of external terminals. And to some degree at present unknown, the operation of such terminals, either from the point at which data originates, or at a central point where written data is transcribed, have cut into sales of all keyboard data-entry systems.

**Character-Reading Equipment.** Two other devices have been used to convert written or printed information directly into digital electrical signals. The magnetic-ink-character recognition (MICR) system reads the magnetically preprinted bank number and account number from checks, along with the amount of the check, which has been manually entered on a keyboard-to-magnetic-ink printer. These devices, widely used by the banking industry to sort, distribute, and process the enormous volume of personal checks which have been written in recent years, grew rapidly in the early sixties and represent a substantial proportion of the dollar value of all data-entry equipment. (See Figure 1.23.4). The optical character reader (OCR), which reads typewritten, printed, or handwritten characters, has been less successful. The technological problems have been difficult to solve, and standard type fonts have evolved very slowly. It has not been possible to develop a machine which reliably reads a great variety of handwritten documents, of the kind which are created at the point of origin of the data. As a result, OCR success has come through the development of applications and equipments which involve the reading of printed information—account numbers and charges printed at the point of sale on charge-account receipts (another banking application)—and typewritten pages, prepared at a central point from original documents so that a typewriter replaces the keypunch, key-to-tape, or key-to-disk keyboards.

Technological and application limitations have thus restricted the market for character-reading equipment, with the result shown in Figure 1.23.3: for every character-reader in use there were in 1974 over 50 data-entry keyboards. But although the number of character-reading devices in use seems low, their contribution to data processing operations is considerable. Their maximum data input rates are typically 100 times that of the operator-limited keyboards (see Table II.2.120.3), and in aggregate it seems likely that U.S. data processing systems collect more data per year from character readers than from keyboards.

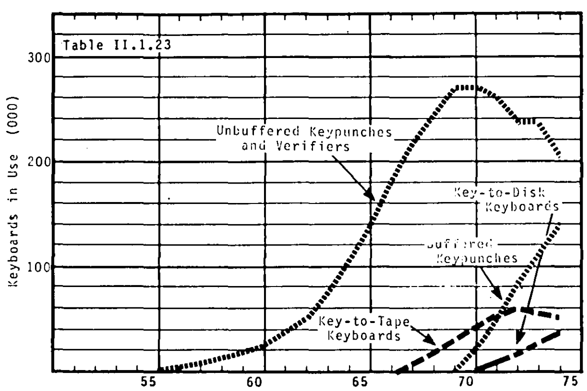



FIGURE 1.23.1 DATA ENTRY EQUIPMENT I.
NUMBER OF KEYBOARD SYSTEMS IN USE IN U.S.

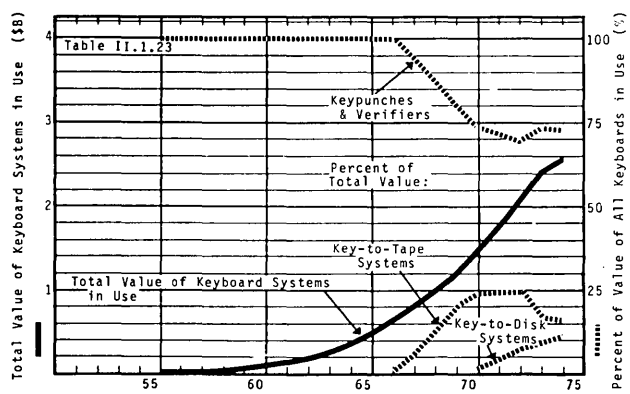



FIGURE 1.23.2 DATA ENTRY EQUIPMENT II.
VALUE OF KEYBOARD SYSTEMS IN USE IN U.S.

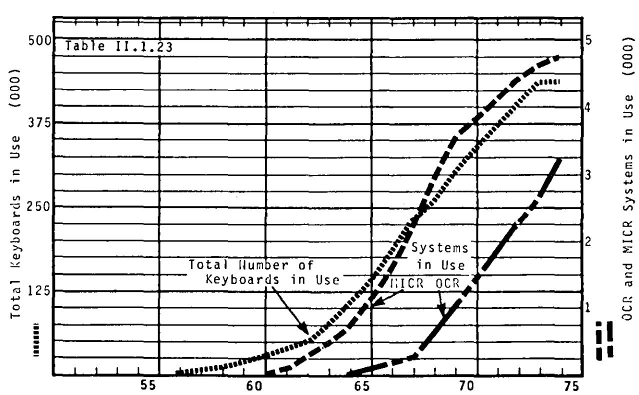



FIGURE 1.23.3 DATA ENTRY EQUIPMENT III.
NUMBER OF OCR, MICR, & KEYBOARD SYSTEMS IN USE IN U.S.

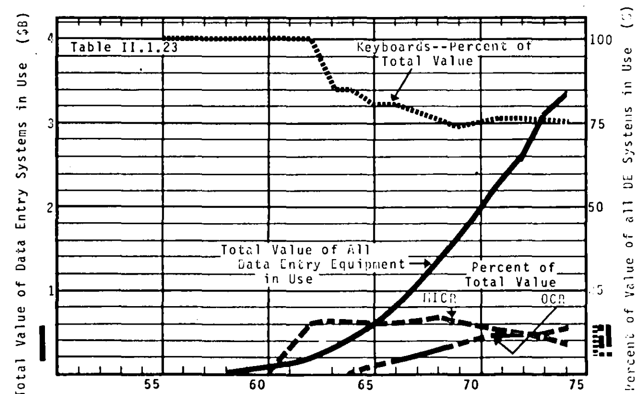



FIGURE 1.23.4 DATA ENTRY EQUIPMENT IV.
VALUE OF SYSTEMS IN USE IN THE U.S.

## 1.24 DATA COMMUNICATIONS AND TERMINALS ●

As computer systems grew more powerful, more cost-effective, and more numerous, it became evident that there was a large potential market for common-carrier facilities to transmit data. Accordingly, AT&T first offered private line data communications facilities in 1958, and since then has marketed data sets, which connect to their data lines and make it possible to transmit and receive digital information at the rate of tens, later hundreds, and most recently thousands of characters per second. Other common carriers followed with similar facilities and equipment; and the growth of this market (along with government action which made it legal to connect non-telephone-company devices to telephone lines) has encouraged a number of private companies to develop and market data sets. The extent to which GP system users have taken advantage of the communications facilities available is shown in Figure 1.24.1. Note that it took ten years of rapid growth to equip only a quarter of the systems with communications connections.

These facilities have been used for four quite different purposes: to give geographically separated users access to a common data base (e.g. airline sales agents access to reservation status, or brokers access to stock prices); to provide a small user with access to the computational facilities of a large machine (via time-sharing or remote-batch services); to reduce the cost of conventional communications traffic, by multiplexing many low-speed channels on a cheaper high-speed channel, and by using computers to store and relay messages; and to improve the speed of, or reduce the cost of, data-entry and collection (see the discussion in the previous section). Applications have evolved pretty much in the order named, with airline reservation and stock quotation systems being developed in the late fifties and early sixties, time-sharing services and communications applications growing rapidly in the mid-sixties, and remote-batch and data-entry applications evolving starting in the seventies.

All such applications presuppose the existence and availability of devices at the ends of the communication lines. The market for these devices, which are generally called terminals, is thus closely tied to the common-carrier market for data communication facilities. And for that reason, we treat these two subjects together. (For a more precise definition of the word *terminal*, and a discussion of the relationship between terminals and peripherals, see the notes in Part II in connection with Table II.1.24.)

**Data Communication Revenues.** The data communications revenues included in the review of the entire data processing industry (see Figures 1.20.4, 1.20.6, and 1.20.7) are repeated in Figure 1.24.2. Note the only revenue shown is that from the rental of data sets, and from the provision of private lines, assigned full-time to data transmission usage. We therefore ignore two important aspects of this part of the marketplace. First, we ignore the fact referred to above that, particularly in the last few years, a number of independent manufacturers have been *selling* data sets, while AT&T and the other common carriers continue to lease them. By ignoring such sales, we mis-state revenues. Second, we do not include the common carrier revenues contributed by users who transmit data on the Direct Dial (DD) network. There seems to be no analysis available of this segment of the data transmission market, but it is likely that the great majority of bytes transmitted via DD make use of local calls which may tie up telephone company facilities for a long time (e.g. during a several-hour session by a time-sharing user) but provide *zero* incremental income to the common carrier. A smaller proportion of traffic provides DD revenue from users who make toll calls or long distance calls, either because their transmission volume is too light for them to be able to justify the cost of a private line, or because they are using the DD network as emergency back-up for an out-of-service private line. None of this difficult-to-estimate DD service is included in our figures, and all of it worries the telephone companies because it consists of long-duration calls the switched network was not designed to handle.

In Figure 1.24.2 we have also plotted AT&T's reported "data service revenue". It is not clear exactly what is included in the AT&T figures, but, in addition to their revenue from data sets and from data-carrying private lines, it appears AT&T includes revenue from the sales and lease of teletype equipment and other terminals, and from AT&T's Telex service, which was handed over to Western Union in 1971. The two curves are thus not exactly comparable as measures of data transmission business, though they are obviously related.

The number and value of data sets in use are shown in Figures 1.24.3 and 1.24.4. As was previously mentioned, the figures on data set value were computed on the basis that all units are leased, and ignores the fact that, in recent years, many have been purchased. The two figures also show how the total number of data sets were distributed amongst various models having different capabilities. (The statistics cover the years 1962 through 1968 only, and refer only to Bell System data sets. AT&T has not made more recent data available.) Note that the Series 100 equipment, usable with new 15- and 30-character-per-second terminals, and the Series 300 data sets, which permit high-speed transmission of data between computer centers, substantially increased their percentage share of the data set marketplace in these years. However, the intermediate-speed Series 200 data sets, operating in the range of 2000 to 4800 bits per second and largely used for handling the multiplexed traffic from a number of simultaneously-operating terminals, still represented, in 1968, half of the value of all data sets in use.

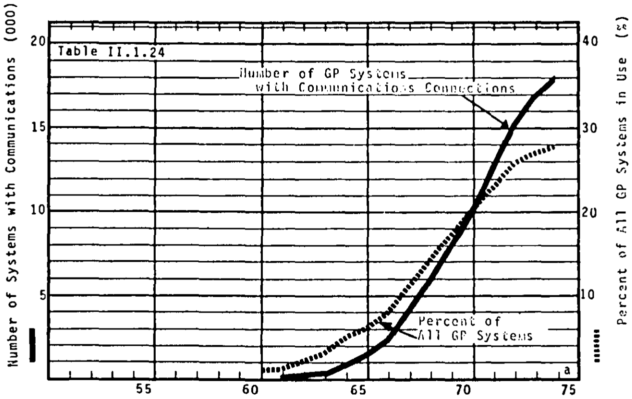



FIGURE 1.24.1 GP COMPUTER SYSTEMS IN USE CONNECTED TO COMMUNICATIONS LINES

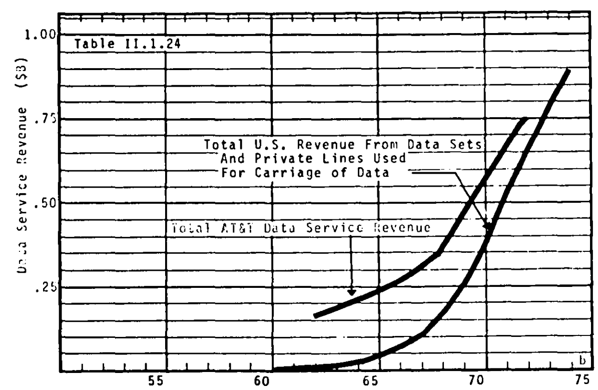



FIGURE 1.24.2 DATA COMMUNICATIONS REVENUES
TOTAL U.S. REVENUE, AND AT & T "DATA SERVICE REVENUE"

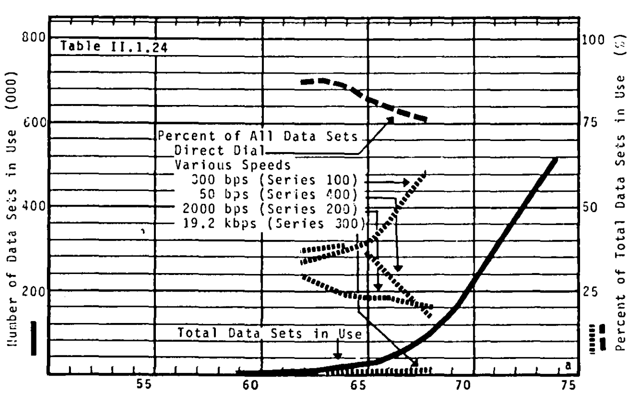



FIGURE 1.24.3 DATA SETS IN USE IN THE U.S. I.
TOTAL NUMBER AND DISTRIBUTION BY NUMBER

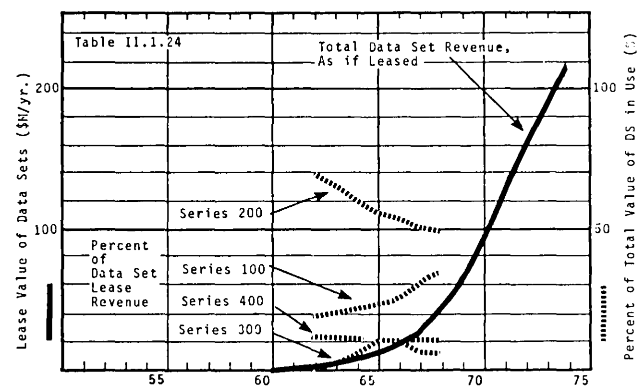



FIGURE 1.24.4 DATA SETS IN USE IN THE U.S. II
TOTAL LEASE VALUE OF DATA SETS, AND DISTRIBUTION

**Terminals.** The 515,000 data sets installed by the end of 1974 were, of course, the means to an end, and not an end in themselves. The vast majority of them were employed, directly or indirectly, to handle traffic from a growing population of computer terminals. Figures 1.24.5 and 1.24.6 provide some insight into the number and value of terminals installed in the United States. It also shows how the terminal population is divided between three main types: application-oriented terminals, designed with some special function in mind (e.g. terminals used for airline reservations, stock quotations, credit authorization, retail sales, etc.); general-purpose terminals, having a typewriter-like keyboard and either a local printer, cathode-ray-tube, or both; and machine-to-machine terminals, used to provide card-handling and line-printing functions at a location remote from a central computer. The first commercial computer terminals were used to process airline reservations, and were followed, in the early sixties, by stock market quotation terminals—all application-oriented. In the mid-sixties, the rapid growth of the time-sharing business led to the widespread distribution of general-purpose terminals, especially Bell System Teletype machines and IBM 2741's. More recently, the relative growth rate of the general-purpose terminals has slowed with the advent of machine-to-machine terminals, and with the successful introduction of application-oriented banking and point-of-sale (retail) terminals.

**Terminals, Data Sets, and Systems.** An analysis of some available statistics (described in Part II in connection with Table II.1.24) indicates that, though the distribution of data sets was changing, the average revenue per data set remained fairly constant at $420 per year, and the common-carrier revenue for transporting data remained fairly constant at $1400 per data set. If we assume these ratios have remained relatively fixed, we compute that 23% of the total U.S. revenue shown in Figure 1.24.2 comes from data sets, the other 77% from the carriage of data. Other ratios of interest are shown in Figure 1.24.7 and 1.24.8, though they should be regarded with some suspicion because of the great uncertainty inherent in a very rapidly-growing field. The number of terminals per system having terminals has remained fairly constant, at somewhere between 20 and 40. The number of terminals in use per data set is a complicated function of many variables. A system having a full-time private line assigned to each terminal requires two data sets per terminal—one at the terminal end of the line, and the other at the computer end. Many of the early, low-speed terminals operated directly on the common-carrier's low-speed lines, and required no data sets. Individual terminals on the DD network require one and a fraction data sets per terminal—one at the terminal, and one at the computer center, able to handle a large number of terminals because, on the average, only one terminal is connected at any given time. Finally, a cluster of terminals at one location may share a common pair of data sets, one of which multiplexes and de-multiplexes their simultaneous traffic on a high-speed line at the remote location, and the other which performs the inverse function at the computer center. The distribution of terminals per data set shown in Figure 1.24.7 is the resultant of these conflicting forces.

The communications costs of systems having terminals are shown as solid lines in Figure 1.24.8. In addition, the dotted line shows the trend in terminal investment per system. Note that the equivalent annual expense of that terminal investment (assuming a four-year life for the terminal) is comparable to the annual communication expenses.

## 1.25 SOFTWARE EXPENSES ●

Total annual expenses for the development of computer programs in the United States exceeded $10B in 1972, as is shown in Figure 1.25.1. Three elements are included in the total expenses plotted there: the applications programming costs of the users of computer systems; the development programming costs of the manufacturers who supply computer hardware; and revenue received by the software industry for the development of custom programs, or for the sale of standard programs. The dotted lines in Figure 1.25.1 show that the software industry and the software development costs of hardware manufacturers together account for only about 10% of the total expenditures. Close to 90% of the total is now, and has always been, spent by computer users.

The manufacturers' and users' costs discussed on these pages do not include expenses for minicomputer software. I offer three excuses for this omission. First, it is difficult to locate any estimate of minicomputer manufacturers' software development costs. Second, those costs must be relatively low, compared to those of the GP manufacturers, for minicomputers have "traditionally" been sold with only a minimum amount of software; and the development budgets of these manufacturers have necessarily been low. And third, minicomputer users need relatively little applications software, partly because minicomputer memories have been small, but principally because these systems have largely been used in fixed applications, where a program, once developed, is used with little or no change for a number of years, and where one program may serve a large number of computers used in identical applications.

**Users' Software Expenses.** The enormous cost to the user of writing and maintaining the applications programs which solve the user's specific problems is estimated in Figure 1.25.2. Note that these costs are comparable to total domestic data processing shipments and revenues (see Figure 1.20.2). That is to say, the burdened cost of the user's systems analysts and programmers is about the same as the total value of hardware shipments, plus the total amount paid for data processing services, supplies, and communications. The figures shown are based on the assumption that the number of systems analysts and programers *per dollar value of GP computer* has remained fairly constant—an assumption I adopted in the absence of any specific data on trends in the employment of these extremely important and expensive people. My figures thus may not reflect any improvement (or deterioration) which may have taken place in recent years as a result of the widespread use of small systems like IBM's System/3.

The embarrassingly high cost of application programming has been widely discussed and we will return to it in Section 4.22, where we discuss programming costs. However, we must keep in mind that the system analysts and programmers are really just procedure writers. If the computer had not been invented, or if computer programmers suddenly and magically cost nothing, it would still be necessary for *someone* in each organization to determine, in detail, the precise rules which are to be followed in processing the organization's data. Since that is a major portion of the systems analysts' job, we must conclude that "free" programming would not eliminate all of the costs shown in Figure 1.25.2.

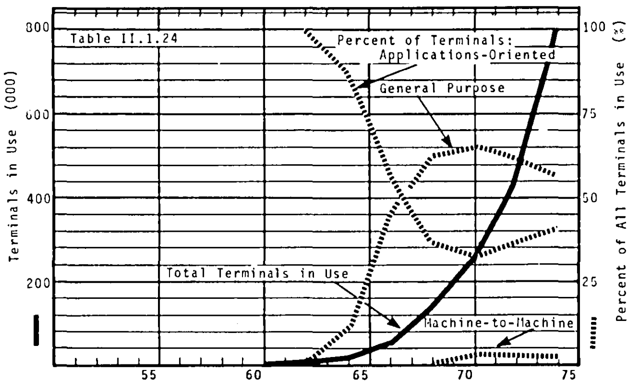



FIGURE 1.24.5 TERMINALS IN USE IN U.S. I
TOTAL NUMBER AND DISTRIBUTION BY NUMBER

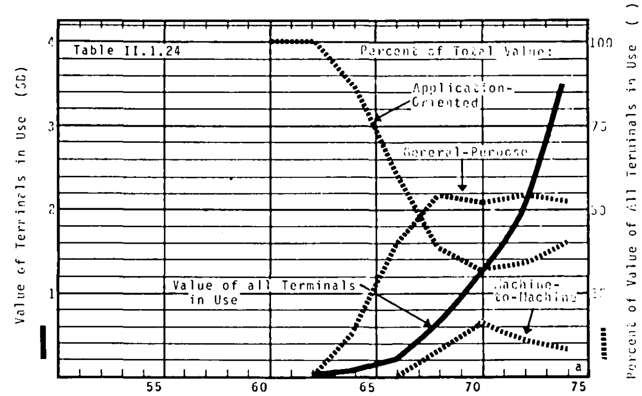



FIGURE 1.24.6 TERMINALS IN USE IN U.S. II.
TOTAL VALUE AND DISTRIBUTION BY VALUE

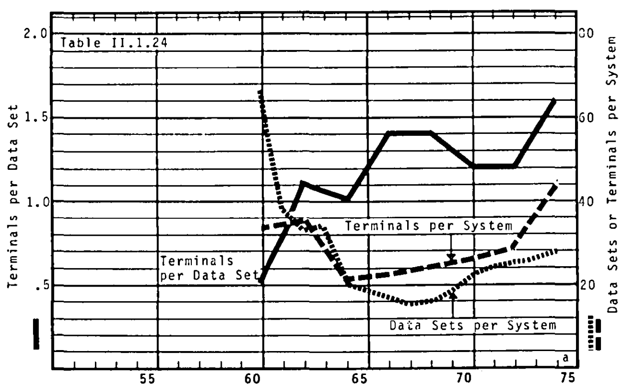



FIGURE 1.24.7 DATA SETS AND TERMINALS IN USE
SOME RATIOS

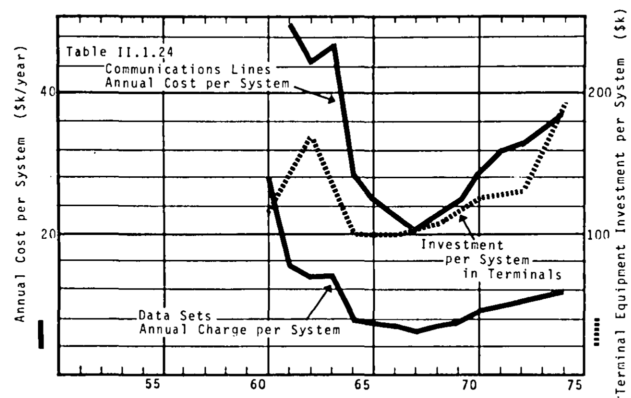



FIGURE 1.24.8 COMMUNICATIONS AND TERMINAL COSTS
OF SYSTEMS CONNECTED TO COMMUNICATIONS LINES

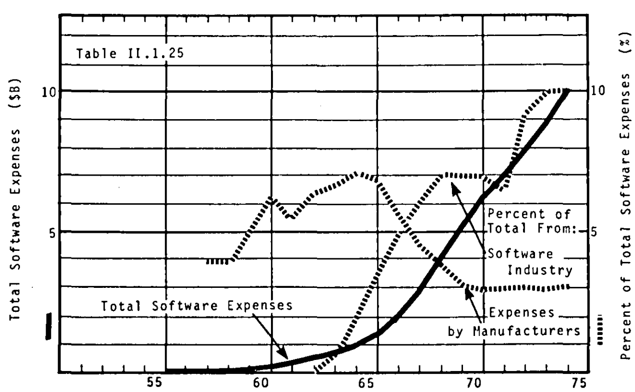



FIGURE 1.25.1 DOMESTIC SOFTWARE EXPENSES
TOTAL, AND MANUFACTURERS' AND INDEPENDENTS' SHARE OF THE TOTAL

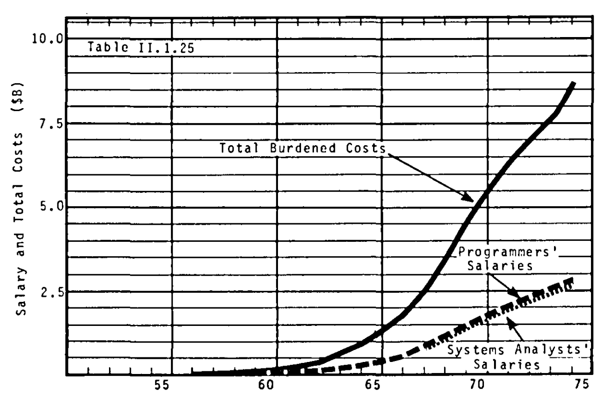



FIGURE 1.25.2 GP COMPUTER USERS' DIRECT SOFTWARE COSTS
SALARY AND BURDENED TOTAL COSTS OF APPLICATIONS PROGRAMS

**The Software Industry.** In the early sixties, the high cost and importance of software encouraged a number of entrepeneurs to form companies specializing in the development of computer programs. These organizations offered their services to computer manufacturers as well as to computer users. From the former they received contracts to develop assemblers, compilers, and utility routines of various kinds; from the latter, contracts to write a variety of application programs, both for batch processing and for on-line, real-time systems. The shortage of good programming talent and the fact that system manufacturers on the whole had not devoted enough attention to programming resulted in the rapid growth of this new industry, as is shown Figure 1.25.3. In the late 1960's, several things happened to change the complexion of the business.

1. The software companies perceived it might be practical and profitable to develop and sell specialized program products aimed at particular applications, despite the fact that these "standard packages" were not patentable and could in theory be copied and given away or even resold by an organization which had purchased one. (Some software has since been patented, and the patents are now being tested in the courts. However, many of the most successful "standard packages" are unpatented, and their distribution is in practice protected by the fact that the buyer usually needs and receives a good deal of support from the developer and seller of the program.)

2. A variety of "standard packages", together with programming manpower for writing custom software, had always been supplied "free" by manufacturers whenever they sold a computer system. Pressure from the independent software industry, which was of course selling its products and services in competition with the manufacturers, and concern regarding the anti-trust implications of these "free" products and services, led IBM in 1969 to announce that it was "unbundling" some previously free software and services from hardware sales, and was instituting standard charges for the items unbundled. Some other manufacturers have since followed IBM's lead.

3. By the early sixties, system manufacturers had begun to appreciate the importance of programming to the success of their ventures, and correspondingly made substantial increases in the proportion of their R & D budgets assigned to software. The result was a reduction in the contract work given to outside programming organizations.

4. The recession of 1969 to 1971 caused users to cut back on outside expenditures for software services, though the market for standard packages did not suffer and was perhaps stimulated by the users' search for cost savings.

The net result of these factors is shown in Figure 1.25.3: standard package revenue has grown very rapidly since 1971 while the growth in the market for custom software has slowed.

**Manufacturers' Software.** An estimate of the total software expenses by U.S. GP manufacturers is plotted in Figure 1.25.4, along with the proportion that expenditure represents of total hardware plus software development costs. From a level less than 10% of total development costs in the late 1950's, software costs spurted to nearly 40% of the total in 1965, as manufacturers devoted increasing attention to increasingly complex software, and as preparations for the third computer generation were made. Since 1965, software development costs have tripled, to almost $300M, though their proportion of the total has dropped to about 35%. The basis for this estimate is indicated in Figures 1.25.5 and 1.25.6. In 1954, IBM supplied about 6,000 lines of code as programming support for their very successful 650 computer. The company provided an assembler and a few basic utility routines, and not much more. As time passed, the software required per CPU model number increased exponentially. Compilers were invented, in an effort to reduce the user's programing costs, and it became standard practice to offer one or more compilers with every machine. And with the third generation, the Operating System, developed to improve system performance and to provide the user with a great variety of useful operating features, further escalated the software requirements per CPU. By the late 1960's, manufacturers found themselves offering more than one operating system per CPU, as well as more than one compiler; and IBM offered over 5 million lines of code with their 360 family. The requirements for various machines are shown in Figure 1.25.5, along with my estimate of the average requirement *per CPU type* for IBM, and for the other GP system manufacturers.

The costs shown in Figure 1.25.3, and the cumulative total lines of code required shown in Figure 1.25.6, are based on the "average" curves in Figure 1.25.4, and on the number of GP CPU models developed, from Figure 1.21.8. (See the discussion in connection with Table II.1.4.2, lines 64 to 115.) By 1974, over 125 million lines of code had been completed by the system manufacturers. And yet we must remember, referring back to Figure 1.25.1, that this enormous body of work cost substantially less than 5% of total domestic software expenses.

In summary: the explosive growth of the remarkably versatile and powerful computer has been accompanied by an equally spectacular, but largely hidden growth in a new entity—intangible, expensive, and extraordinarily complex procedures called computer programs.

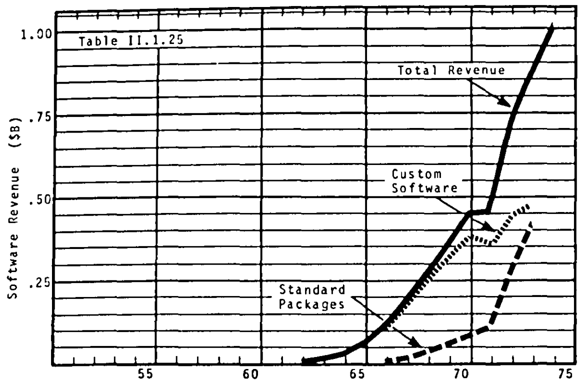



FIGURE 1.25.3 SOFTWARE INDUSTRY REVENUE
CUSTOM SOFTWARE AND STANDARD PACKAGES

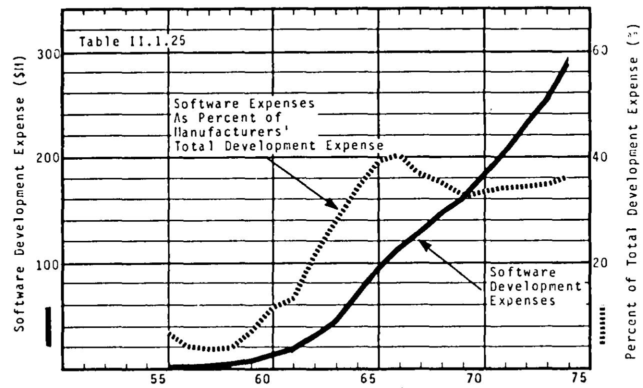



FIGURE 1.25.4 MANUFACTURERS' SOFTWARE DEVELOPMENT EXPENSE

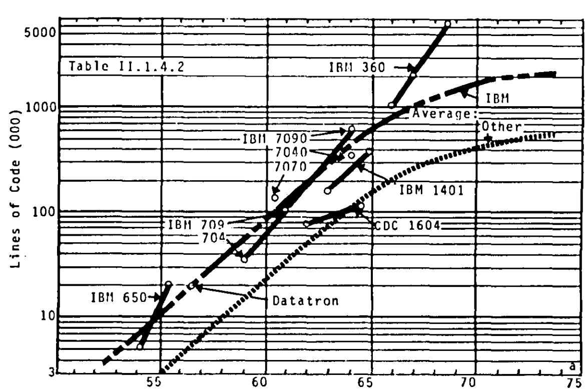



FIGURE 1.25.5 LINES OF CODE PROVIDED BY MANUFACTURERS
AS STANDARD PROGRAMMING SUPPORT

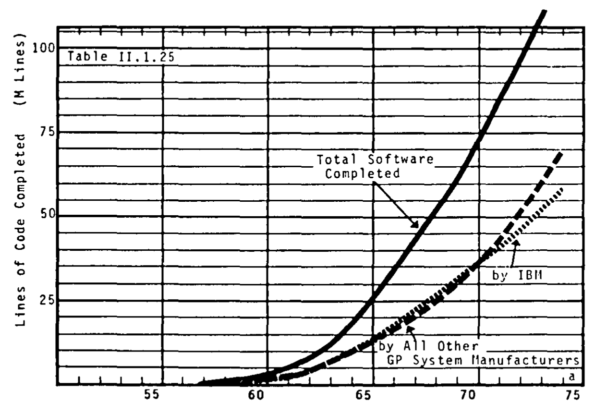



FIGURE 1.25.6 LINES OF CODE PROVIDED BY MANUFACTURERS II.
CUMULATIVE TOTAL SOFTWARE COMPLETED

## 1.26 THE DATA PROCESSING SERVICE INDUSTRY ●

Since 1967 The Association of Data Processing Service Organizations (ADAPSO) has annually published a survey of firms in the service industry. This continuing effort represents a unique attempt to measure the progress and growth of an important segment of the marketplace, and to provide helpful statistics about operations and problems of the industry's member firms. The basic data presented here is adapted, with little change, from the ADAPSO studies.

The various component parts of the industry, as defined and described in the studies, are shown in Figures 1.26.1 and 1.26.2, both in absolute dollars, and as percentages of the total. (Note that the software industry, described in the previous section, is included as one of the components.) Companies which operate computer centers and which process data on a periodic basis for a variety of customers, receiving raw data from them and delivering processed data to them by mail or messenger, were the orginators of the service business. Their batch data processing revenues still represent the largest component of the industry.

As computer and communication technology progressed, various service companies developed and began to market a host of new services where access to the computer was provided by means of communication lines and terminals, rather than mail and messengers. These "on-line" processing services started in the early sixties, and have since been growing very rapidly. Meanwhile, the rapid growth of the computer business spawned a number of new sub-industries, contributing "other" revenue (Figure 1.26.1) by operating computers for other companies (Facilities Management), training programmers, computer operators, and keypunch operators, printing computer-generated documents on microfilm, supplying data-entry services via keyboards or optical-character-reading equipment, and performing computer maintenance. The "other" revenue from this heterogeneous collection of firms is also shown in Figure 1.26.1, though ADAPSO has so far provided no analysis of its component parts.

A more detailed analysis of the batch and on-line data processing portion of the service industry is given in Table 1.26.1. In that table, the $1.5B in revenues generated in 1971 are broken down into nine component parts based on three methods a customer can use to gain access to services (the first three columns), and three ways the customer may use the computer (the first three rows). Looking at the columns, we see that the first (total revenue $1.06B) comprises the batch data processing revenue shown in Figure 1.26.1, and the second and third together (total revenue $.44B) break down the on-line DP revenues in that same figure. Furthermore, the table points out that on-line services can be provided either via remote-batch terminals, which generally contain a card reader and line printer and permit the customer to submit jobs and obtain printed results as if those devices were peripherals on his own local computer; or via a keyboard, which a customer uses to enter data or make inquiries. The customer using keyboard terminals receives acknowledgements and replies to his entries and questions on a local printer or cathode-ray-tube display. This immediate response, coupled with the user's ability to make a further inquiry or entry based on that response, suggests that this access category be labeled "interactive"; and the relative growth of the remote-batch and interactive services are indicated, as a percent of total service industry revenue, in Figure 1.26.3.

Let us now look at the three ways a service customer can use the computer—the first three rows on Table 1.26.1. First of all, he can write his own computer programs and simply purchase raw computer power from a service company. This mode of use accounted for $.38B of revenues in 1971, or about 25% of the total batch and on-line revenues. About half of that total came from customers who submitted their jobs in batches, either via mail and messenger, or through a remote-batch terminal. The other half came from interactive purchasers of raw power—the time-sharing users who generally use their terminals to solve relatively small, one-time scientific and business problems. This time-sharing business was, in 1971, the second largest of the nine categories shown in the table.

A customer can also avoid the expense and difficulty of writing computer programs, relying on the vendor to supply software as well as computer power. The second row on the table describes this form of service. And the first entry on this line, representing the situation in which a customer regularly submits his standard jobs for routine processing by the vendor's programs, is the oldest form of service and by far the largest of the nine categories. The customers for this service are the thousands of small firms, too big to perform their data processing operations manually with any efficiency, but unwilling to lease or purchase their own computer. And the processing generally includes payroll, customer billing, accounts payable, and accounts receivable. A small but rapidly-growing fraction of this form of service is being performed via computer terminals. The last few years have seen time-sharing companies, which formally provided nothing but raw computer power on an interactive basis, begin to offer specialized business services based on their own proprietary software. The result has been a transfer of revenue from the first to the third column of the second row.

The "regular calculations" described in the second row usually require that the vendor's software updates his customers' private files in the course of processing input data and preparing output reports. For example, a vendor may maintain a customer status file for a user, updating it with input data on orders, shipments, concellations, new customers, etc., and preparing reports on order status, shipments, accounts receivable, etc. In such applications, the files involved are private and confidential, and are accessed only by the individual customers. The third category of computer use shown in Table 1.26.1 includes systems which *permit* access to common or public files via the vendor's software. Examples include reservation files (airlines, sporting and theatrical events, campsites), stock market transaction files, consumer credit files, and U.S. census files. By far the biggest portion of this business is of course the interactive segment: as was mentioned in Section 1.24, the specialized airline reservation and stock quotation keyboard terminals provided the very first on-line computer services.

The distinguishing characteristic of the service industry has always been the large number of firms which provide services. Batch and on-line processing firms are described in Figure 1.26.4, both by the number of firms included and the average revenue per firm. The growth in average revenue during the late 1960's was brought about in part by the success of the on-line processing firms, whose minimum revenues must be measured in millions of dollars if they are able profitably to support the cost of one or more computer systems, each large enough to provide on-line services. A more detailed picture of the character of these firms is provided by Table 1.26.2, which compares the average firm with the average of the 70 largest and of the 1230 smallest. The former, which comprise only 5.4% of the total *number* of firms, account for 54% of the total revenue. Note that the largest firms have roughly 20 times the annual revenue, number of employees, and number of customers of the smallest firms, so the revenue per employee and the average revenue paid per customer are nearly the same. However, the revenue received per office and per computer is substantially greater for the large firms than for the smaller ones.

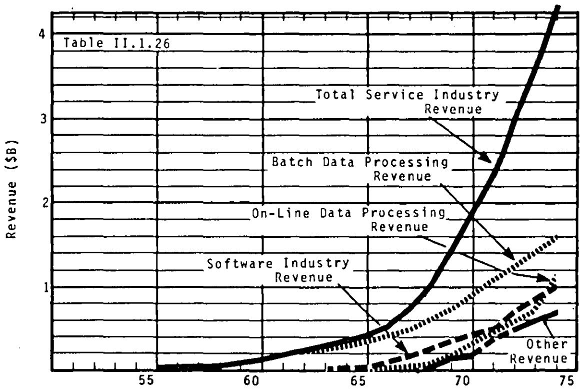



FIGURE 1.26.1 SERVICE INDUSTRY REVENUE I
PRINCIPAL COMPONENTS OF REVENUE

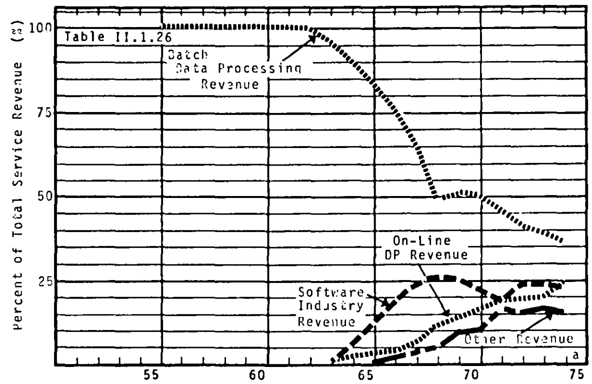



FIGURE 1.26.2 SERVICE INDUSTRY REVENUE II.
DISTRIBUTION OF PRINCIPAL COMPONENTS

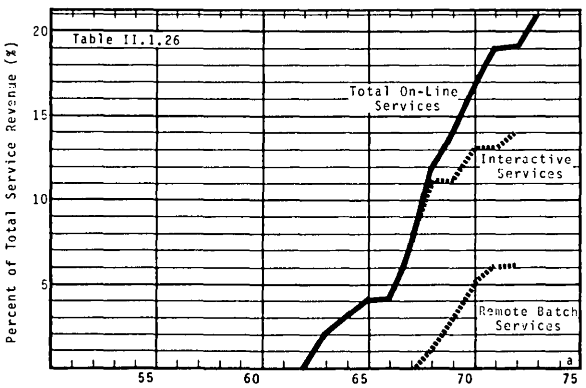



FIGURE 1.26.3 ON-LINE PROCESSING SERVICES
AS PERCENT OF TOTAL SERVICE REVENUE

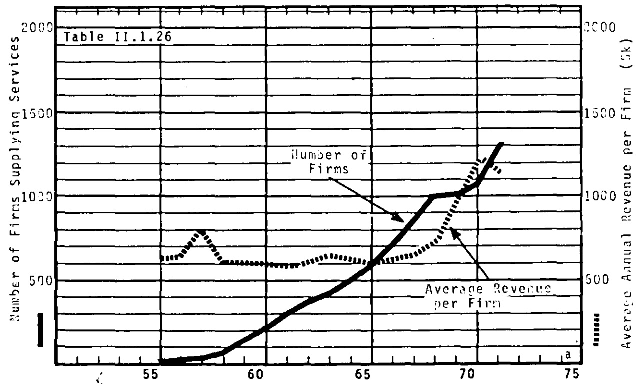



FIGURE 1.26.4 BATCH-PROCESSING AND ON-LINE SERVICE FIRMS

**TABLE 1.26.1 ANALYSIS OF BATCH AND ON-LINE DATA PROCESSING SERVICE REVENUES (1971)**

| Computer Use | Computer Access Means: Messenger or Mail (Batch) | Computer Terminal (On-Line): Remote Batch | Computer Terminal (On-Line): Keyboard (Interactive) | Total Revenue |
|---|---|---|---|---|
| Purchase Raw Computer Power | $95M (6.3%) | $100M (6.7%) | $185M (12.3%) | $380M (25.3%) |
| Perform Regular Calculations With Vendor's Software | $960M (64.0%) | $25M (1.7%) | $45M (3.0%) | $1030M (68.7%) |
| Access Common Files With Vendor's Software | $5M (0.3%) | $5M (0.3%) | $80M (5.3%) | $90M (6.0%) |
| Total Revenue | $1060M (70.7%) | $130M (8.7%) | $310M (20.7%) | $1500M (100%) |

Source: *EDP/IR* Sept. 15, 1972.

**TABLE 1.26.2 ANALYSIS OF BATCH AND ON-LINE DATA PROCESSING SERVICE FIRMS (1971)**

| | All 1300 Firms | Averages of: 70 Largest Firms | 1230 Smallest Firms |
|---|---|---|---|
| Annual Revenue | $1.139M | $11.429M | $.553M |
| Costs—Personnel | 37% | | |
| Equipment | 28% | | |
| Number of—Offices | 3.2 | 9.6 | 2.8 |
| Employees | 81 | 823 | 39 |
| Customers | 232 | 2325 | 113 |
| Computers | 3.1 | 9.8 | 2.8 |
| Revenue Per—Office | $359k | $1190k | $197k |
| Employee | $14.1k | $13.9k | $14.3k |
| Customer | $4.9k | $4.9k | $4.9k |
| Computer | $363k | $1164k | $200k |

Source: IDCServ71,72. See Notes in Part II. The data is based on a total revenue of $1.481B, compared to the $1.5B shown in Tables II.1.26 and 1.26.1.

## 1.27 DATA PROCESSING SUPPLIES ●

As was mentioned in the Overview in connection with Figure 1.20.6, computer system users purchase a variety of supplies, and especially media, used for recording data. In this section we will discuss the expenditures made for printing paper, tabulating cards, magnetic tape, and disk packs. There are other expenditures directly related to the use of data processing systems which might be included in the category "supplies", but which are difficult to estimate and will not be included here. For example, users purchase false floors for their computing rooms, storage cabinets and racks especially designed for media, and special equipment to process media (e.g. to recondition magnetic tape or disk packs, and to strip the carbon paper from continuous forms).

The major media expenditures are summarized in Figure 1.27.1. Total revenues in 1974 were over $1.8B, and although magnetic tape accounted for over one quarter of the expenditures in the mid-sixties, printing paper (continuous forms) and tabulating cards now account for over 90% of the total.

**Continuous Forms.** Line printers have a ravenous appetite for paper, and the printing and paper industries have responded appropriately with a host of standard forms, and the capability of supplying a wide variety of special ones. All the forms products have the property that they consist of long, continuous stretches of paper (so the printer does not have to be frequently reloaded with paper), that they have a series of small holes near the long edges (to accomodate the printer's sprocket drive, necessary to keep the paper aligned), and that they are perforated (to make it easy to separate the long sheets into segments of manageable or useful size). Standard forms are offered in a dozen principal sizes, and each size is generally available either as a single sheet, or accompanied by one to five additional sheets with interleaved carbon paper. Custom forms, which probably account for the larger share of total dollar sales, are designed to provide special sizes, special printing, special perforations, and special paper. The annual forms shipment revenue is shown in Figure 1.27.2, along with the annual cost per line printer, computed by dividing total shipments by the number of line printers in use from Figure 1.22.14. Note that the average cost of paper for a line printer has for some time been greater than the average annual lease price for a printer. The reduction in the average annual cost of paper per line printer, from over $15,000 in the late fifties to about $10,000 in the late sixties, probably came about partly through a reduction in the unit cost of continuous forms, and partly because of a reduction in the number of lines printed per month per printer.

**Tabulating Cards.** The total value of card shipments is given in Figure 1.27.3, and the trend in the selling price of blank cards appears in Figure 1.27.5. Once again, the figures I present are based on very sparse data (see the discussion in Part II in connection with Table II.1.27). That portion of the total value which is attributable to cards punched by keypunch operators is also shown in Figure 1.27.3, and is based on the assumption that an operator punches about 100 cards an hour. The large increase in card costs in 1974 is the consequence of a large increase in unit price–see Figure 1.27.5.

**Magnetic Tape.** Data on the number of magnetic tape reels in use per tape drive in use, on total tape revenue, and on the average price of a reel of tape, are all given in Figures 1.27.4 and 1.27.5. As is explained in Part II, the figures on tape shipments were computed based on the assumed growth in tape usage, the estimated price per tape, and the further assumption that tapes have an average useful life of five years. The sharp reduction in shipment value in the late 1960's was a result of the success of the moving-head disk drive, which slowed the growth in the sale of tape units. The resulting drop in sales of tapes for new drives, during a period when tape sales had been increasing, probably led to an oversupply of tapes and caused the substantial drop in tape price per reel in 1968, as is shown in Figure 1.27.5. Since 1970, more tapes have been shipped per year as replacements for worn tape than have been shipped for new units, or to provide increased off-line storage for existing units.

**Disk Packs.** We have already discussed the growth of magnetic tape shipments in connection with Figure 1.27.4. The same figure also shows the growth in sales of disk packs–the removable medium for the popular and widely used moving-head files. Figures 1.27.6 and 1.27.7 provide some additional detail on the distribution and use of these devices. Comments:

1. There are typically an average of two to ten disk packs in use per spindle, compared with the several hundred tape reels in use per tape drive. This difference comes about, of course, because of the large ratio of disk pack to tape reel prices. As each new disk drive has been introduced, users have started by purchasing two disk packs per spindle, on the average. They have then added one or two disk packs per year per spindle (and have bought an increasing number of packs to go with any new spindles they have purchased), until another generation of disk drives became available. As sales of new spindles level off in anticipation of shipments of a new drive, so do sales of disk packs.

2. The early adoption by other companies of IBM's magnetic tape standard was very important to the development of the tape industry. It has been possible to increase storage density by a factor of ten without changing the basic dimensions of the magnetic tape medium. However, as moving-head files have evolved, it has not been possible to provide capacity and performance improvements without changes in the media; and each new equipment generation required new and more expensive disk packs. Once a new disk pack is introduced and is manufactured by companies other than IBM, its price begins to drop (see Figure 1.27.5). But the changing technology has prevented the long-term price reductions which were possible with cards and tape. (For a discussion of media prices *per byte*, see Section 2.16.)

Finally, let us look again at the history of the total available storage capacity on magnetic tape and disks. In Figures 1.22.9 and 1.22.11, we observed the rapid increase on-line capacity of tape and disks–the storage capacity of the media actually mounted on existing tape drives and spindles. Note that since 1970, on-line spindle capacity has exceeded on-line tape unit capacity. The corresponding off-line situation is shown in Figure 1.27.8, where we see that over 95% of the data recorded on magnetic media is still recorded on compact, low-cost magnetic tape.

## MARKETPLACE–1.27 Data Processing Supplies

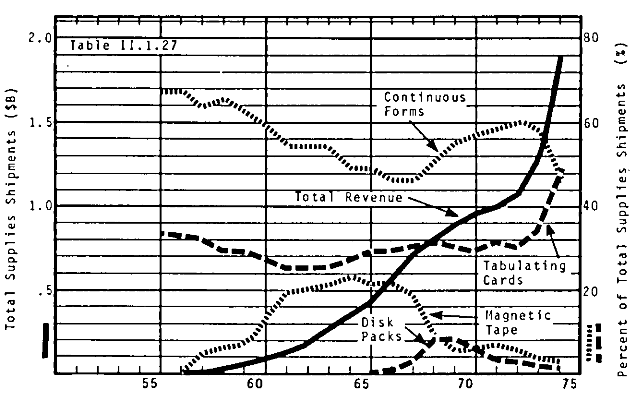



FIGURE 1.27.1 SUPPLIES INDUSTRY REVENUES I
TOTAL DOMESTIC SHIPMENTS AND DISTRIBUTION BY TYPES

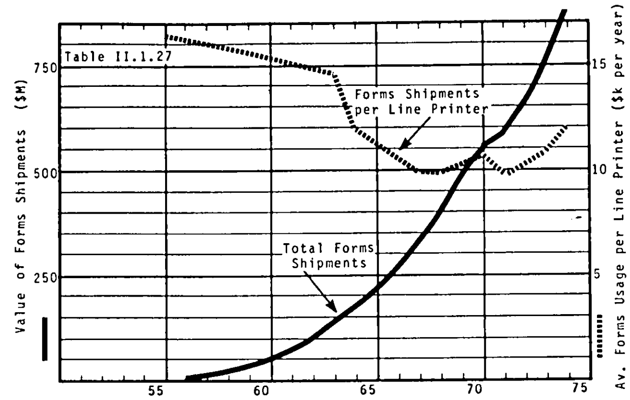



FIGURE 1.27.2 SUPPLIES INDUSTRY REVENUES II.
CONTINUOUS FORMS FOR EDP PRINTERS

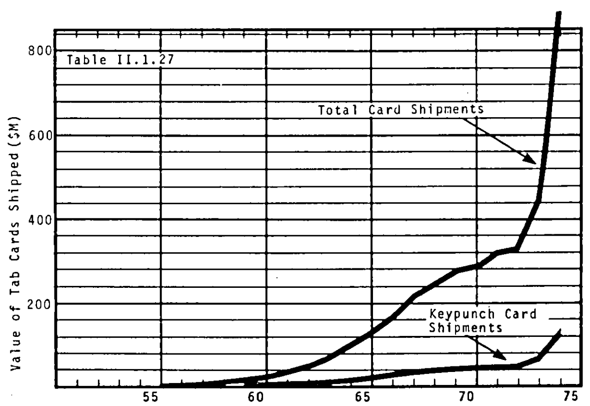



FIGURE 1.27.3 SUPPLIES INDUSTRY REVENUES III
TABULATING CARDS FOR EDP USE

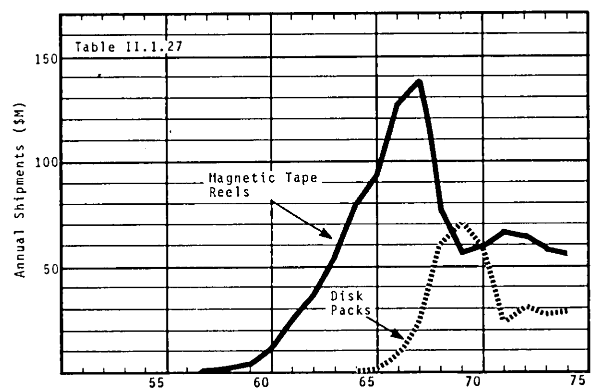



FIGURE 1.27 4 SUPPLIES INDUSTRY REVENUES IV
MAGNETIC TAPE AND DISK PACK SHIPMENTS

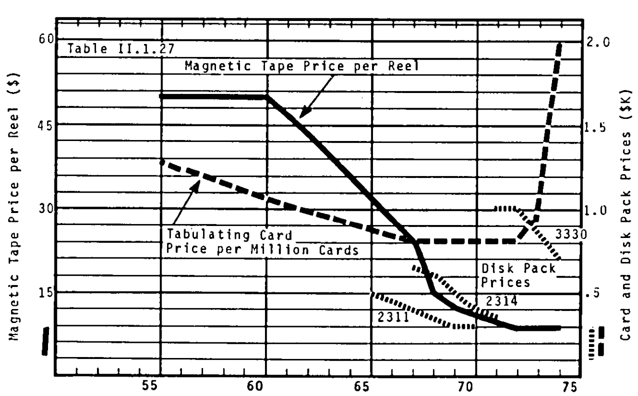



FIGURE 1.27.5 PRICES OF SUPPLIES
MAGNETIC TAPE, TABULATING CARDS, AND DISK PACKS

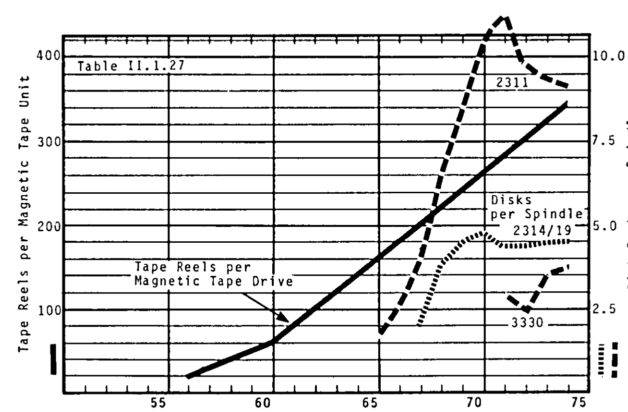



FIGURE 1.27.6 MAGNETIC TAPE AND DISK-PACK INVENTORIES I
TAPES PER DRIVE AND DISKS PER SPINDLE

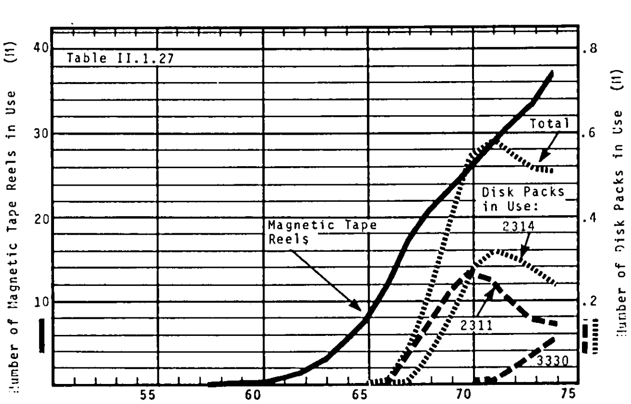



FIGURE 1.27.7 MAGNETIC TAPE AND DISK-PACK INVENTORIES II
TOTAL TAPES AND DISK PACKS IN USE

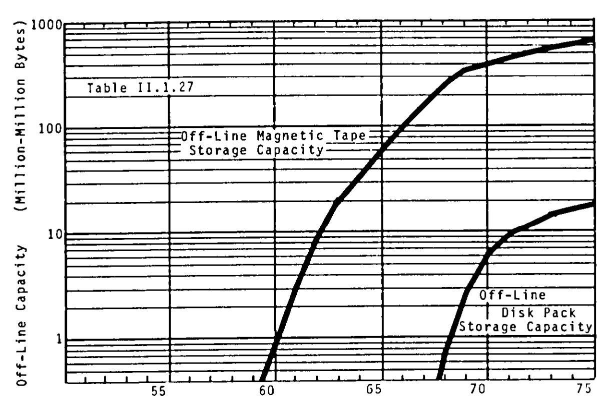



FIGURE 1.27.8 OFF-LINE STORAGE CAPACITY
OF MAGNETIC TAPE & DISK PACK MEDIA

## 1.28 WORLDWIDE COMPUTER INSTALLATIONS

Wherever an organization exists, there also exists a need for data and data processing. People must be paid, records must be kept, plans must be recorded, and the managers of the organization must be given some information to help them make decisions. The need for data processing is universal, and as a natural consequence computers are used throughout the world.

**Computers in Use.** Outside of the United States, the principal users of computers have been West Germany, Japan, France, and the United Kingdom. Figures 1.28.1 through 1.28.3 show how computer populations have grown in those four countries, and in the rest of the world, both in absolute numbers and proportionately. Comments:

1. In Figure 1.28.1, we see the computer populations in the three European countries and Japan grew at much the same rate until the late Sixties, despite the enormous differences between those four countries. Since about 1967, the Japanese computer population has grown much faster than that of any other country.

2. The United States has always led the world in number of computers installed (and in ratios of computers per unit population and GNP, as we shall see). The American proportion of total world installations has, however, dropped from its high of over 80% in the early 1950's; nevertheless, even today over half of all computers in use in the world are located in the United States.

3. Looking at Figure 1.28.3, we see that the Western European computer population grew more than proportionately in the late fifties and early sixties, and has since levelled off; that the Japanese share has grown fairly consistently during the past fifteen years; and that there was considerable relative growth in the populations in "other" countries, especially the USSR, Canada, and Australia, during the mid-sixties.

4. It is extremely difficult to obtain reliable information on the computer populations of the USSR, China, and other Iron Curtain countries. The estimated 150,000 computers installed at the end of 1971 included an estimated 5,500 systems in the USSR; but there are other estimates of the Russian population at that time, some as high as 7,000. The number of Russian computers in use is thus apparently comparable to the number installed in the four countries described by Figure 1.28.1.

**Relative Use of Computers.** The number of computers in use in a country, taken by itself, is of course not a fair measure of the comparative extent to which computers are used for data processing in that country. Presumably data processing activity in a country is in some way related to the number and complexity of organizations in that country; and organizational complexity is in turn related to population and GNP—two quantities relatively easily measured. In Figures 1.28.4 and 1.28.5 we compare computers in use per million population and per $B of GNP for the United States and various geographical entities. The most interesting aspects of these figures are the questions they raise—questions for which there appear to be no ready answers. When and where will the curves flatten out? Why have the values of these ratios for Japan and the Western European countries remained so close together over the years? Why are those ratios so different from the American ones? Will the curves of Figures 1.28.4 and 1.28.5 ultimately converge, or is there some reason to expect that the saturation point for computer usage will be different for different countries? What implications does that have for computer markets in the rest of the world?

**U.S. Computers Abroad.** For the most part, this book documents the history and condition of the American computer business. The modern, stored-program computer was invented here, the first commercial models were developed and marketed here, and our well-known preoccupation with and delight in things new and novel has perhaps encouraged us to accept and use computer technology more rapidly than our opposite numbers abroad. The rapid development of our domestic industry led American firms to market their products overseas, with the result that roughly 90% of the worldwide total number of computers in use (Figure 1.28.2) have been made by American manufacturers.

This situation has been a matter of considerable concern to some foreign governments. They argue that: (a) Organizations must use computers, both in product development and in management operations, to remain competitive in the world marketplace. If computers are therefore essential, it is unwise to have to rely on another country as a source of supply. (b) The electronic technology employed in computer manufacture is useful in the manufacture of other products, and therefore its local development should be encouraged. (c) A domestic computer manufacturing operation can improve trade balances, both by reducing the necessity for importing American equipment and by increasing the export of domestic equipment.

Of course, these arguments and attitudes only developed over a period of time, as the importance of computers became apparent. The influence of American computer firms on the markets in Germany, France, Japan, and the United Kingdom is shown in Figure 1.28.6, and has led those four countries to take steps officially to encourage local computer development and manufacture. Of the four markets shown, West Germany's has been dominated most effectively by American firms; and starting in 1967 the German government provided loans and grants to German-owned computer firms to help support research and development. The French computer industry, led by *Cie des Machines Bull*, had competed very successfully in the fifties and early sixties. However, it ran into serious financial difficulties in the early sixties, and in 1964 was purchased by GE and subsequently sold to Honeywell. Partly as a result of this purchase, and partly because the U.S. State Department put an embargo on the shipment of large CDC computers to the French Atomic Energy Authority in 1963, the French government developed the *Plan Calcul*, aimed at building up a French-controlled industry. As part of that plan, the *Compagnie Internationale pour l'Informatique* (CII) was formed in 1966, and from then until 1975 the French government supported it (and other computer-related organizations) with development grants and loans. By 1975 the continuing investment had become a burden, and the government sold CII to Honeywell-Bull.

A number of British firms entered the computer business very early, and initially were very successful in selling products in the British market. (Probably this early success stemmed in part from the fact that much of the early work on computer development was carried out in British Universities and government laboratories, so that a pool of experienced hardware and software people was available starting in the early fifties.) However, the British companies had difficulty competing with American firms, and simultaneously had difficulty in achieving profitability. The result was a series of mergers, which culminated in 1968 with the formation, under strong government encouragement, of International Computers Ltd. (ICL). The government took a 10% share of ICL's capital, and has helped support the company with loans and development grants.

The Japanese government has participated in the development of a local computer industry in Japan almost from the first. The participation has included active encouragement of domestic firms, and specific restrictions on the imports and local sales activities of foreign firms.

Generally speaking, the government-directed European activities have not been successful—or at least not as successful as the various governments would like. American firms continue to dominate the marketplace; and ICL and CII remain uncomfortably unprofitable despite their government subsidies. The domestic Japanese computer manufacturers, on the other hand, have achieved success and are beginning to market their products outside of Japan.

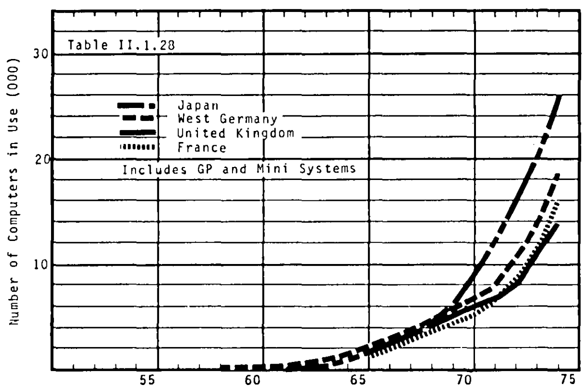



FIGURE 1.28.1 INTERNATIONAL INSTALLATIONS I.
COMPUTERS IN USE IN FOUR COUNTRIES

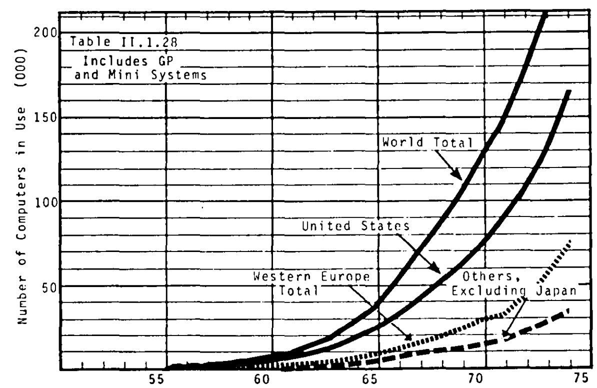



FIGURE 1.28.2 INTERNATIONAL INSTALLATIONS II.
COMPUTERS IN USE WORLDWIDE

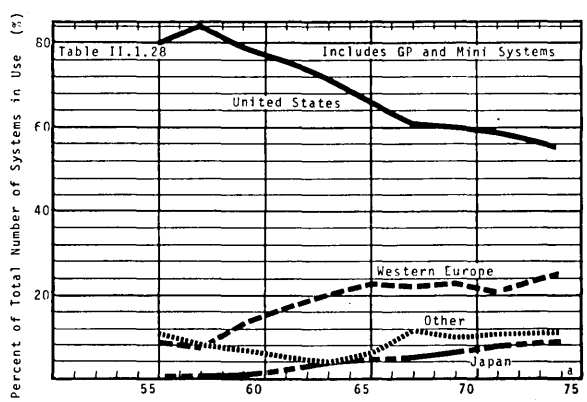



FIGURE 1.28.3 INTERNATIONAL INSTALLATIONS III.
PROPORTION OF TOTAL NUMBER IN USE, WORLDWIDE

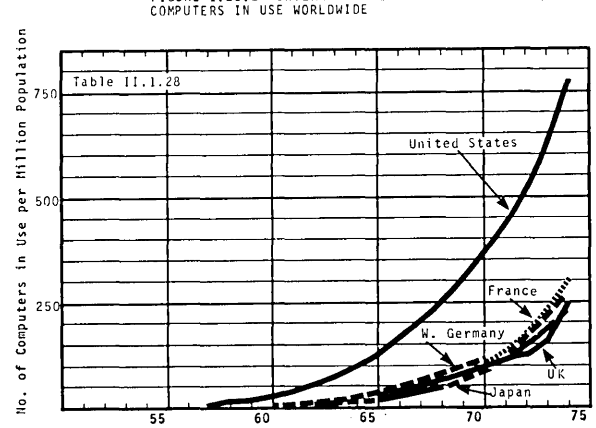



FIGURE 1.28.4 COMPUTERS IN USE PER MILLION POPULATION

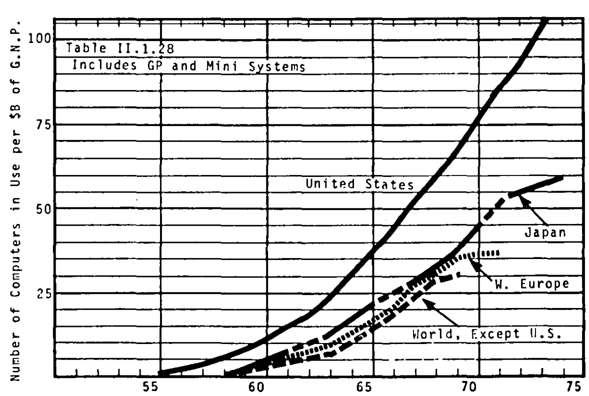



FIGURE 1.28.5 COMPUTERS IN USE
PER BILLION DOLLARS OF GROSS NATIONAL PRODUCT

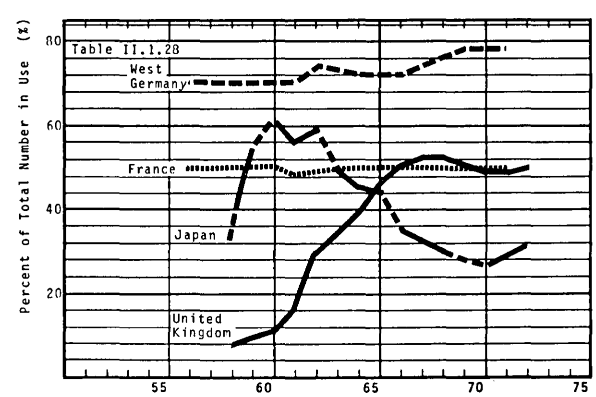



FIGURE 1.28.6 COMPUTERS MADE BY AMERICAN MANUFACTURERS
PROPORTION OF TOTAL SYSTEMS IN USE IN FOUR COUNTRIES

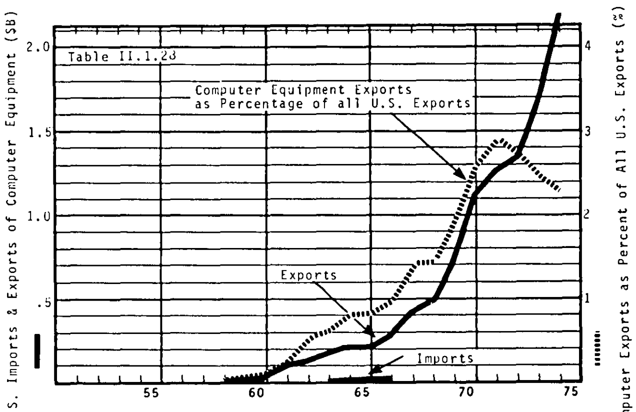



FIGURE 1.28.7 U.S. BALANCE OF TRADE I.
COMPUTER EQUIPMENT EXPORTS AND IMPORTS

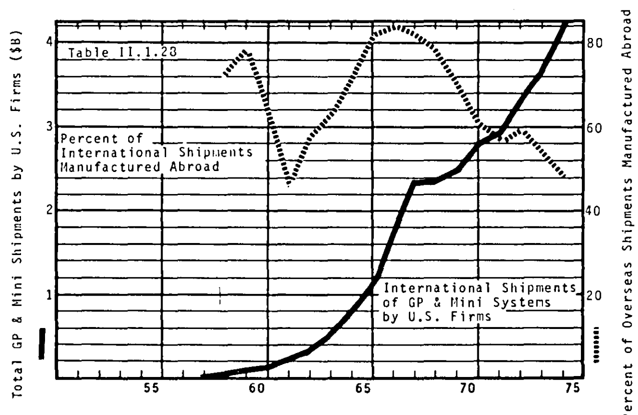



FIGURE 1.28.8 U.S. BALANCE OF TRADE II.
TOTAL INTERNATIONAL SHIPMENTS OF SYSTEMS MANUFACTURED BY U.S. FIRMS

**U.S. Balance of Trade.** The computer business has been a helpful contributor to the U.S. balance of trade, as is shown in Figure 1.28.7. Exports of computer equipment passed the billion dollar mark in 1970, having grown to represent over 2.5% of all U.S. exports. However, these figures represent only a portion of the total impact of American computer companies, for it includes only computer equipment manufactured in the United States and shipped abroad. Most of the equipment delivered abroad by American computer companies is manufactured outside the United States; and the effect of these shipments on the American balance of trade is difficult to judge—the profits from such shipments are largely reinvested abroad to finance lease equipment and to construct new manufacturing facilities. Total shipments abroad by U.S. firms are shown as the solid line in Figure 1.28.8. And the dotted line in that figure is an estimate of the proportion of international shipments manufactured abroad. However, the dollar value of the overseas manufactures is computed by subtracting Department of Commerce figures on U.S. computer equipment exports from IDC estimates of international GP and minisystem shipments, and must be regarded with some suspicion—it seems unlikely that, in the early seventies, only fifty or sixty percent of international shipments by U.S. firms were manufactured abroad.

## 1.3 Companies •

### 1.30 INTRODUCTION •

The explosive growth described in the preceeding pages is the direct result of a lot of hard work by thousands of individuals. All this individual effort was coordinated and directed in a variety of commercial organizations, large and small; and no picture of the industry can be complete unless it includes some discussion and description of the companies which participated in and contributed to the growth of the industry. Our approach will be to identify the principal companies involved in some sectors of the industry, and then to select a few specific organizations for more detailed description and analysis. In selecting organizations for detailed discussion, I have been influenced by the size of the organization, and by the accessibility of data covering its operations in the computer business. (It is the problem of availability of pertinent data which leads me to describe Control Data Corporation's computer business rather than Sperry-Rand's, for example. The latter organization has the bigger share of the total business; but it is very difficult to separate the data processing portion of the business from other operations of the large corporations.) In selecting company data for discussion, I have generally concentrated on operations management (selling, manufacturing, engineering) rather than financial management (capitalization, cash flow, debt). I make this choice on the grounds that operations management is industry-oriented while financial management, while extremely important, is not industry-specific. This is of course an oversimplification. For example, the rapid growth of the industry and the spectacular success of some new firms has made it relatively easy for enterpeneurs to raise capital; and the fact that much data processing equipment is rented or leased has both created financing problems and also helped maintain corporate revenue growths in years when product changes or recessions limited the growth in shipments of new equipment.

Section 1.31 will review all the systems companies. In Section 1.310 we will briefly look at Burroughs Corp., Honeywell, NCR, and Sperry-Rand. The next two sections cover IBM and Control Data Corporation in considerable detail. The financial history of a few other companies will be found in Part II.

The companies which participated in and contributed to the growth of the data processing industry generally have four characteristics in common.

1. They have had to deal with an extraordinary set of changes. Technology has changed—from the vacuum tube to the transistor to the integrated circuit. Applications have changed—an emphasis on scientific computation has been replaced by a preponderance of commercial installations, and an emphasis on computation has given way to an emphasis on data storage and retrieval. Products have changed—peripherals displaced processors as producers of revenue, and time-sharing services compete with batch processing services and with small, stand-alone processors. Competition changes—new companies appear from nowhere, established companies go bankrupt or are acquired by their competitors. Personnel change—individuals change jobs voluntarily to take advantage of new opportunities, or involuntarily because they have been unable to cope with the rapid rate of change.

2. They have attracted competence and stimulated hard work by providing very substantial financial gains to employees willing to risk capital. Stock options or stock purchase plans or both have been offered by most companies, and by all new companies, and have been amazingly effective in encouraging productivity, inventiveness, and hard work from unusually competent people.

3. They have had a strong technical bias. Because the computer and its technology are so complex, the industry has attracted engineers and scientists from many fields. Top and middle management, as a result, has an unusally high proportion of people with technical backgrounds. Because technical fields have always attracted students of unusual ability, the general result has been that there are an unusual proportion of unusually bright people in all branches of the industry.

4. They have benefitted from the intrinsic fascination of computers. Opportunities for promotion, for financial reward, and for association with stimulating colleagues have both characterized data processing industry companies, and stimulated their growth. But to some extent, industry growth is occasioned by the fascinating complexity and flexibility of the computer. It is an intellectual challenge to design a system which monitors and optimizes its own performance, or which solves numerical problems never before tackled, or which gives each of one hundred users the impression that he alone is using the machine, or which provides corporate management with new insights into operating problems. And this challenge has delighted and continues to delight many people, and gives the industry a unique flavor.

## 1.31 SYSTEMS COMPANIES ●

The systems companies are defined as those which manufacture and ship complete systems, including processors, peripherals, and software, and which offer their customers post-shipment support ranging from system maintenance (the minimum) to the delivery and installation of a working system which contains specially- designed hardware and software as well as the company's standard products. These companies, which produce both GP and mini systems, account for the lion's share of the data processing business—see Figures 1.20.4 and 1.20.5. In the ensuing pages, we will examine them in some detail.

**Systems in Use.** One measure of a company's importance is the number of its computers which are in use at any time, and Figures 1.31.1 through 1.31.8 compare the major systems companies on that basis, showing what percentage of all computers in use in the U.S. at the end of each year were supplied by each of the major manufacturers. The first four figures refer to GP systems only, the last four to mini systems. Comments:

1. IBM has dominated the GP systems market since the fifties. The first commercial stored- program computer to be shipped was actually Eckert-Mauchly's Univac I, and (though Figure 1.31.2 does not extend that far back) that company, soon purchased by Sperry-Rand, established a handsome lead for itself in the very early fifties. But IBM's ability to market this new generation of products— to train people who could help customers plan for, program, install, and operate computers—and its obvious committment to the business as indicated by the parade of new products it developed, resulted in the concentration of market power shown in Figure 1.31.1.

2. The industry, dominated as it is by one large company, has also always been one which could be entered by a few bright and aggressive people, who generally found it easy to raise capital and start a new company in this glamorous and rapidly-growing field. Many of the resulting firms were bought by larger companies desiring an entry in the business. Thus Eckert-Mauchly was acquired by Remington-Rand, Computer Research Corporation by National Cash Register (NCR), Electrodata by Burroughs, Computer Control Corp. by Honeywell, and Scientific Data Systems (SDS) by Xerox. Others have failed (e.g. Viatron) or simply faded away and disappeared (e.g. Alwac Corp.).

3. Three very large companies have attempted to establish themselves in the field only to decide ultimately that the investment required to compete profitably with IBM would be prohibitive. One, the Ford Motor Company, simply dropped out before its investment was too large. Two others, RCA and General Electric, had acquired moderate shares of the total market when they decided to give up. GE sold most of its business to Honeywell in 1970, keeping only the process control and time-sharing service divisions. And RCA sold out in 1971 to Univac. Figures 1.31.2 and 1.31.3, and other later figures giving revenues and the value of equipment in use, show the companies both separately, and as if they had always been merged together.

4. Looking at Figures 1.31.2 to 1.31.4 we can summarize the history of the five largest 'other' system manufacturers as follows. Univac was for many years clearly the second most important company after IBM. But its share of the market in terms of number of machines has fluctuated, and its share in terms of installed value has (as we shall see) dropped. Honeywell has fairly consistently been growing until, in the early seventies, its market share was comparable to Univac's. Meanwhile NCR's and Burrough's shares of the total number of systems installed have grown fairly consistently after sliding during the late fifties; and Control Data Corporation's (CDC) share has remained fairly constant. *However, we must remember that number of systems in use is only one measure of market share.* In later figures we will see measures of market share based on value of systems in use, and on revenues.

5. The minicomputer market has in effect been dominated by two different companies. In the early sixties, CDC bought Librascope's and Bendix's business, including primarily the LGP-30 and G-15, and very successfully sold their own 160 family of machines. However, the main focus of CDC's attention soon turned to very large and powerful systems, starting with the 6600 in 1964. And in the meantime Digital Equipment Corp. (DEC) introduced the PDP-8, at a price substantially lower than the CDC 160, and discovered a new, very price-sensitive market. Figures 1.31.5 and 1.31.6 show the result. For a time Xerox (then SDS) competed with DEC, but while DEC developed even smaller machines in exploiting the small-system market, Xerox consciously decided to pursue the market for larger machines, and to move into the GP marketplace. That decision certainly contributed to its demise in 1975.

6. DEC's success stimulated the formation and growth of a number of imitators, five of which are shown in Figure 1.31.7. IBM's solitary entry, The System/7, did very well for a while, until it became clear that IBM did not intend to compete with the very low-cost systems. But the minicomputer marketplace has always been easy for new firms to enter, inasmuch as an experienced group of engineers can quickly and cheaply develop a processor and can market it for *direct sale* (no capital required to finance leases) with a minimum complement of purchased peripherals. Figure 1.31.8 indicates that 'other' manufacturers, not identified in the earlier figures, have generally installed 15% to 20% of the systems in use. The proliferation of minicomputers has, however, increased that percentage recently.

Another measure of the success of the companies which have participated in the growth of the computer business is the *value* of equipment in use, and the next six figures show the worldwide installed value of both GP and mini systems for the major manufacturers. Comments:

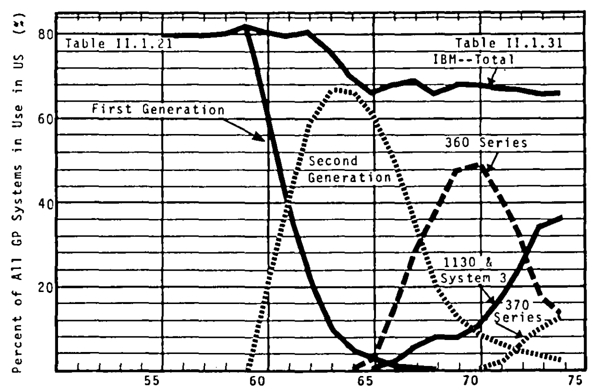



FIGURE 1.31.1 MANUFACTURERS' SHARES OF U.S. G.P. MARKET I.
PERCENT OF NUMBER OF SYSTEMS IN USE:IBM

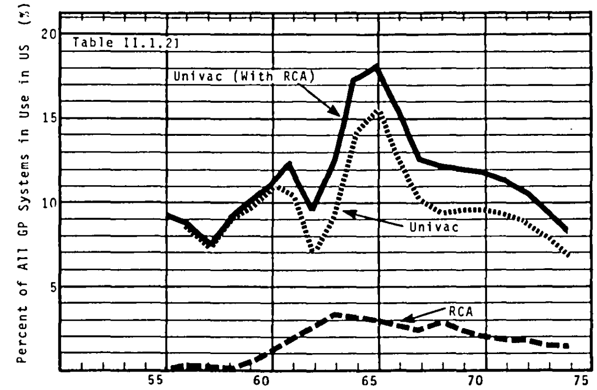



FIGURE 1.31.2 MANUFACTURERS' SHARES OF U.S. G.P. MARKET II.
PERCENT OF NUMBER OF SYSTEMS IN USE :Univac, RCA

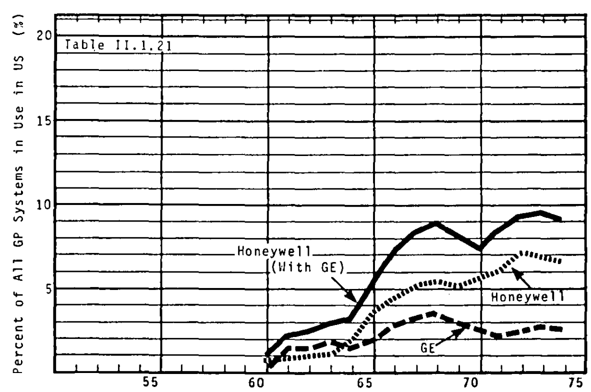



FIGURE 1.31.3 MANUFACTURERS' SHARES OF U.S. G.P. MARKET III.
PERCENT OF NUMBER OF SYSTEMS IN USE :Honeywell, GE

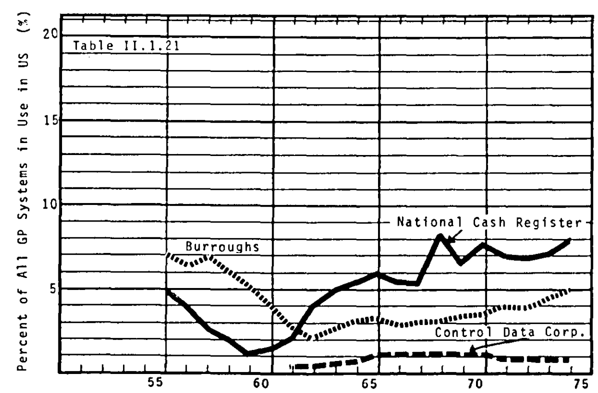



FIGURE 1.31.4 MANUFACTURERS' SHARES OF U.S. G.P. MARKET IV.
PERCENT OF NUMBER OF SYSTEMS IN USE :NCR, BGH, CDC

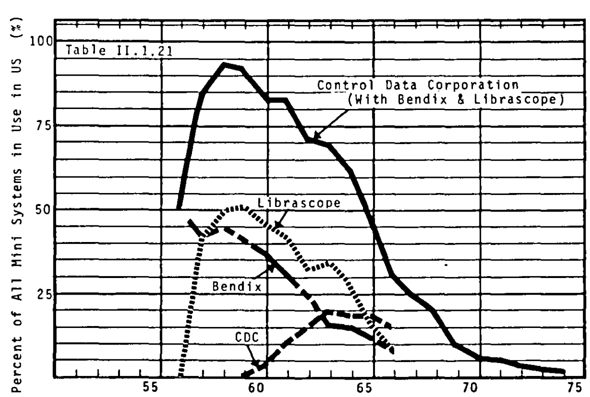



FIGURE 1.31.5 MANUFACTURERS' SHARES OF U.S. MINI MARKET I.
PERCENT OF NUMBER OF SYSTEMS IN USE

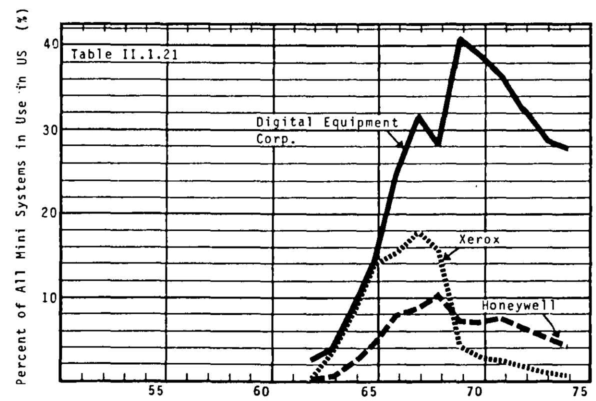



FIGURE 1.31.6 MANUFACTURERS' SHARES OF U.S. MINI MARKET II.
PERCENT OF NUMBER OF SYSTEMS IN USE

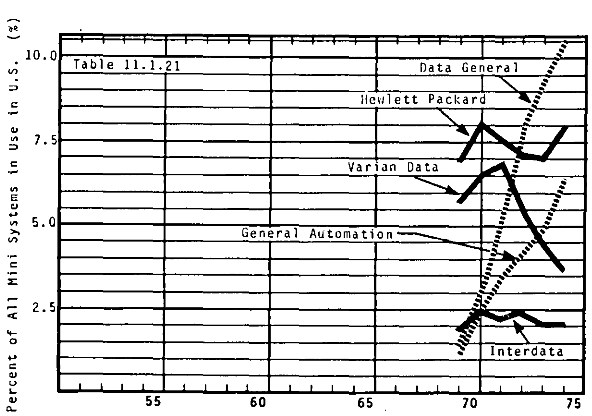



FIGURE 1.31.7 MANUFACTURERS' SHARES OF U.S. MINI MARKET III
PERCENT OF NUMBER OF SYSTEMS IN USE

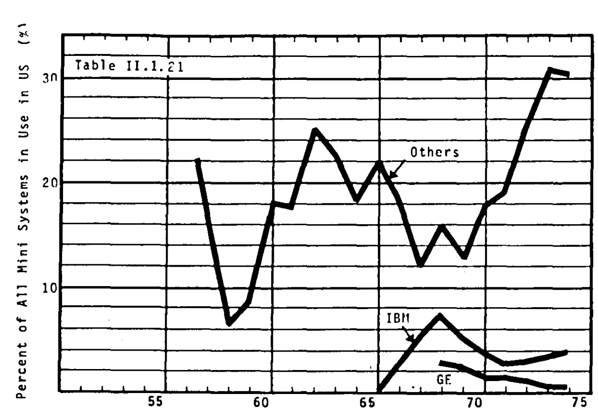



FIGURE 1.31.8 MANUFACTURERS' SHARES OF U.S. MINI MARKET IV.
PERCENT OF NUMBER OF SYSTEMS IN USE

1. By 1970, IBM had $25B in computer equipment installed, and 65% to 70% of the market, as shown in Figures 1.31.9 and 1.31.10. At that point Univac and Honeywell (including RCA and GE) each had only $3B worth installed. IBM's percent share of the market peaked in the early sixties at about 80% and then fell somewhat as other manufacturers introduced equipment competitive with its second- generation equipment. The arrival of IBM's third-generation 360 family, in the mid-sixties, stopped the slide. Meanwhile Univac's percentage of installed *value* dropped somewhat, though its percentage of *number* installed increased (Figure 1.31.2), as the average value of installed Univac systems fell off. And Honeywell's percentage increased until in 1972 it passed Univac's.

2. IBM's success, and the fact that the IBM 360 system design provided a standard electrical interface between processors and peripherals, encouraged a number of smaller peripheral manufacturers to develop equipment, mostly tape units and moving-head files, which was compatible with and cheaper than IBM's, and could be sold to customers as replacements for their rented IBM peripherals, or as increments to expand system capacity. By the end of 1974, these 'plug-compatible attachments' accounted for over 4% of total equipment installed value.

3. The growth of Univac, Honeywell, RCA, and GE, as measured by the value of GP and mini systems in use worldwide, is shown in more detail in Figures 1.31.11 and 1.31.12. Note that the two companies which sold out (GE and RCA) had market shares seemingly comparable to those of Univac and Honeywell. GE and RCA left the computer business because that business was unprofitable for them, not because it failed to grow.

4. The consolidation of two computer companies, having different computer systems with different technologies, sold by different sales forces operating under different policies, maintained by different field engineering organizations, and employing different product development plans and strategies, provides management with a very formidable set of problems. A smooth consolidation, which continues support for all customers and adopts the best from each company while eliminating redundant functions and costs, is essential both for the companies and for their customers. It seems likely that Honeywell has achieved such a consolidation, and that Univac will achieve it.

5. The growth of Burroughs, CDC, and NCR, and of the 'other' manufacturers not explicitly shown in Figures 1.31.9 through 1.31.12, is shown in Figures 1.31.13 and 1.31.14. Comparing these two figures with Figure 1.31.4, we notice particularly that CDC's and NCR's positions are reversed: NCR has much the larger share of the market in terms of number of systems installed, and CDC the larger share in terms of system value.

We can better understand the relationship between number of systems in use and value in use by examining their ratio, the average value. The average value of GP and minisystems in use worldwide, at the end of each year is shown in Figures 1.31.15 to 1.31.17 for the eight major system manufacturers, for the other manufacturers, and for all companies taken together. Comments:

1. The average value of IBM systems has remained remarkably constant and slightly higher than the average for all systems. It has fallen off since 1970 with the introduction of the small System/3.

2. The systems initially installed by Univac and RCA were very large: Univac I and Bizmac were multi-million dollar systems. Their second-generation systems included the SS80, 90, the RCA 501 and 301, and then the Univac 1004, which were lower-priced and quite successful, and brought the average installed value down remarkably. With the third generation the trend was reversed. RCA's third generation systems, which imitated IBM's 360 series, were not very successful; but the larger ones were proportionally more successful than the smaller ones, and the average value rose. Meanwhile Univac's very powerful 1108 gained wide acceptance and helped increase Univac's average, despite the concurrent shipment of many small 9200's and 9300's.

3. Honeywell's 800 system was followed by the extraordinarily successful 200, introduced in 1964, which was adopted by large numbers of IBM customers as replacements for their IBM 1401's. The result was a large drop in Honeywell's average system value, and the trend continued in the late 60's, in part as a result of the success of the even smaller Honeywell 120. GE's average value meanwhile was increasing, and as a result the effective average value for the merged combination has remained fairly constant.

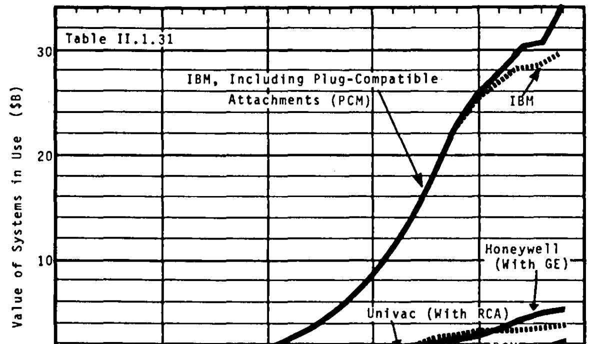



FIGURE 1.31.9 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET I. VALUE OF G.P. AND MINI SYSTEMS IN USE

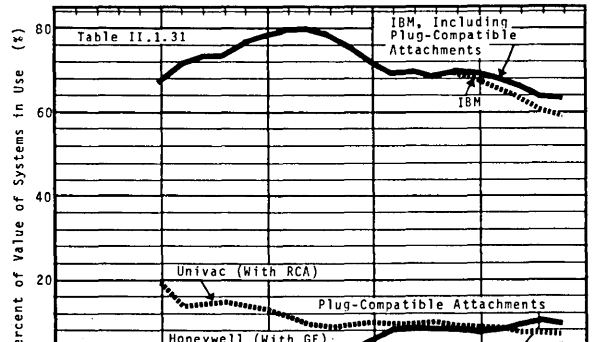



FIGURE 1.31.10 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET II. PERCENT BY VALUE OF G.P. AND MINI SYSTEMS IN USE

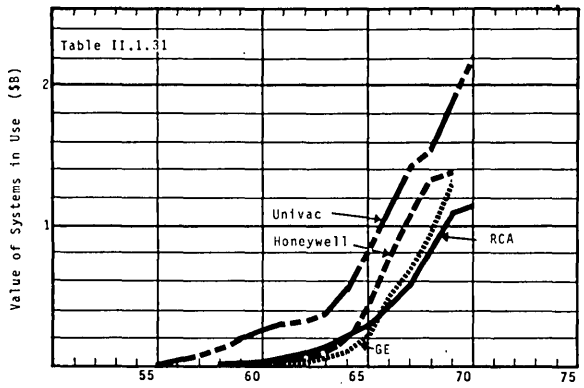



FIGURE 1.31.11 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET III. VALUE OF G.P. AND MINI SYSTEMS IN USE

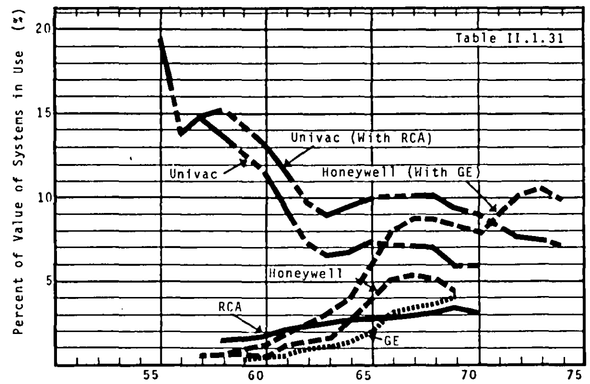



FIGURE 1.31.12 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET IV. PERCENT BY VALUE OF G.P. AND MINI SYSTEMS IN USE

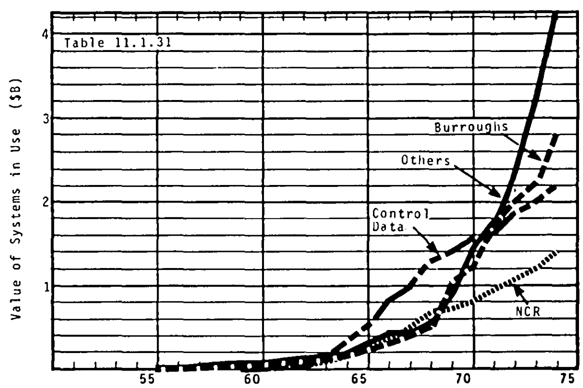



FIGURE 1.31.13 MANUFACTURERS' SHARE OF TOTAL WORLDWIDE MARKET V VALUE OF GP & MINI SYSTEMS IN USE

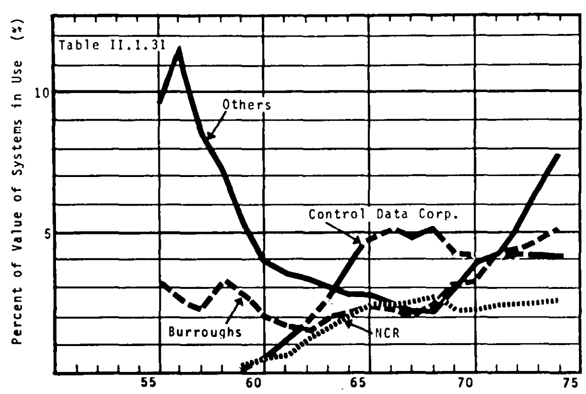



FIGURE 1.31.14 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET VI. PERCENT BY VALUE OF G.P. AND MINI SYSTEMS IN USE

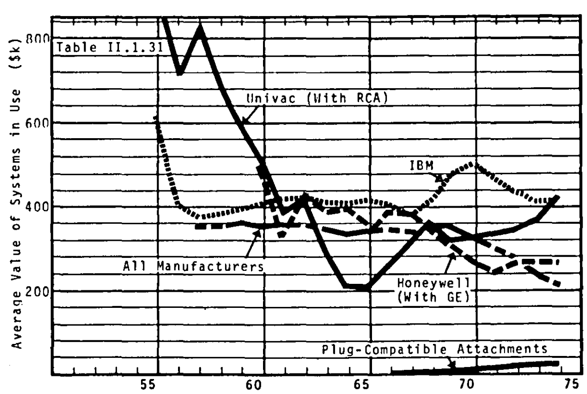



FIGURE 1.31.15 AVERAGE VALUE OF G.P. & MINI SYSTEMS IN USE. I.

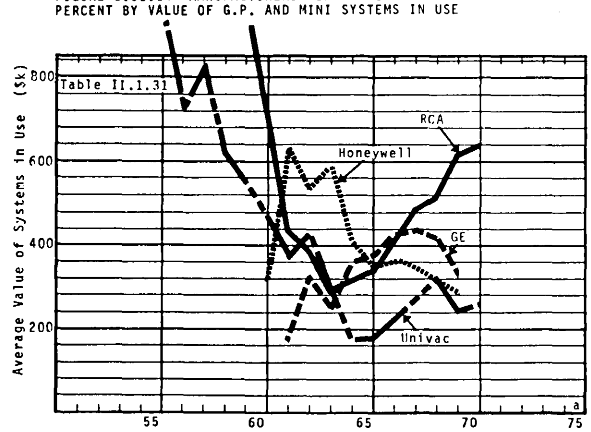



FIGURE 1.31.16 AVERAGE VALUE OF GP AND MINI SYSTEMS IN USE II

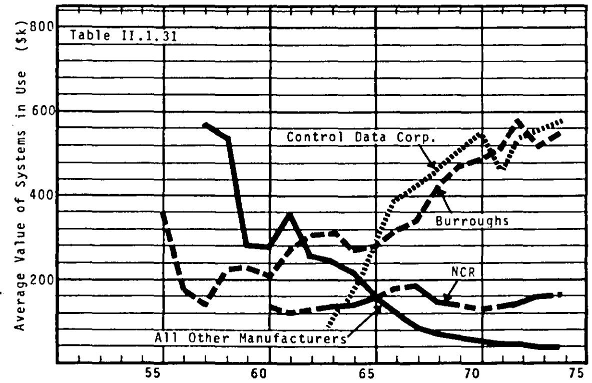



FIGURE 1.31.17 AVERAGE VALUE OF GP AND MINI SYSTEMS IN USE III

4. Some generalizations may be inferred from Figure 1.31.17. The average value of NCR systems has, like IBM's, remained fairly constant, but at a level lower than that of any other manufacturer. CDC and Burroughs have consistently been able to increase average system value as a result of the success of their larger systems. And the average value of the systems installed by manufacturers not identified in Figures 1.31.15 to 1.31.17 has consistently dropped— note that DEC and all the other minicomputer manufacturers fall in this category.

5. Average in-use value for any manufacturer is of course an extraordinarily complicated function of the company's current and past product line. Its constituent parts are however critically important to the manufacturer. His small systems, sold in large numbers, help him by introducing his name and capability to customers some of whom will later want to buy other, and bigger, systems. Small systems also help by increasing manufacturing volume, thus reducing the impact of fixed overhead costs. But small systems have the disadvantage that they must compete in an active marketplace and often do not enjoy a large profit margin. Large systems are more difficult to sell, but tend to be much more profitable. The manufacturer must develop, price, and market his products in such a way as to strike a happy balance between these various factors.

**Shipments.** Another measure of the success of a manufacturer is the value of the equipment it ships each year, and in the next six figures we examine worldwide shipments of GP and mini systems for the eight major manufacturers, showing both dollar values and percentages of the total. The data shown is for gross shipments, and does not include the effect of leased equipment which was returned to the manufacturer each year. Comments:

1. IBM's remarkable growth in shipment rate, shown in Figures 1.31.18 and 1.31.19, accelerated with the introduction of the 360 family in 1965, and was finally reversed during the 1969-1971 recession. Its percent share of all shipments has dropped since the mid-fifties, but remains between 60% and 70%, five to ten times bigger than the nearest competitor.

2. Univac's shipments peaked in the late fifties and then actually declined, at a time when IBM had introduced second-generation systems and business should have been booming. Although shipments subsequently surged again, Univac had lost her commanding second-place position in the industry and since then has struggled with Honeywell for leadership of the second echelon. As is evident from Figures 1.31.20 and 1.31.21, Univac, Honeywell, RCA, and GE all saw shipments grow rapidly in the early sixties and then level out in the late sixties, partly because of the difficulty of competing with IBM's third- generation 360 family of computers, and later because of the recession.

3. Meanwhile, as indicated in Figures 1.31.22 and 1.31.23, three other companies became formidable competitors. CDC, whose founders left Univac in the late fifties, introduced a line of increasingly powerful, cost-effective, and innovative systems in the early sixties, culminating in the 6600, first shipped in 1964. Burroughs, which in the mid fifties had acquired Electrodata and a strong position in the fledgling industry, lost its momentum by the end of that decade but since has enjoyed a period of sustained though uneven growth. NCR's even earlier acquisition of Computer Research Corporation was even less helpful in giving it a good start in the field; and NCR's sturdy growth during the 1960's is unique in that it is based largely on the shipment of small- and medium-sized systems—NCR has in no way tried to compete with the CDC 6600, the Burroughs 5500, or the IBM 360/65.

4. Shipments by "other" manufacturers represented a large share of the total in the early years, when many small independent companies were scrambling to enter the business. As time went on, the more successful companies bought out the less successful, and the 'others' share of total revenues dropped. And then, in the late sixties, the rapid growth of the minicomputer market, and of shipments by DEC, XDS, Data General Corp., and others again increased the share identified as 'others'.

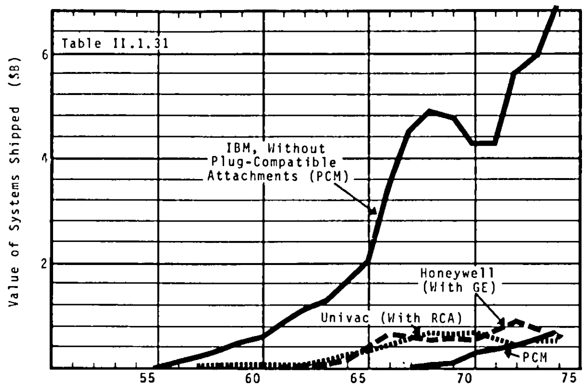



FIGURE 1.31.18 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET VII. VALUE OF G.P. AND MINI SYSTEMS SHIPPED

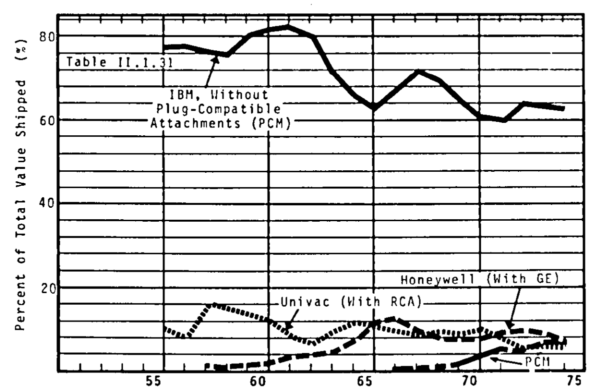



FIGURE 1.31.19 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET VIII. PERCENT OF TOTAL VALUE OF G.P. AND MINI SYSTEMS SHIPPED

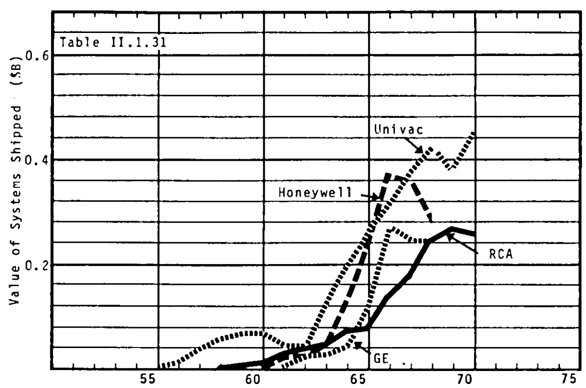



FIGURE 1.31.20 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET IX. VALUE OF G.P. AND MINI SYSTEMS SHIPPED

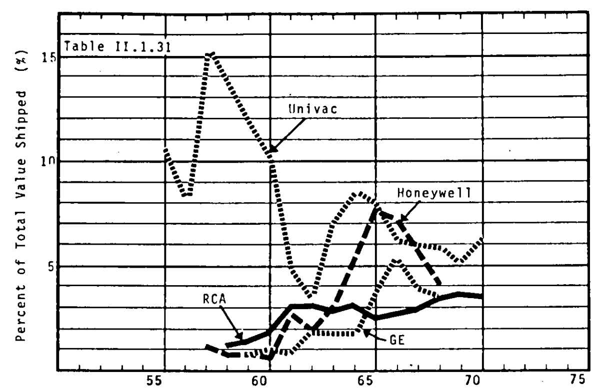



FIGURE 1.31.21 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET X. PERCENT OF TOTAL VALUE OF G.P. AND MINI SYSTEMS SHIPPED

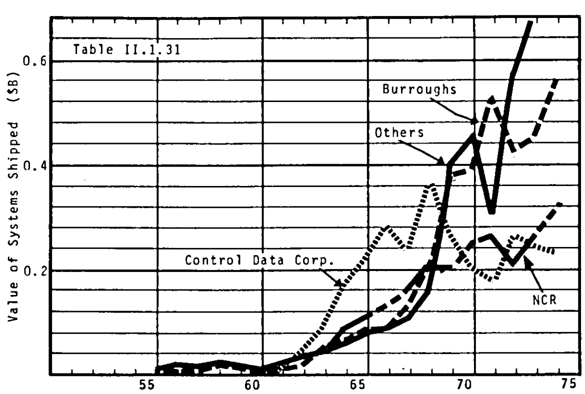



FIGURE 1.31.22 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET XI. VALUE OF G.P. AND MINI SYSTEMS SHIPPED

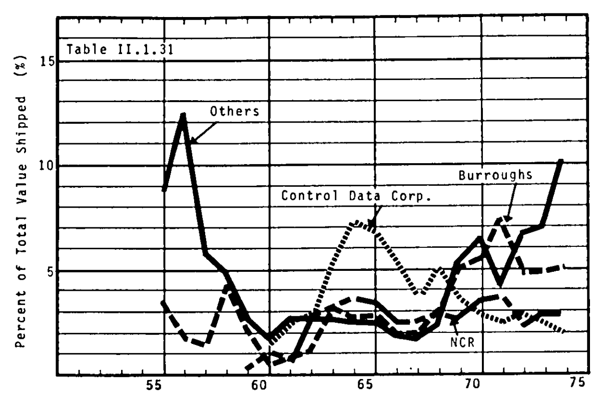



FIGURE 1.31.23 MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET XII. PERCENT OF TOTAL VALUE OF G.P. AND MINI SYSTEMS SHIPPED

**Revenues.** Two final measures of a company's success are the revenues it receives as payments from customers, and the income it derives from those revenues, after deducting the expenses made in support of the revenue. The principal components of revenue are the monies received in payment for purchased equipment, the monthly charges for leased equipment, and the monthly maintenance charges for maintaining purchased equipment (maintenance charges for leased equipment are generally included in the lease price.) However, companies may include other revenues under the general "Data Processing" category— for example, revenues from the sale of supplies (magnetic tape, punched cards, etc.), spare parts, or time-sharing services. In Figures 1.31.24 to 1.31.37 we will examine DP revenues from various points of view, and in Figures 1.31.26 and 1.31.27 will briefly look at income.

Total revenues grew from $30M in 1955 to over $5B in 1967, and reached nearly $13B by 1974. Figure 1.31.24 shows the total along with its GP and minisystem components. GP revenues are derived partly from leases and partly from sales, but minicomputers are seldom leased, so shipments and revenues are nearly the same. Minicomputer revenue has fluctuated at around five percent of the total, as shown by the dotted line in the figure. The sharp break in the total revenue curve at 1969 was caused by the recession which started in that year.

The revenue estimates plotted in Figure 1.31.24 are from one source, and are intended to include GP and minisystem revenues only. The data in the next figure is derived from what companies report as their "Data Processing System Revenue," though each company in general uses a different term. It therefore includes revenue from various accounting machines, including keypunches and verifiers, as well as that from computers. Note that IBM's share of total revenue has fluctuated between 60% and 75% of total revenues.

The net income, before taxes, derived by a manufacturer from his data processing business is of course a very important factor in a company's operations. Losses sustained over many years by GE, RCA and Xerox were the chief factor persuading those companies to sell their interests in the computer business. As might be expected, the income figures are as secret as they are important. But in late 1971 *EDP/IR* published its estimate of revenues and pre-tax income for IBM and for the other system companies, and this data is plotted as dashed lines in Figures 1.31.26 and 1.31.27. The dotted lines in these figures are the ratios of income to revenues— pre-tax income as a per cent of revenue. Note that, for the six-year period for which the data was given, IBM's income passed the billion-dollar mark, and was around 25% of revenues; but the pre-tax income of all the other manufacturers together ranged from a loss to something less than $200M, and was at best about 6% of revenues. (These figures are, of course, the algebraic sums of the losses and gains of a number of companies. However, not even the most profitable of these others could boast incomes approaching IBM's 25% of revenue).

The revenue shown as solid lines in Figures 1.31.26 and 1.31.27 were computed from industry data on GP systems shipped and in use, and are plotted there for comparative purposes. Complete descriptions of the calculations will be found in Part II, but basically they assume that 75% of GP systems are on lease and 25% are purchased, and that all the systems are maintained by the manufacturer. Note the solid lines are in fair agreement with the *EDP/IR* data (dashed lines) in these two figures, except that *EDP/IR* estimated IBM's revenue at an increasingly lower level starting in 1969. The sum of IBM and non-IBM GP revenues, computed in the same way, appears as a solid line in Figure 1.31.28 and may be compared with the total revenue data shown in Figure 1.31.24. The dotted lines in Figure 1.31.28 show the three contributors to total revenue as percentages of that total. With shipments growing at an increasing rate, lease revenue (which incidentally includes the maintenance of leased systems) became an increasing fraction of the total, reaching 80% in the early seventies. Revenue for maintenance of purchased systems has remained fairly constant at about 3% of the total and the remaining revenue was from outright sales. Because many leases are cancellable with very short notice, the large lease revenue theoretically puts the industry in a very vulnerable position: if many customers simultaneously fell upon hard times, cancelled their leases, and returned their equipment, systems manufacturers' revenues would fall sharply. But in practice the customers' abilities to cancel leases on computer equipment are limited, for they have come to depend on that equipment to execute many of their operating procedures. And consequently in practice vulnerability to lease cancellation has only been a danger when a customer can use cancellation to substitute lower-cost equipment for leased equipment— as IBM found when the Honeywell 200 replaced the IBM 1401 in the mid-sixties, and more recently when the plug-compatible peripherals replaced IBM leased peripherals.

Data in the last three figures is based on the assumption that 75% of systems are leased and 25% purchased. In fact, of course, the percentages vary from year to year, and no one knows exactly what they are. In Figure 1.31.29 we see the effect on computed revenue of five different assumptions regarding the lease-purchase ratio, ranging from the situation where all systems are sold, to that for which all are leased, and including mini as well as GP systems. In the early years, when shipments were growing rapidly, more revenue would have been produced through the sale of all systems than through their lease. But in the late sixties the growth rate fell sharply, and during the recession of 1969- 1971 the value shipped actually dropped. (See worldwide shipment data in Table II.1.21. Domestic shipments, which suffered even more, are plotted in Figure 1.21.3.) As a result, the all-systems-leased and all-systems-sold situations would have produced nearly identical revenues of about $8B in 1969, and since that year the large lease base would have produced the greater revenue. The actual proportions of systems leased and purchased of course lie between these two extremes. And probably the 75%-25% ratio used in deriving data for the earlier figures is closest to the actual average ratio.

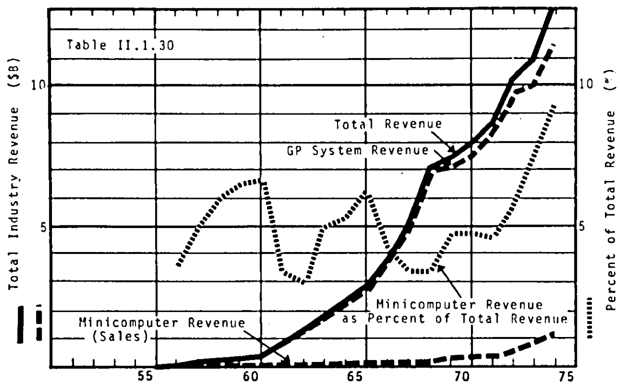



FIGURE 1.31.24 DATA PROCESSING INDUSTRY REVENUES I. GP SYSTEM REVENUE AND MINICOMPUTER SALES

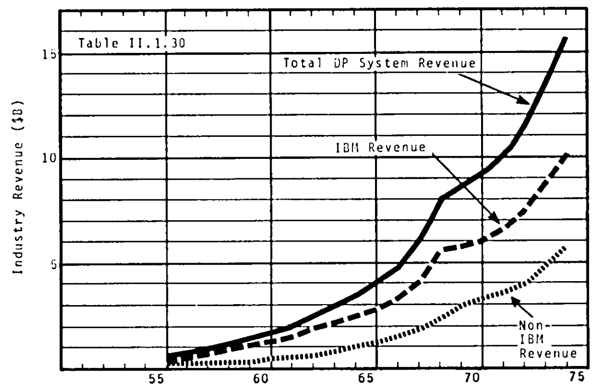



FIGURE 1.31.25 DATA PROCESSING INDUSTRY REVENUES II. IBM AND NON-IBM DP SYSTEM REVENUE, AS REPORTED

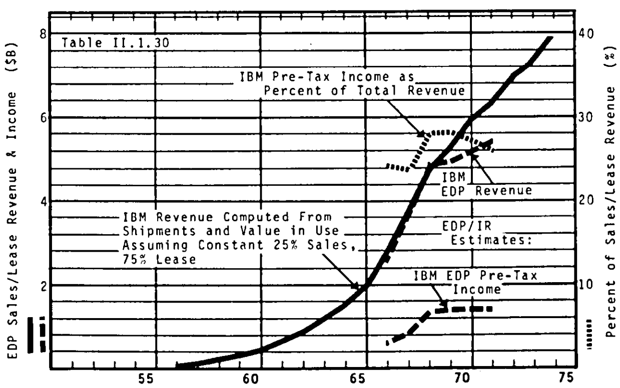



FIGURE 1.31.26 DATA PROCESSING INDUSTRY REVENUES III. IBM REVENUE AND PROFITS

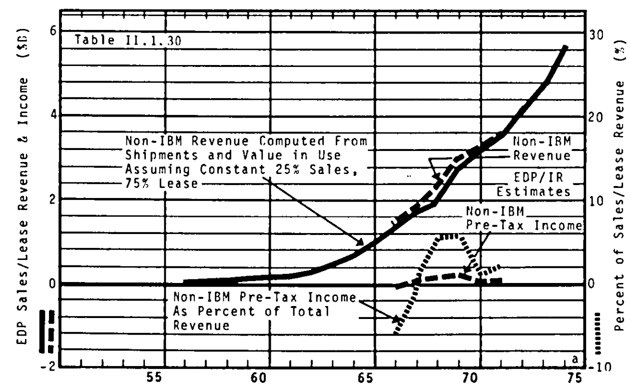



FIGURE 1.31.27 DATA PROCESSING INDUSTRY REVENUES IV. NON-IBM REVENUE AND PROFITS

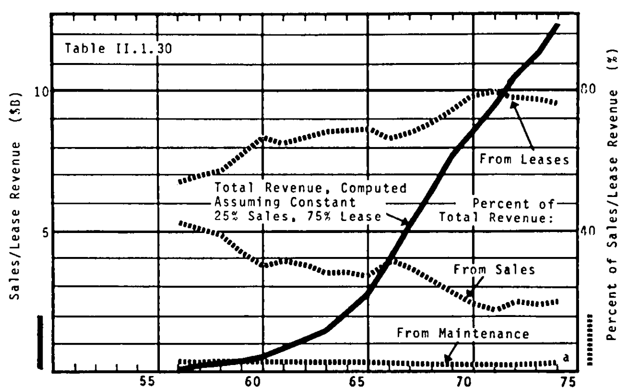



FIGURE 1.31.28 DATA PROCESSING INDUSTRY REVENUES V. ESTIMATED COMPONENTS OF INDUSTRY REVENUE

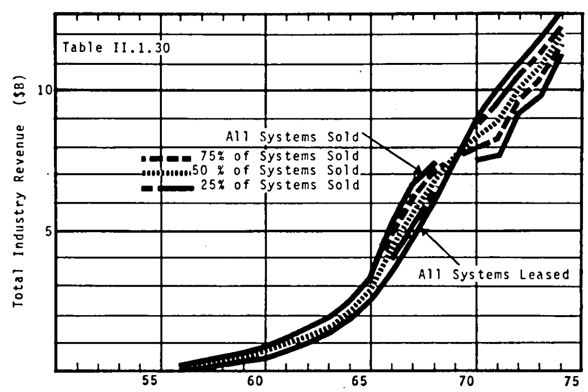



FIGURE 1.31.29 DATA PROCESSING INDUSTRY REVENUES VI. COMPUTATIONS TO SHOW THE EFFECT OF DIFFERENT LEASE/PURCHASE RATIOS

The revenue data plotted in Figure 1.31.25 is analyzed in Figures 1.31.30 to 1.31.32 to show what proportion of worldwide data processing revenues is claimed by the major manufacturers. As usual (compare IBM's number-in-use and value-in-use and value-shipped curves in Figures 1.31.1, 1.31.10, and 1.31.19) IBM dominates the field. Univac started with a strong second place in the market, but has consistently lost ground and contends with Honeywell for second at a level less than ten percent of total revenues. GE and RCA had captured some three to five percent of revenues when they gave up and sold out to Honeywell and Univac. XDS and CDC improved their relative market positions until 1970, when the recession caused unusually severe problems—both companies were committed to the sale of relatively large systems, and neither had enough equipment out on lease to be able to depend on lease revenues. Meanwhile DEC gained relatively, even during the recession, because the minicomputer market which they pioneered continued to grow even during bad years. Burroughs has had a fluctuating share of the revenue market, and NCR a smaller but more nearly constant share. Both the latter companies, with relatively *large* proportions of their systems out on lease, contrived to gain some ground during the recession. Note that, since we are in these figures dealing with percentage shares of revenue, the growth enjoyed by Honeywell, GE, RCA, XDS, DEC, and CDC during the sixties had to be at the expense of some other companies: from 1960 to 1969 Univac's share of total revenue dropped from 17% to 7%, and IBM's from 72% to 65%.

The various manufacturers which have participated in the growth of the data processing industry have derived some share of their revenues from other sources. IBM sells typewriters, NCR cash registers, Sperry-Rand (Univac) farm equipment, GE light bulbs, RCA television sets, etc. Figures 1.31.33 to 1.31.35 show data processing revenue as a percentage of total revenue for the various companies and thus provide some indication of how important the computer business is to each corporation. Generally speaking, we see that revenues from DP systems operations (which admittedly are not defined in a uniform way from company to company, or even from year to year in a given company) have represented an increasing share of the revenue of the various corporations. For IBM and CDC, three quarters of total revenues come from data process operations, while for Burroughs, Honeywell, and Sperry-Rand the figure is close to 50%. NCR is alone in the 15% range, and XDS (reported as a proportion of Xerox revenue, even for the years before Xerox purchased SDS), GE, and RCA never reached 10%. The steady increase in importance of data processing to Honeywell and Burroughs, the very slow growth in GE, RCA and NCR, and the sharp drop in XDS's fortunes soon after its purchase by Xerox—all are worth noting.

The last two figures provide another measure of the relative success of various companies in the minicomputer business. (Compare with Figures 1.31.5 to 1.31.8.) Four companies have succeeded one another as market leaders. In the early sixties, CDC was clearly in front, in part because it purchased the Bendix and Librascope minicomputer business, but mostly because of the success of its own small computers. However, during the mid- sixties, when CDC turned its attention to very large systems, XDS (then Scientific Data Systems) took over the lead with a succession of innovative and powerful small systems many of which were purchased by the government and used in the then-booming Space Program. In the late sixties, XDS began to concentrate on larger GP systems, and IBM's recently-introduced System/7 briefly gave that company the lead in minicomputer revenues. But it became evident that IBM was not going to support the System/7 with newer, better systems—that in fact IBM seemed only interested in being able to offer a minisystem to those GP customers having special requirements. And meantime, as mentioned earlier, DEC was producing and aggressively marketing a line of very-low-cost systems whose success really created the minicomputer market.

DEC's success, and the apparent size of the new market DEC had identified, led many other companies to enter the field. Two of the more successful of these, Hewlett Packard and Data General, are shown in Figure 1.31.37, along with minisystem results for Honeywell, and for Systems Engineering Laboratories (SEL), an early competitor. In the early seventies DEC seems to be firmly ensconced in the leading position; but DEC's lead is not nearly as large as that of IBM over its leading competitors in the GP market. And of course IBM, with its large inventory of systems on lease and its huge development budget, is the dominant industry force where DEC is merely the front-runner in the much smaller minisystem market.

### 1.310 THE MIDDLE FOUR ●

The system companies whose market share we reviewed in the last paragraphs were once known as "Snow White and the Seven Dwarfs." According to this conceit Snow White was IBM, and the seven dwarfs were Univac, Honeywell, RCA, GE, CDC, NCR, and Burroughs. With the departure of RCA and GE there are now only five dwarfs. One of them, CDC, is like IBM primarily a computer system company, and will be described in Section 1.312. IBM itself is the subject of Section 1.311. In this section we will briefly discuss the remaining four, which have in common the property that electronic computers represent an important and growing segment of their total business, but not the preponderant part of that business.

**Burroughs Corp.** Burroughs' business has always been data processing, but originally their equipment was electromechanical—they marketed accounting machines, principally for use in banks, and the forms and supplies which went with the machines. In 1956 they acquired Electrodata, a small California corporation which had developed and was selling an electronic computer called the Datatron, later renamed the Burroughs 205. The Electrodata Division subsequently developed the Burroughs 220, and since then has developed and manufactured other Burroughs products.

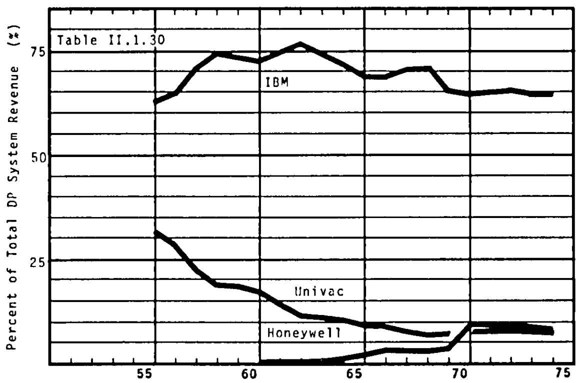



FIGURE 1.31.30 SYSTEM COMPANIES' MARKET SHARES I.
AS PERCENT OF TOTAL INDUSTRY DP SYSTEMS REVENUE

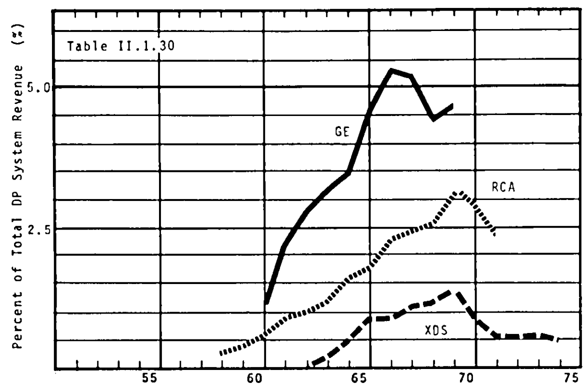



FIGURE 1.31.31 SYSTEM COMPANIES' MARKET SHARES II.
AS PERCENT OF TOTAL INDUSTRY DP SYSTEMS REVENUE

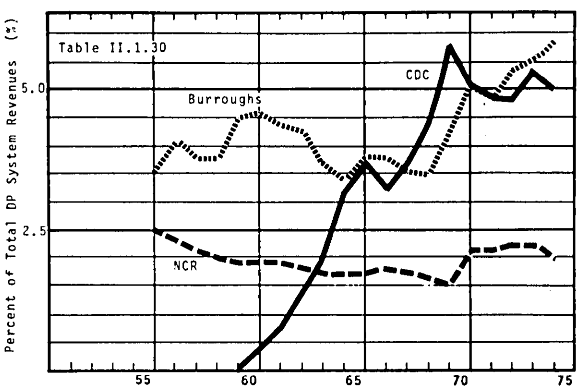



FIGURE 1.31.32 SYSTEM COMPANIES' MARKET SHARES III.
AS PERCENTAGE OF TOTAL INDUSTRY DP SYSTEMS REVENUE

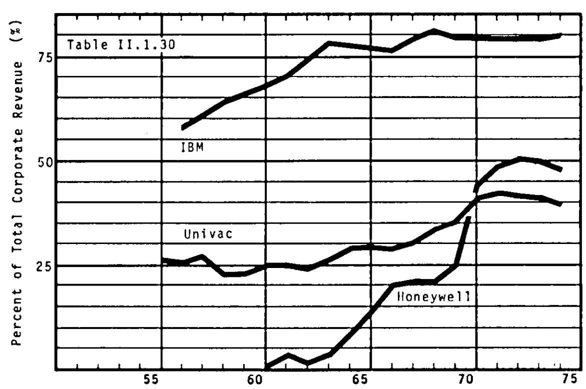



FIGURE 1.31.33 IMPORTANCE OF DP REVENUE WITHIN THE CORPORATION I.
RATIO OF DP REVENUE TO TOTAL CORPORATE REVENUE

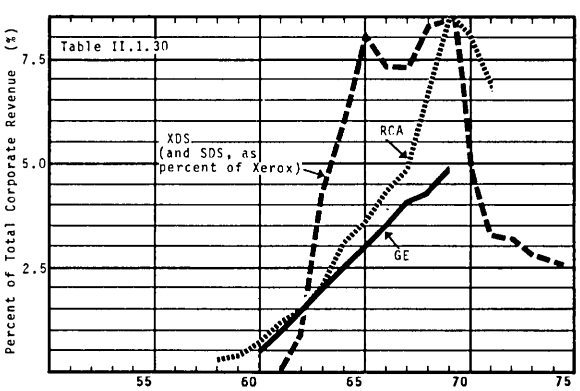



FIGURE 1.31.34 IMPORTANCE OF DP REVENUE WITHIN THE CORPORATION II.
RATIO OF DP REVENUE TO TOTAL CORPORATE REVENUE

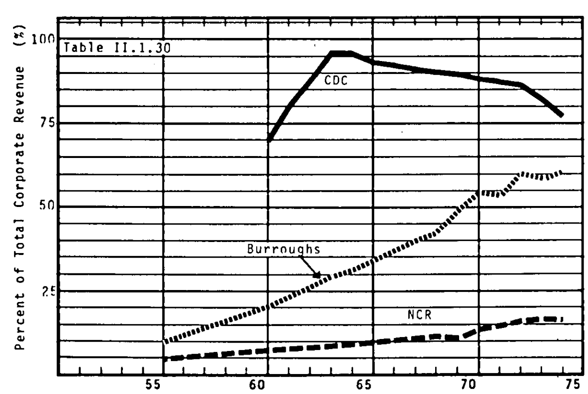



FIGURE 1.31.35 IMPORTANCE OF DP REVENUE WITHIN THE CORPORATION III.
RATIO OF DP REVENUE TO TOTAL CORPORATE REVENUE

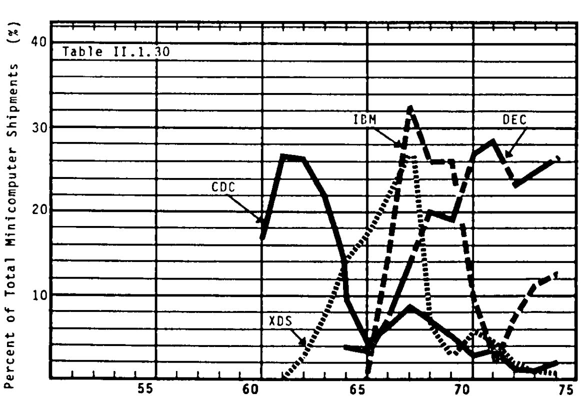



FIGURE 1.31.36 SYSTEM COMPANIES' MARKET SHARES I.
AS PERCENT OF TOTAL MINICOMPUTER REVENUES

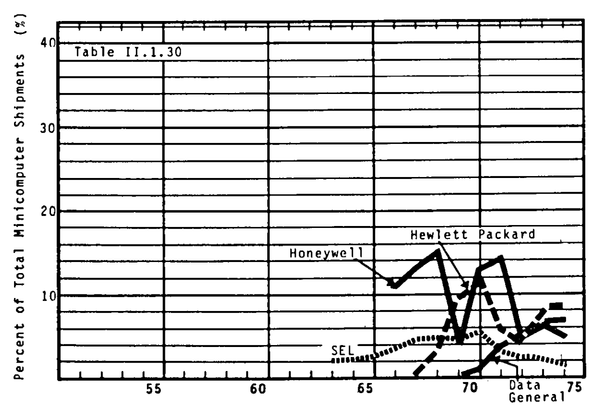



FIGURE 1.31.37 SYSTEM COMPANIES' MARKET SHARES II.
AS PERCENT OF TOTAL MINICOMPUTER REVENUE

As is indicated in Figure 1.310.1, the "computer products" share of Burroughs' revenues has increased from less than 10% to over 60% of corporate revenue, which itself has increased six-fold in the past twenty years. Field engineering services, supplies, and custom and standard products represent another breakdown of total revenue. In Figure 1.310.2 we see that Burroughs has been increasingly profitable during the past ten years when its growth has been greatest. We also note that R & D expenses have held at 4% to 6% of revenue, and that international revenues are a substantial share of the total.

**Honeywell.** Minneapolis-Honeywell was primarily a manufacturer of industrial and commercial control equipment when it joined with Raytheon to develop the Datamatic 1000, first shipped in 1957. Subsequent machines, developed by Honeywell alone, increased the computer share of total revenue to about 20% in the mid-sixties, as shown in Figure 1.310.3. The H-200, introduced in 1964, was a notable success, being an innovation which directly attacked IBM's very large installed base of 1400 systems by providing software which would convert IBM programs for those machines to H-200 programs which could run faster on cheaper equipment configurations.

The introduction of IBM's third generation slowed Honeywell's growth, and in fact hardware shipments actually fell off in the late sixties (see Figure 1.31.20). Then in 1970 General Electric decided to drop out of the computer business and Honeywell, which had in 1966 acquired the Computer Control Company, a minicomputer manufacturer, arranged to take over GE's computer operations. As a result, the computer share of Honeywell's revenues grew substantially and is now roughly half of the total. Home and Building Controls, Automation systems, and Aerospace and Defense business share about equally in most of the remaining revenue. Note that Honeywell's net income has been a shrinking percentage of total revenue, as shown in Figure 1.310.4. Note also that Honeywell has spent a higher share of revenue on R & D than was spent by Burroughs—or, in fact, than has generally been spent by most of the major system manufacturers in recent years.

**National Cash Register.** Like Burroughs and IBM, NCR started as a manufacturer of electromechanical data processing equipment, including accounting machines and cash registers. Like Burroughs and Sperry Rand (Univac), NCR entered the computer business by buying a small company: Computer Research Corp., another Southern California firm. However, whether by intent or by accident, NCR's computer business has grown slowly and, as shown in Figure 1.310.5, accounts for only about 15% of total revenues–income from accounting machines, retail systems (cash registers), and services each bring in a larger share of revenue than do computers.

Net income for NCR has held close to 4% of revenue except for the perios 1970-1972, when a combination of factors led to a drop in earnings and finally a loss in 1972. R & D expenses have also remained fairly constant at 3.5% to 4% of revenues. International revenue has always been high, and increased substantially in the 1968-1974 period. All these factors are plotted on Figure 1.310.6.

**Sperry-Rand.** J.P. Eckert and J.W. Mauchly were part of the group at the University of Pennsylvania which developed the first electronic computers for the U.S. government. In 1946 they established a partnership and soon after formed Eckert-Mauchly Computer Corp., which developed UNIVAC under contract with the National Bureau of Standards. In 1950, a year before delivery of UNIVAC, they were acquired by Remington Rand, a manufacturer of business equipment, including typewriters. In 1952 Remington-Rand acquired Engineering Research Associates (ERA) of St. Paul, Minnesota, which had developed and was marketing a line of computers. And in 1955 Remington-Rand merged with Sperry Gyroscope to form Sperry Rand.

Radio Corporations of America (RCA) had, in the meantime, decided to enter the computer field and in 1956 shipped their first machine, the Bizmac. In the early sixties they developed and shipped a moderately successful line of systems, and in the mid-sixties developed another family, program— compatible with IBM's System 360. In 1971 RCA management decided that it would take too many unprofitable years and too much additional capital to stay in the business. And Sperry-Rand took over the RCA product line.

Figure 1.310.7 displays the net results. Note that in total dollar revenue, Sperry-Rand is the biggest of the four companies discussed here. But despite all the acquisitions, despite the fact that it was marketing UNIVAC well before the first IBM GP computer was available, Sperry-Rand has been unsuccessful in achieving a really strong position in the industry, and has in fact fallen behind Honeywell in revenues, shipments, and value of equipment in use.

Sperry-Rand's revenue comes not only from information-handling equipment but also from instruments and controls, from business machines other than computers, and from other products and services, including in large part hydraulic and farm equipment. All these component parts are shown in Figure 1.310.7. Finally in the last figure we see that Sperry-Rand's profitability has risen comfortably since the early sixties, that R & D expenses have likewise risen as a percentage of revenues, and that Sperry-Rand, like the other manufacturers, has actively pursued international business.

**Summary.** Examining the four firms all together, we see many similarities: Mid-seventies revenues in the range of \$1.5B to \$3.0B; net income in the range 3% to 9% of revenues; R & D expenses 3% to 8% of revenues; international business growing during the past ten years to roughly 40% of total revenues; and mergers with or purchases of other firms an important element in entering the business or in expanding. We also see differences: Burroughs and NCR are primarily in the data processing business while Honeywell and Sperry-Rand derive substantial revenue from control systems or machinery entirely unrelated to computers; and the revenue derived from computers ranged from 15% to 60% of total revenue in the mid-seventies.

These characteristics can be compared to those of IBM, treated in the next section: Over \$12B in revenue in 1974; net income 12% to 14% of revenues; data processing revenue 80% of the total; R & D expenses 5% to 7% of revenues; and international revenues 45% of the total.

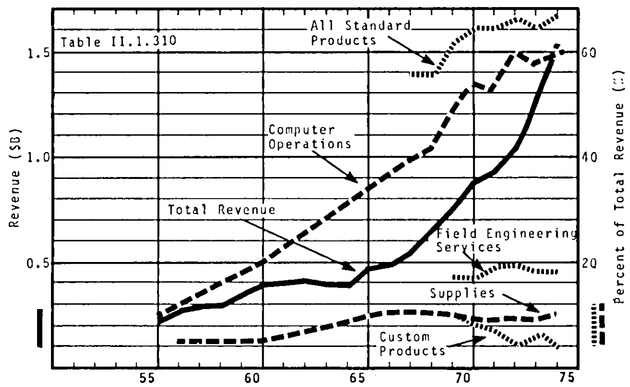



FIGURE 1.310.1 BURROUGHS CORPORATION I
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

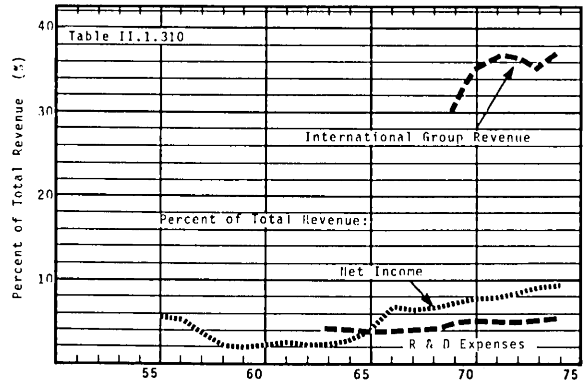



FIGURE 1.310.2 BURROUGHS CORPORATION II.
NET INCOME, R&D EXPENSES, AND INTERNATIONAL REVENUE

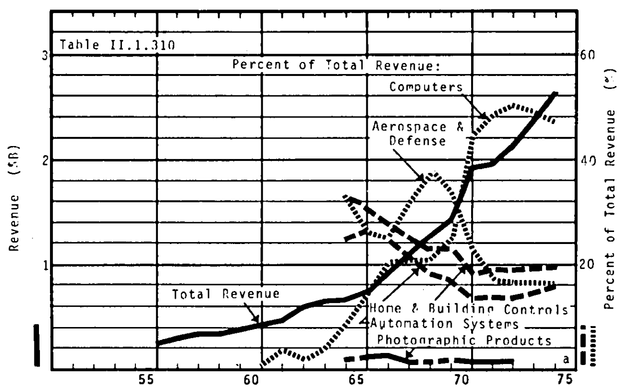



FIGURE 1.310.3 HONEYWELL, INC. I.
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

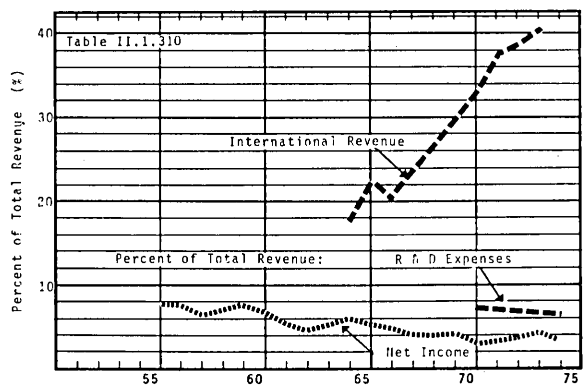



FIGURE 1.310.4 HONEYWELL, INC. II.
NET INCOME, R&D EXPENSES, AND INTERNATIONAL REVENUE

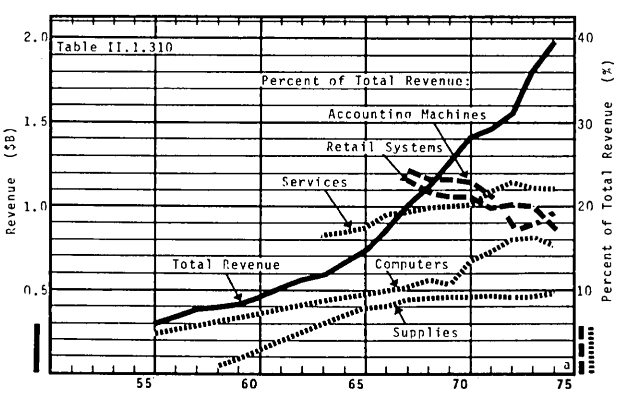



FIGURE 1.310.5 NATIONAL CASH REGISTER I.
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

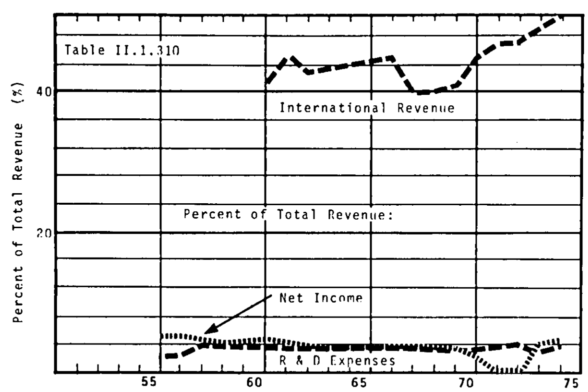



FIGURE 1.310.6 NATIONAL CASH REGISTER II.
NET INCOME, R&D EXPENSES, AND INTERNATIONAL REVENUE

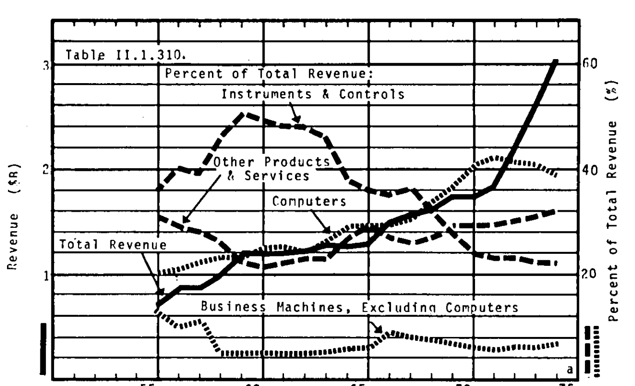



FIGURE 1.310.7 SPERRY-RAND (UNIVAC) I.
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

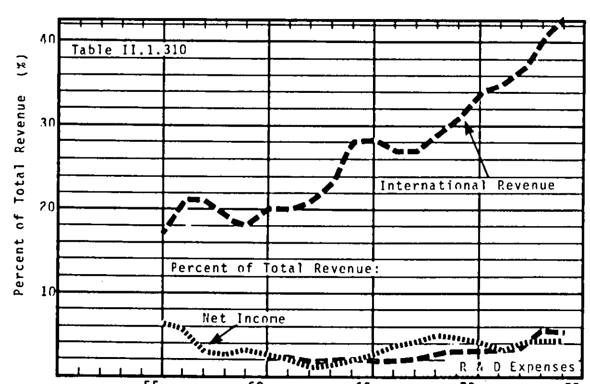



FIGURE 1.310.8 SPERRY-RAND (UNIVAC) II.
NET INCOME, R&D EXPENSES, AND INTERNATIONAL REVENUE

## 1.311 INTERNATIONAL BUSINESS MACHINES, INC. ●

**History.** IBM, originally called the Computing-Tabulating-Recording Company, was formed in 1911, a combination of the Tabulating Company (founded by Dr. Herman Hollerith), the Computing Scale Company, and the International Time Recording Company. In 1914 Thomas J. Watson, 40, became president and the company closed the year with 1346 employees and a gross income of $4M. In 1924 C-T-R adopted its present name, International Business Machines. IBM's first big computer was developed during World War II, but its first stored-program computer product, the 701, was announced in 1952 and first delivered in 1953.

Figure 1.311.1 shows key events in IBM history since 1952, to help us understand and interpret what follows. T.J. Watson, Jr.'s assumption of the presidency in 1956, and his settlement of the U. S. Government's anti-trust suit with the Consent Decree, set the stage for a period of unprecedented growth. In the late 1960's, IBM's continuing success attracted the attention of leasing companies, which purchased computers from IBM and leased them to users; and of peripheral equipment companies, which began to sell their own products as lower-cost replacements for IBM equipment. The changes in manufacturing operations implied in switchovers from one "generation" of machines to another gave rise to a multitude of problems and opportunities. The dates of introduction of the systems which comprise a "generation" are shown in Figure 1.311.1, and the total IBM populations of systems in use at the end of each year appear in Figure 1.311.2.

**Product Categories** IBM's total revenue can be analyzed in a variety of ways , and in Figures 1.311.3 and 1.311.4 we look at the major product constituents . The largest, of course, is revenue from the sales, service, and rental of DP machines and systems. Next is income from other regular products and services, including: information records (DP cards, magnetic tape and cards, business forms, and other media used in information-handling systems); office products (typewriters, dictation equipment, copying equipment, and direct-impression composing products); education products (from subsidiary Science Research Associates, which sells textbooks, educational kits, learning systems, testing materials and services); computing services (from subsidiary The Service Bureau Corp., which offered time-sharing and other data processing services until its sale to Control Data Corp. in 1973 as a part of a settlement of a lawsuit with CDC); and system analyst and programming services (until 1969 included free with equipment). Finally, there is revenue from special products and services provided for U.S. Government agencies. Comments;

1. Total revenue has grown at an astonishing average rate of $.63B per year for the period 1955-1974—a compounded growth rate of 16.5% per year. For the first ten years of that time, the rate was a fairly uniform $.29B or 17.7% per year. But between 1965 and 1968, System 360 shipments were high, and in addition IBM *sold* an unusually high proportion of its shipments to leasing companies, with the result that revenues increased an average of $1.11B (24.4%) per year. Between 1968 and 1971, which included a serious recession in the U.S., the rate slipped back to $.46B or 6.2% per year, but the growth resumed in 1972.

2. Data processing has, since 1963, accounted for about 80% of IBM's revenue, making it by far the most important factor in IBM's business decions. Note that DP revenues in 1967 and 1968 were as great as IBM *total* revenues in the 1966 and 1967 period.

3. Special Products sold to the U.S. Government have remained a relatively constant around $200M per year, but have dropped drastically in importance—from 17% to 3% of gross revenue.

4. During the past ten years, IBM's "miscellaneous" products and services have grown as fast, proportionally, as its DP products and services.

**Sales and Service Revenue.** Figure 1.311.5 shows total revenue ,broken down into revenue from rentals and services, and revenue from product sales. The former has tended to increase somewhat smoothly and predictably, at an increasing rate, while the latter has often fluctuated markedly from year to year. Note that even though total sales (and shipments—see Figure 1.31.18) actually decreased in 1969 and 1970 from their 1968 leasing-company sales peak, IBM was able to maintain a growth in total revenue.

**Cost of Sales.** The enormous technical strength of IBM is illustrated in Fig. 1.311.6, which plots cost of sales and services. Cost of sales is the key figure, for cost of services and rentals is determined by financial policy as much as by product costs. Costs of products sold started at 70% of sales price in the mid-fifties, leaving only 30% of revenues to cover all marketing, management, and development costs. Costs declined steadily and the cost of sales percentage was actually halved by 1968, when the DP sales bulge occured. There are a great many factors involved in the changes in cost of sales, of course. The reduced proportion of special products for the U.S. Government (a typically low-profit business) has reduced cost of sales. New product introductions tended to lead to *increased* costs of sales while manufacturing start-up problems are being solved (the "flat" cost of sales in 1958-1959 was probably caused by production start-up of the seven thousand series machines, the small change in 1960-1961 by the 1400 start-up, and the cost of sales *increases* in 1964-1966 and in 1969-1971 by Series 360 and 370 start-up). And of course it is the growth in shipments that has made it economic for IBM to invest in the tooling which helps make low-cost manufacturing possible. But without question, the strikingly low value of cost of sales is a reflection of engineering and manufacturing determination and excellence, and makes it clear that the enormous sums invested by IBM in R & D have paid off. And the real signifigance of the low cost is the freedom it gives IBM to maintain profitability while reducing prices to meet competition, and to spend money lavishly for marketing and sales support.

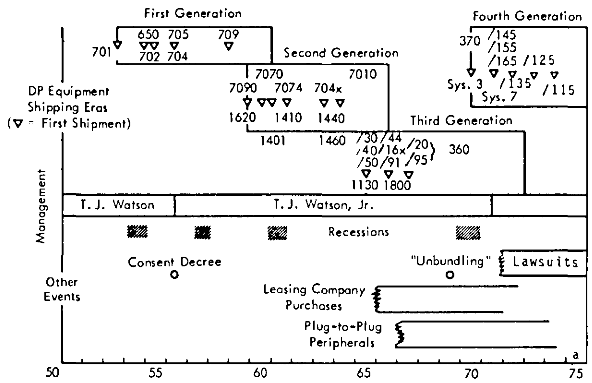



FIGURE 1.311.1 RECENT IBM HISTORY

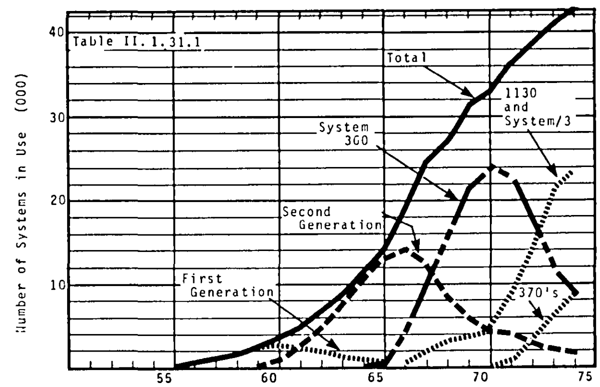



FIGURE 1.311.2 IBM COMPUTER SYSTEMS IN USE
GP SYSTEMS IN USE IN THE U.S.

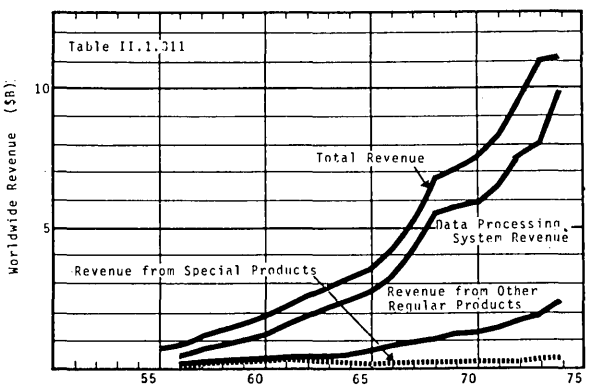



FIGURE 1.311.3 I.B.M. WORLDWIDE REVENUES I.
WORLDWIDE REVENUE AND DISTRIBUTION TO MAJOR CATEGORIES

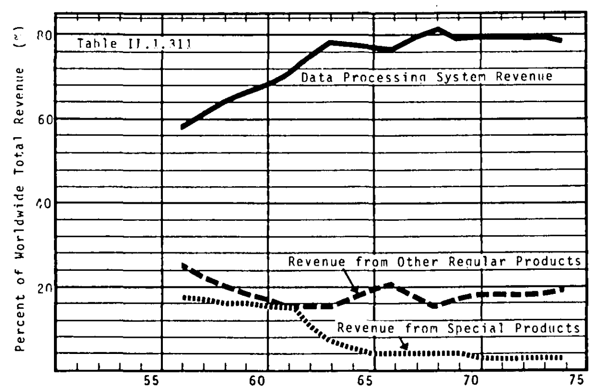



FIGURE 1.311.4 I.B.M. WORLDWIDE REVENUES II.
PERCENTAGE DISTRIBUTION TO MAJOR CATEGORIES

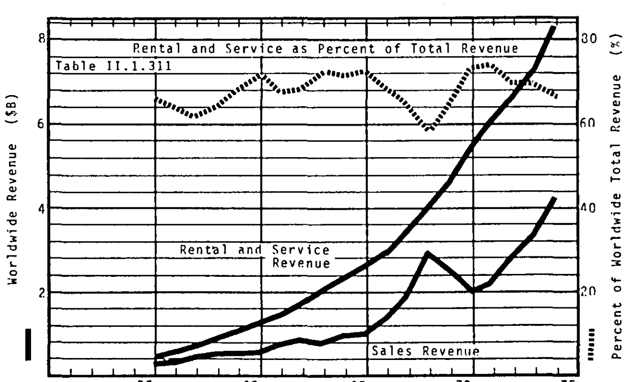



FIGURE 1.311.5 I.B.M. WORLDWIDE SALES AND SERVICE REVENUE

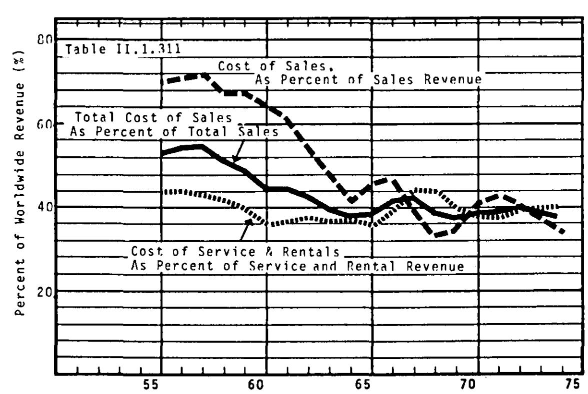



FIGURE 1.311.6 I.B.M. WORLDWIDE COST OF SALES AND SERVICE
PERCENTAGES OF SALES AND SERVICE REVENUES

**Costs and Earnings.** Figure 1.311.7 shows how various categories of identifiable costs have fluctuated since 1955; and Figure 1.311.8 displays the same data as a percentage of gross revenue. Comments:

1. Three cost categories are distinguished: cost of sales and service, repeated from Figure 1.311.6; administrative and selling costs, which include direct selling, marketing, and general management costs; and R & D costs. "Other" costs not shown include taxes, royalties, interest costs, patent and good will amortization, and maintenance and depreciation (but *not* maintenance or depreciation of rental equipment or other capital equipment directly associated with cost of sales).

2. Total indirect costs (the selling, administrative, warranty, and "other" costs) have increased their proportion of IBM's revenue by over 51% in the period 1955-1974—from 24.7% to 37.5%.

3. Selling and administrative expenses cannot be distinguished from one another by reference to publicly available data. As a percentage of revenues, their proportionate increase has been less than the increase in R & D costs, but their dollar value is enormous, surpassing $1B per year since 1967. It is the marketing and selling portion of this large expenditure, consistently applied with vigor and imagination, which got for IBM the reputation of a Marketing Company. Note the bulge in selling cost percentage in 1960 and 1965, when the 1400/1700 and 360 systems were first being shipped; the fall-off in percentages immediately following those years, as shipments really started; and the fall in percentage in the recession of 1970—that was the first year since 1964 when selling and administrative costs increased by less than $100M over the previous year.

4. R & D costs have increased greatly both as a percentage of gross revenue and in absolute value. The $500M spent in 1970 on R & D by IBM is, of course, more than the total annual revenue of many of its competitors, and is a key factor in IBM's success in bringing to market new products which meet market requirements, are reliable, and are cheap to manufacture. In 1947 IBM spent only 2.1% of its domestic revenue on R & D in the U.S. The growth to 7.0% of worldwide revenue by 1974 is, of course, striking, and probably reflects a higher-than-proportional overseas expenditure on R & D.

5. Between 1957 and 1965, IBM reduced product costs, and balanced that reduction with increases in selling, adminstrative, and R & D costs in such a fashion that the after-tax earnings percentage increased each year—from 9.2% to 13.4% of revenue. In 1966 the System 360 manufacturing start-up problems made another increase impossible and the "string" was broken. A new series of increases began in 1967, but the recession of 1969-1971 and the introduction of the Series 370 product line in 1971 (with a presumed new set of extra manufacturing start-up costs) again led to a reduction in percentage profit.

6. In 1970 IBM's before-tax earnings (not shown in the figures) actually were less than the previous year in the first time in decades. An 80% increase in "other income mostly interest" made possible an increase in after-tax earnings, however.

**The World Trade Corporation (WTC).** Figures 1.311.9 through 1.311.14 supply what data is available on the relative domestic and international operations of IBM. Domestic and WTC total revenues are shown as solid lines in the first of these figures, and WTC revenue as a percentage of total appears as a dotted line. Note that WTC revenues grew as a percentage of the total until 1966, that the phenomenal success of the 360 family in the U.S. caused a slight reduction in that percentage during 1967 and 1968, and that the 1969-1971 recession, which caused IBM's domestic revenues to fall for the first time in over 20 years, did not affect WTC sales at all. The striking importance of IBM's overseas operation is really apparent when we look at after-tax earnings, in Figure 1.311.10. Note that, since 1970, the World Trade Corporation has actually contributed more than half of IBM's total earnings.

The last four figures in this series compare IBM's domestic and WTC sales and service revenues, and costs. From Figures 1.311.11 and 1.311.12 we see that rental and service revenue consistently represented a higher proportion of revenues overseas than they did in the United States; and from Figures 1.311.13 and 1.311.14 we correspondingly see that WTC costs of both sales and service have been a lower percentage of revenues than domestic costs have been of domestic revenues. Unfortunately, comparable data for the years since 1963 is not available. However, the earnings figures shown in Figure 1.311.10 seem to indicate that WTC operations have continued to be more profitable than domestic ones.

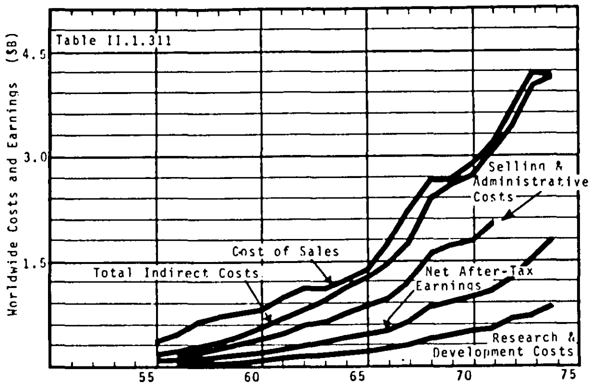



FIGURE 1.311.7 I.B.M. WORLDWIDE COSTS AND EARNINGS I.

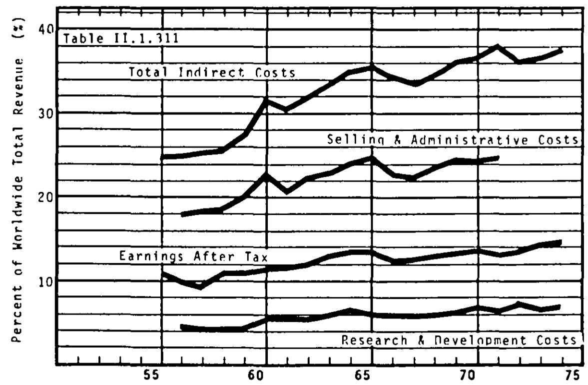



FIGURE 1.311.8 I.B.M. WORLDWIDE COSTS AND EARNINGS II. AS PERCENT OF TOTAL WORLDWIDE REVENUE

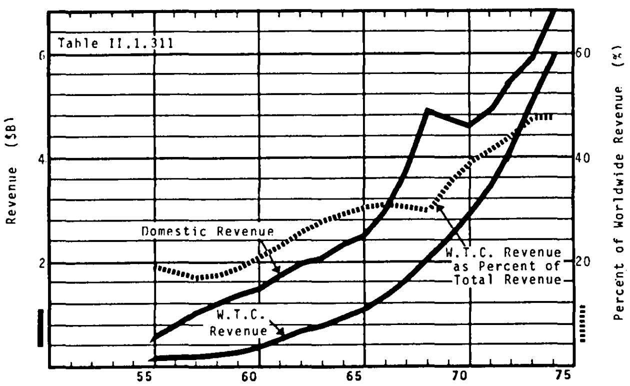



FIGURE 1.311.9 I.B.M. DOMESTIC AND W.T.C. REVENUE

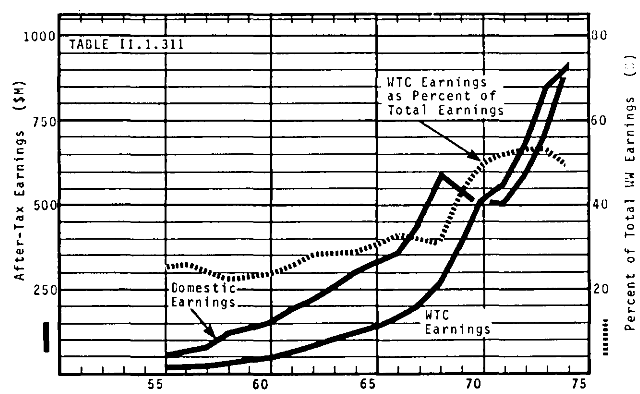



FIGURE 1.311.10 IBM DOMESTIC AND WTC AFTER-TAX EARNINGS

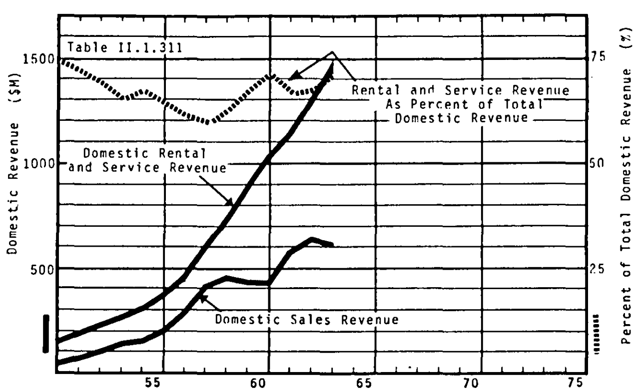



FIGURE 1.311.11 I.B.M. DOMESTIC SALES & SERVICE REVENUE

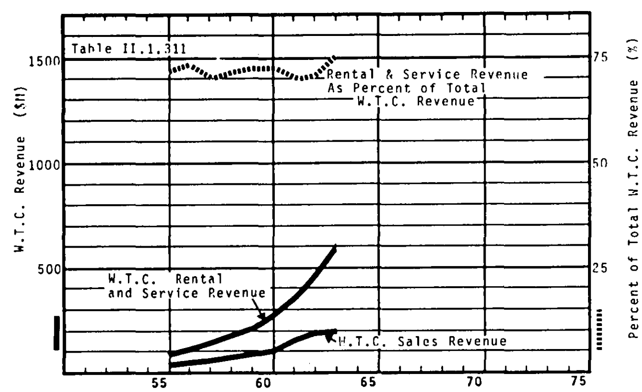



FIGURE 1.311.12 I.B.M. W.T.C. SALES AND SERVICE REVENUE

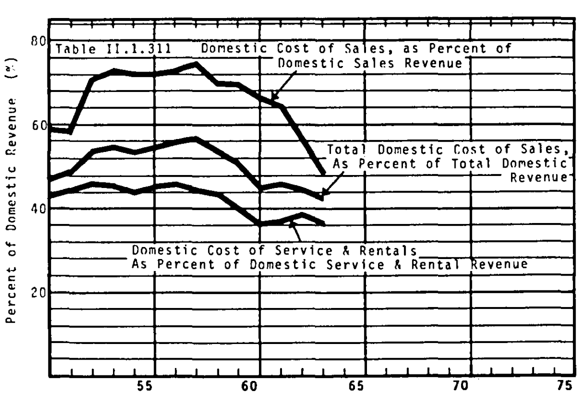



FIGURE 1.311.13 I.B.M. DOMESTIC COST OF SALES AND SERVICE

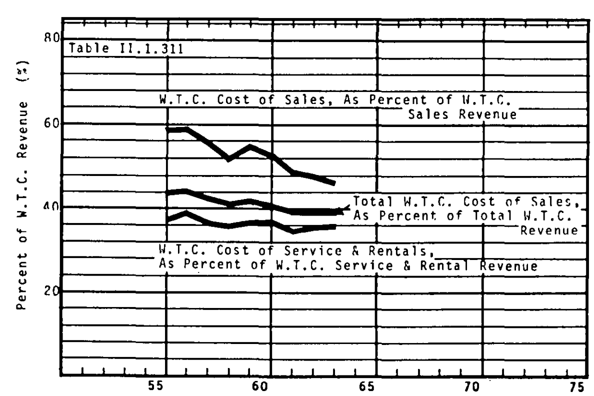



FIGURE 1.311.14 I.B.M. W.T.C. COST OF SALES AND SERVICE

**Employees.** As IBM has grown, so has its employee population. As shown in Figure 1.311.15, the number of employees increased almost five-fold between 1955 and 1970. The recession of 1969-1971, with its traumatic impact on revenues, caused IBM actually to reduce its employee population in 1971 and 1972. Note that WTC employment had increased from about 30 to about 35% of total employment between 1955 and 1965, the last year when employment data was provided for the two entities.

IBM revenue per employee is shown in Figure 1.311.16. Comments:

1. In anticipation of the advent of the 360 series, IBM hired heavily in 1965. Revenue per employee fell as a result, but then accelerated as the 360 family became a success.

2. The drop in domestic sales during the 1969-1971 recession resulted in a corresponding drop in revenue per employee, despite the fact that total revenues continued to increase.

3. Part of the revenue increase, of course, is due to a general increase in prices everywhere. The dotted line shows the growth in revenue per employee with the effects of inflation removed. The improvement in real productivity is still, of course, very impressive.

4. According to IBM Prospectuses and 10k reports, about 30% of all employees are salesmen, customer engineers, and systems engineers (15,800 domestic in 1957; 32,000 domestic and 55,000 worldwide in 1966). A little less than 4% (10,500) were employed in R & D in 1970.

**Assets.** The next four figures provide a look at IBM's total assets, and give some detail on inventories and on property, including rental equipment. Total assets are shown in Figure 1.311.17 (which also portrays domestic assets for the years when they were separately broken out). Total inventories, and the net value (after depreciation) of rental machines and parts are also shown.

The inventory figures are shown in detail in Figure 1.311.18, and present a very interesting picture. To begin with, note that the data appears in two not-quite comparable parts—the years 1963 and earlier representing domestic inventories, and those 1964 and later, worldwide. Comments:

1. After remaining more or less fixed (and low) during the late fifties and early sixties, total inventories grew remarkably. Between 1964 and 1970, worldwide inventories actually tripled in value. They thus grew *much* faster than revenue or shipments grew during that same period.

2. Raw materials and supplies shrank as a proportion of total inventories during the period shown. The increases have thus come about primarily as a result of very substantial increases in the value of work in process and of finished goods.

3. Note the relationship between work in process and and finished goods: generally speaking, yesterday's work in process is tomorrow's finished goods. Therefore peaks and valleys in the latter tended to lag peaks and valleys in the former.

4. The cyclical nature of both work in process and finished goods is also clear from the graph. The peaks in finished goods inventories in 1964 and 1969 represented years just before first shipments of the 360 and 370 computer families, respectively. And the troughs of 1966-67 and 1970-72 correspondingly represent periods when shipments were heavy.

The gross value of IBM property is shown in Figure 1.311.19, with a percentage breakdown into its three component parts. Note that rental machines and parts have continually represented a fairly stable 75% of the total gross value of IBM property. IBM's ability to finance this enormous inventory of equipment from its own operations is a striking tribute to its success and wealth. The total dollar value is shown in Figure 1.311.20, along with the value of additons and retirements, for the years for which that data was available. (Note that retirements include both equipment on lease which is returned by the customer and cannot be re-leased by IBM, and equipment which has been on lease but which was subsequently purchased by the user.)

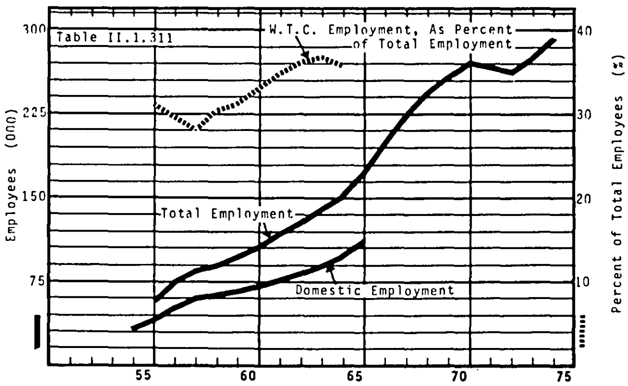



FIGURE 1.311.15 I.B.M. EMPLOYMENT

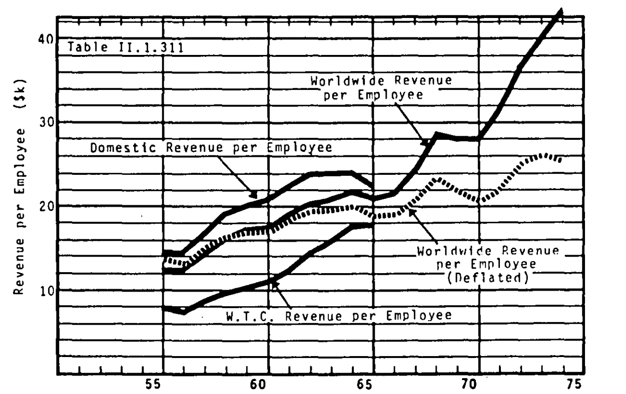



FIGURE 1.311.16 I.B.M. REVENUE PER EMPLOYEE

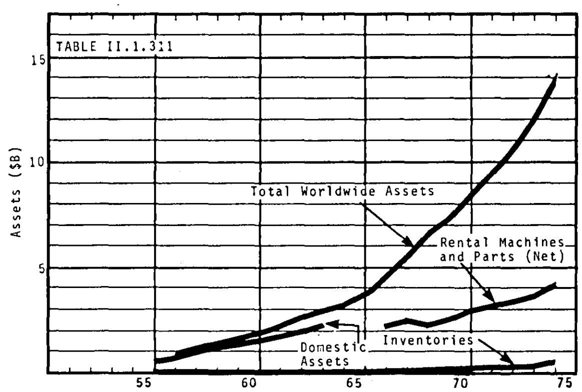



FIGURE 1.311.17 IBM ASSETS I
TOTALS, AND SELECTED ASSETS

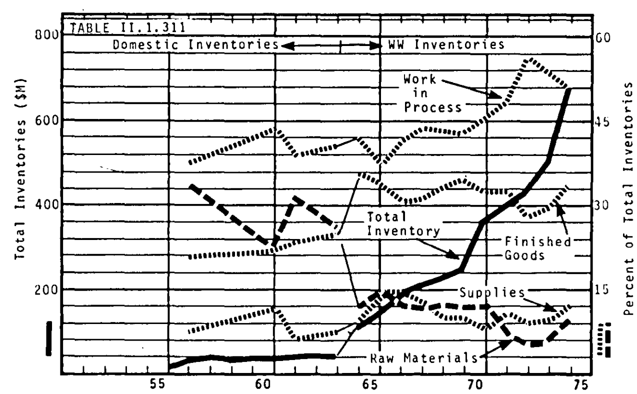



FIGURE 1.311.18 IBM ASSETS II
TOTAL INVENTORIES AND DISTRIBUTION

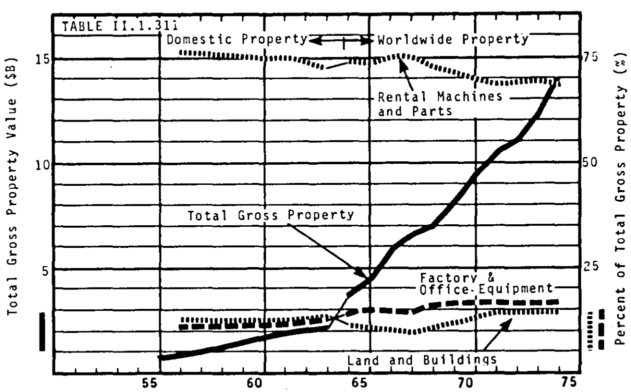



FIGURE 1.311.19 IBM ASSETS III
TOTAL GROSS PROPERTY AND ITS DISTRIBUTION

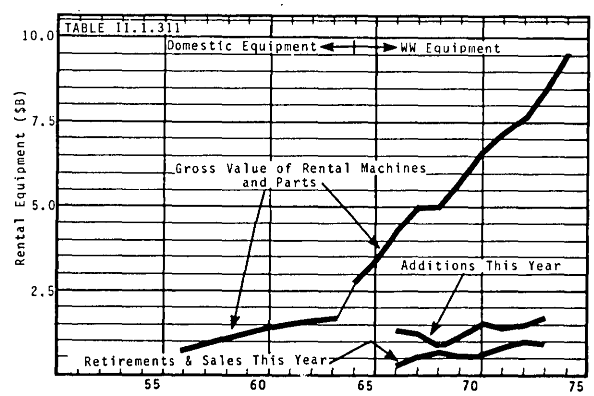



FIGURE 1.311.20 IBM ASSETS IV
GROSS RENTAL EQUIPMENT

## 1.312 CONTROL DATA CORPORATION

In 1957 William C. Norris and a small group of engineers left Sperry Rand in St. Paul and formed the Control Data Corporation in nearby Minneapolis. It was their intent to "design, develop, manufacture, and sell systems, equipment, and components used in electronic data processing and automatic control". (ARCDC58) The company's initial business consisted primarily of engineering services performed under U.S. government contracts. Their first product, delivered in 1960, was a large scientific computer named the CDC 1604. (It is rumored that the 1604 was named by adding CDC's address, 501 Park Avenue, to 1103, the model number of the computer system which had previously been developed in St. Paul by Sperry Rand.) However, in the same year CDC delivered the first of its very powerful and advanced minicomputers, the 160, followed by the still more powerful 160A in 1961.

Figures 1.312.1 and 1.312.2 display CDC's history as measured by events and systems installations. The 1604 was a successful machine, sold in the GP market. But the 160 family was very widely used for dedicated applications, and the purchase by CDC of the Bendix and General Precision (Librascope) computer businesses made CDC the leading force, early in the sixties, in what would soon be the booming minicomputer market (see Figures 1.31.5, 2.10.3). The company was unable, or perhaps unwilling, to anticipate or cash in on the minisystem business, and as a result its growth rate in that field slowed or stopped in the sixties. (The 1968 peak of over 1900 minisystems in use, shown in Figure 1.312.2, is almost certainly an anomaly in the data base and overstates CDC's installations by some 400 systems). Meanwhile, in 1964, CDC shipped the first 6600, an extraordinarily advanced and powerful system, the most powerful available at that time and for several years thereafter. The success of that system and its successors made CDC clearly the leading supplier of high-performance systems, and it was these systems and that success which fueled the late-sixties growth shown in Figure 1.312.3. More recently, CDC's system business has fallen off as recessions and economic uncertainty reduced government and corporate spending on very large systems. CDC's revenues have, however, continued to rise, partly because of its growing service business, and partly because of the growth in sales of peripheral equipment to other system manufacturers—in 1974 revenue from such peripherals accounted for 26% of total revenues.

CDC management determined at an early date that the company would be a factor in the service business. A first computer service center was opened in 1960. By 1968 there were 33 centers throughout the world, connected together with a communications complex which CDC called Cybernet. And in 1973, when IBM settled a lawsuit by selling CDC its Service Bureau Corporation (SBC), Control Data was already a major factor in the service industry. (The Control Data Institute, founded in 1965 to provide education and instruction in computer-related trades, is one component of CDC's service business.) Between 1970 and 1974 service revenue increased from 21% to 36% of total revenue. And in 1974 revenues from services, plus those from equipment rentals, exceeded sales revenues for the first time in CDC's history.

The lawsuit which resulted in CDC's acquisition of SBC was initiated in 1968 when CDC charged that IBM had violated and was violating the Sherman Antitrust Act. The settlement permitted CDC to purchase SBC for $16M, keeps IBM out of the service business until 1979, and committed IBM to do about $11M worth of business with CDC over the period 1973-1977. An earlier lawsuit, filed by Sperry Rand in 1958 charging that CDC was using Sperry Rand trade secrets, was settled out of court in 1962.

Acquisition and merger has always been a factor in CDC's growth, as is indicated at the bottom of Figure 1.312.1. The motives for acquisition have been varied. Cedar Engineering provided production facilities and an instrument and control business. Control Corporation was a supplier of industrial controls. Holley Carborator brought a capability of developing peripheral devices. Bendix and General Precision came with a line of computers. C-E-I-R, Inc. was a computer service corporation, supplying programming and technical services. Commercial Credit Company, whose 1968 gross income was about the same as CDC's, is a financing, lending, leasing, and insurance company, and has subsequently provided financing for CDC leases and for some services. And Computer Peripherals, Inc., is a joint venture with NCR aimed at developing peripheral equipment which can be used by both companies. The various couplings have all been effective in helping CDC grow and prosper.

In reviewing CDC's financial results, it is useful to make comparisons with IBM—though we must remember that some 20% of IBM's revenue is from non-data-processing products and services. Comparing Figures 1.311.6 and 1.312.4 we observe that CDC's cost of sales during the past ten years has been 60-80% of revenues compared with IBM's 35-45%. Selling and administrative costs have been 15-20% compared with IBM's 25%, and net income has never exceeded 6% (and has sometimes been negative), where IBM's has averaged 10% or better—see Figures 1.311.8 and 1.312.5. CDC's international business got off to a late start, but by the early seventies was comparable to IBM's, as a percentage of total revenues (Figures 1.311.9 and 1.312.6.) Revenue per employee (Figures 1.311.16 and 1.312.7) is also comparable for the two companies. IBM's inventories represent a larger percentage of assets than do CDC's (Figures 1.311.18 and 1.312.8).

In short, in examining these two very well-managed companies, one must be struck by the advantages which accrue to the large firm. CDC has over the years spent the same proportions of its revenues on R & D as IBM has. And that money has been spent very effectively—CDC has been the acknowledged leader in the development and manufacture of large systems. But IBM's *dollar* budget for research has been fifteen times CDC's, and that money has brought a much broader product line, including a host of peripheral devices. Furthermore, IBM's enormous manufacturing volume has permitted investments in production facilities which lead to costs much lower than CDC can achieve. And finally, IBM's better profitability enables it to invest much more money and manpower in selling than can CDC. This very effective sales support makes it possible for IBM to give its competitors a price advantage without materially affecting sales; and the price advantage of course further contributes to IBM's profitability.

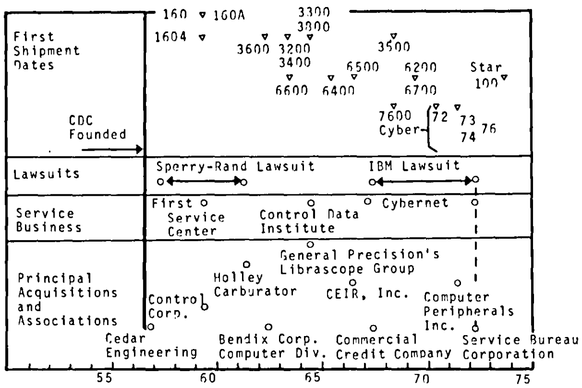



FIGURE 1.312.1 C.D.C. HISTORY

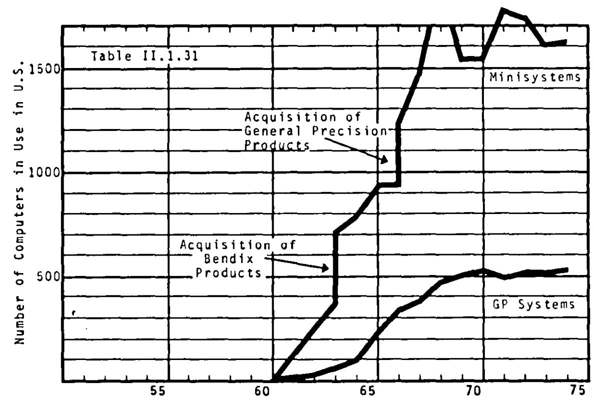



FIGURE 1.312.2 C.D.C. COMPUTERS IN USE

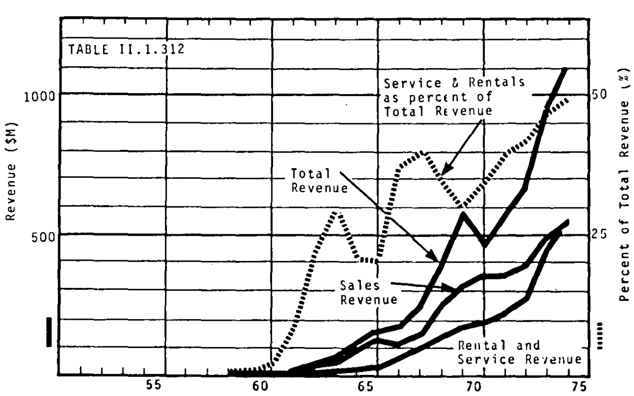



FIGURE 1.312.3 CDC WORLDWIDE REVENUES

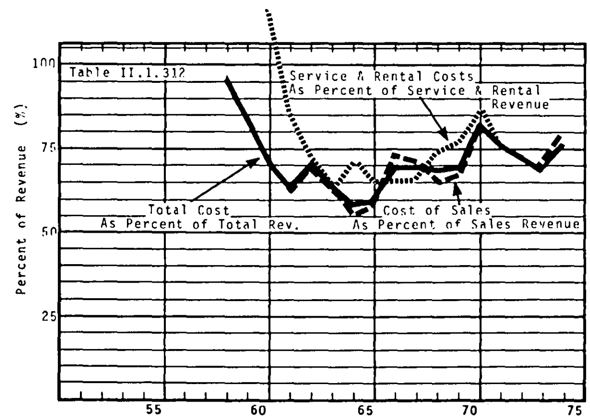



FIGURE 1.312.4 C.D.C. WORLDWIDE COST OF SALES & SERVICE

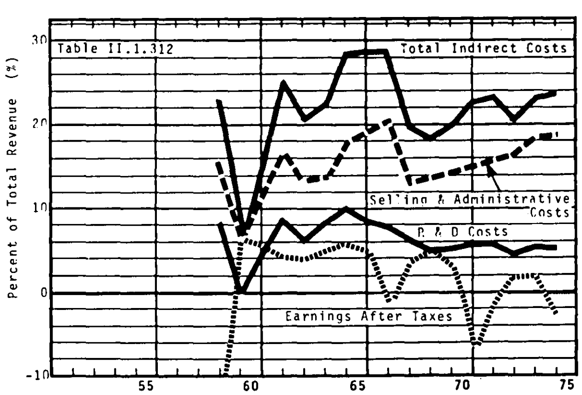



FIGURE 1.312.5 C.D.C. WORLDWIDE COSTS AND EARNINGS AS PERCENT OF TOTAL REVENUE

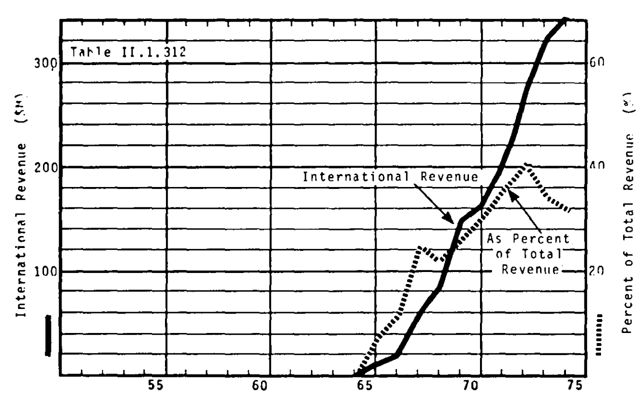



FIGURE 1.312.6 C.D.C. INTERNATIONAL REVENUE

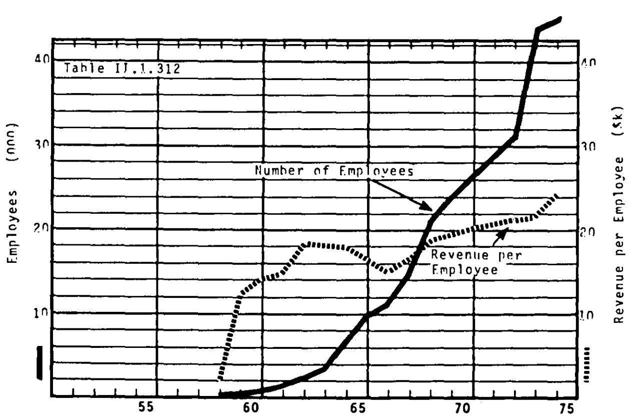



FIGURE 1.312.7 C.D.C. EMPLOYMENT

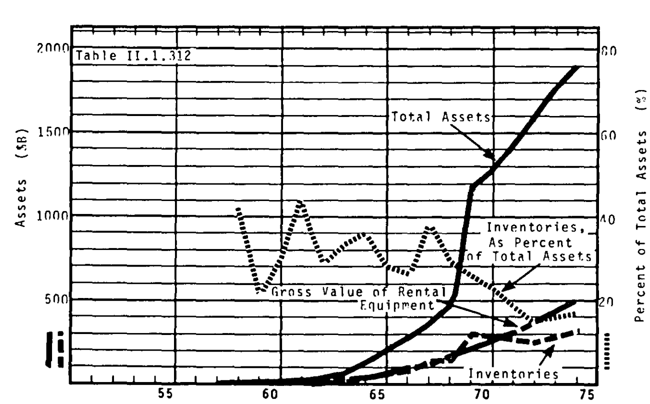



FIGURE 1.312.8 C.D.C. ASSETS

## 1.4 PERSONNEL ●

It was once feared that the advent of the computer would lead to widespread white-collar unemployment as more and more data processing was done automatically, and even to blue-collar unemployment as the "automated factory" became a reality. In practice the fears have proven to be groundless. Certainly the computer has taken over the functions of many clerical people, just as earthmoving equipment has taken over the functions of many ditch-diggers and laborers, and the automatic exchange has taken over the functions of many telephone operators. But the use of new equipment provides two benefits which more than compensate for the displaced jobs. By increasing the amount of work done per person—that is, by increasing productivity—it makes possible an increase in the real wages of the people who remain. And by drastically reducing the cost of doing a unit of work, the new equipment encourages projects, services and activities which otherwise would not be feasible and which give rise to a host of new jobs. Thus for example the extensive American Interstate Highway system would never have been completed without modern earth-moving equipment; the enormous volume of telephone traffic would be impossible without the automatic exchanges; and the current daily flow of bank checks, credit-card vouchers, and airline reservations could hardly exist without the computer. In fact, as shown in Figure 1.4.1, the professional and clerical work forces in the United States have increased both in absolute numbers and as a percentage of the total labor force during the years of explosive growth of the computer industry.

Though it is impossible to estimate how many people have lost their jobs or have had to be retrained to handle different jobs because of the introduction of computers, we can form some estimate of the number of people employed in using and in supplying the machines. The greatest number of people, of course, are employed in making use of GP machines, and the growth of the four principal job categories—keypunch operators, programmers, systems analysts, and computer operators— is shown in Figure 1.4.2. Computer users acturally employ other personnel as well in computer-related jobs (magnetic tape "library" clerks, terminal operators, auditors, and supervisors, to name a few), so the count shown is an underestimate. Nevertheless, it had reached the one million level, well over one percent of the total labor force, by 1973.

The suppliers of computer equipment employ substantially fewer personnel than do the users, and Figures 1.4.3 to 1.4.5 display estimates of employment in the principal job categories for the GP system manufacturers. (I do not include employees of minicomputer, peripheral equipment, terminal, data entry, or data communications equipment manufacturers—see the discussion below in connection with Figure 1.4.5.) The bulk of the employees work on the production line and are therefore categorized as manufacturing direct labor personnel. As shown by the solid line in Figure 1.4.3, over 60,000 people were engaged in such work by the late 1960's, when the recession caused a severe cutback. It is more difficult to determine the number of engineers and programmers developing equipment and systems, but the same figure also shows an estimate of the growth in these categories, again for the GP systems manufacturers only. Taken together, hardware and software development engineers generally amount to only about 20% of the number of production workers.

The growth in maintenance and sales personnel is shown in Figure 1.4.4, where we can observe an interesting and fundamental contrast: basically, the number of sales personnel required by an organization is proportional to the value of systems sold, and the number of maintenance personnel to the value of systems in use. The customer engineer (CE) population has therefore necessarily grown faster and more smoothly than the population of salesmen, which in turn has led to organizational problems in many supplier companies. Because the CE's, like the salesmen, provide service directly to the customer, they historically have been included in the sales organization. When a company is new, the salesmen greatly outnumber the CE's; but as time passes the situation changes, and there are as many CE's as salesmen. Because the selling and maintenance functions are of course quite different, it is essential that company management recognizes and reacts to the change in manpower ratios, and that proportionately more attention is paid to maintenance management as the organization grows.

A summary of the growth in GP system supplier personnel is given in Figure 1.4.5. Once again it is important to recognize that the data underestimates total employment, partially because it excludes employees at non-GP system companies, as was indicated above, but also because it excludes draftsmen, technicians, purchasing, shipping, and receiving personnel, quality control and industrial engineers, clerks and secretaries, supervisors, and other supporting and staff personnel. The four points at the top of Figure 1.4.5, for the years 1967 and 1970 to 1972, provide an independent estimate, based on U.S. Government statistics, of *all* personnel in the companies grouped under Standard Industrial Classification 3573, Electronic Computing Equipment. Note that total employment grew an estimated 41% between 1967 and 1971 while specialized employment in GP system companies grew only an estimated 6.4%. In part this reflects the unsophisticated estimating techniques used in deriving the latter figures—they are based directly on shipment data and assume people were laid off as shipments fell during the recession. In practice the layoffs were not as severe as shown, and 1970's actual employment figures should correspondingly be higher. But the large growth in total employment in those years reflects the relative growth of the non-GP computer segment: in 1967 GP system shipments were 92% of total U.S. hardware shipments; by 1970 that percentage had fallen to 86%, in 1972 it was 81%, and in 1974 72% (see Figure 1.20.5).

The last three figures show trends in salaries and wages for the most important personnel categories. It is a fact of life that all wage and salary trends are upward. In part, the increases reflect the pace of inflation, as measured approximately by the changes in the GNP deflator of Figure 1.1.1. In part they reflect a shortage of and demand for personnel in a rapidly-growing field. And in part they are compensated for by increases in productivity: when an employer invests in equipment to make his employee more productive, he can use part of the resulting savings to increase the employee's wage. We will be using these wage and salary figures in later sections of the book to calculate personnel costs in various situations.

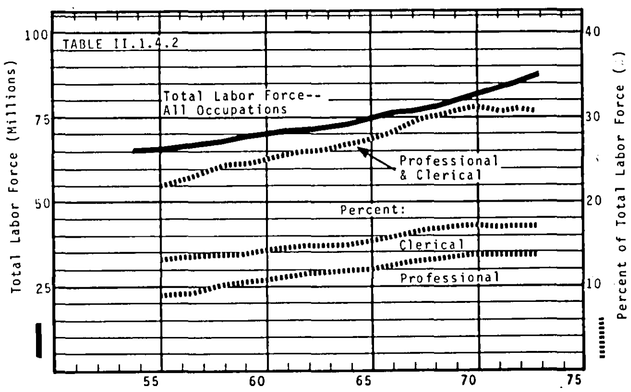



FIGURE 1.4.1 THE U.S. LABOR FORCE
ENUMERATION OF SOME WHITE-COLLAR WORKERS

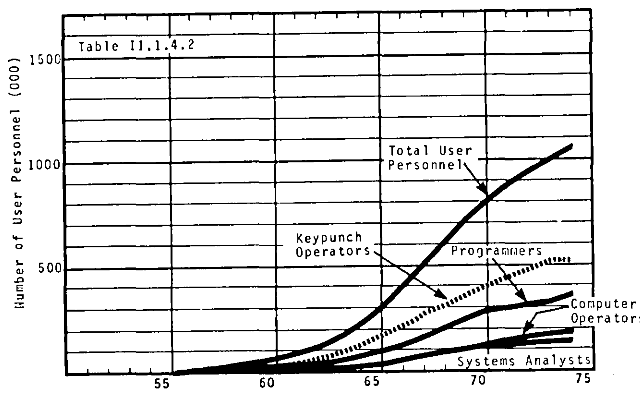



FIGURE 1.4.2 COMPUTER SYSTEM USERS' PERSONNEL

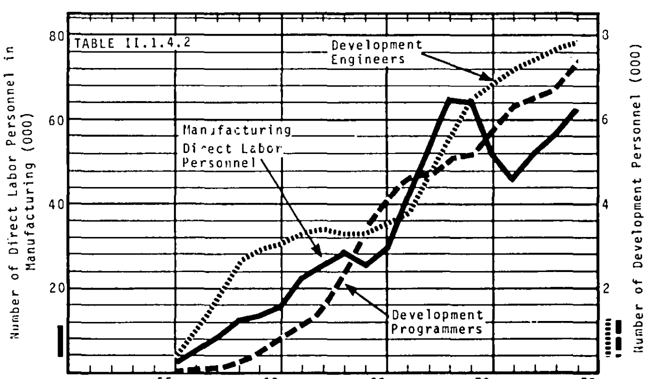



FIGURE 1.4.3 COMPUTER EQUIPMENT SUPPLIERS' PERSONNEL I
MANUFACTURING AND DEVELOPMENT PEOPLE

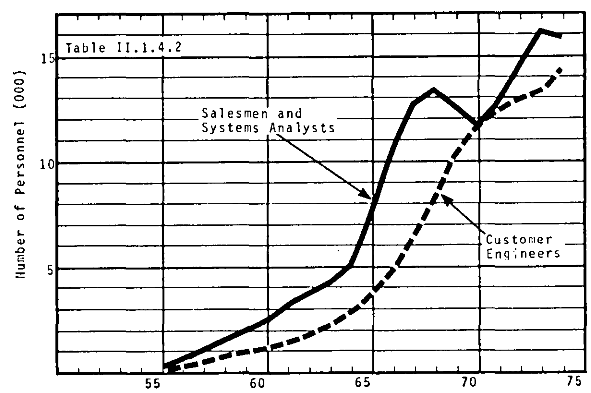



FIGURE 1.4.4 COMPUTER EQUIPMENT SUPPLIERS' PERSONNEL II
SALES AND MAINTENANCE PEOPLE

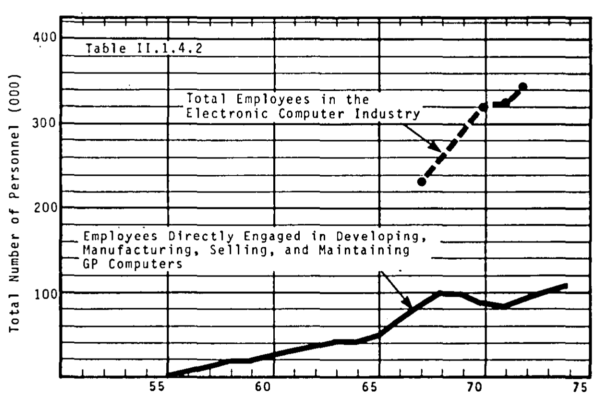



FIGURE 1.4.5 COMPUTER EQUIPMENT SUPPLIERS' PERSONNEL III

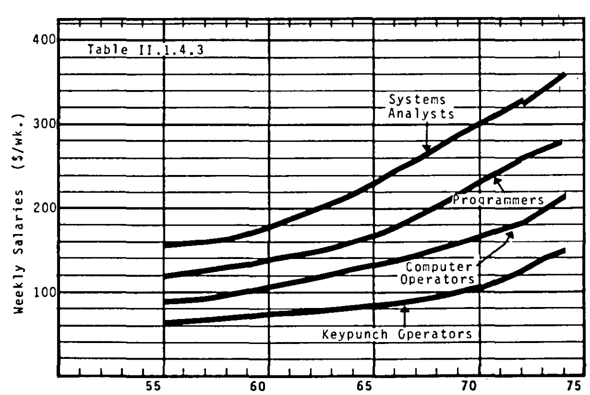



FIGURE 1.4.6 SOME KEY SALARIES I.
USER PERSONNEL WEEKLY PAY

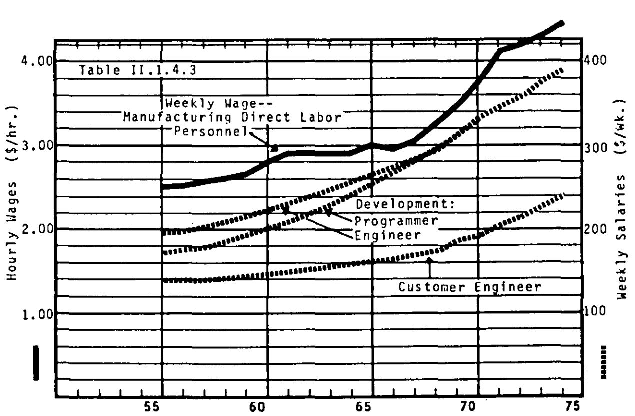



FIGURE 1.4.7 SOME KEY SALARIES II.
SUPPLIER PERSONNEL WEEKLY AND HOURLY PAY

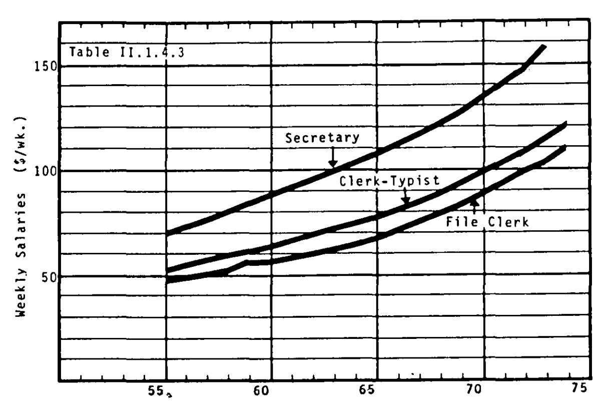



FIGURE 1.4.8 SOME KEY SALARIES III.
WEEKLY PAY OF CLERICAL PERSONNEL

## 2.0 Products — Introduction ●

Having examined the Marketplace, we now have in mind a fair picture of the size, growth rate, complexity, and principal parts of the data processing industry. As was pointed out in the introduction, the remaining three sections of the book, on Products, Applications, and Costs should give the reader some insight into the reasons for the changes which have taken place.

Let us define a product as an item (goods or service) having specified characteristics, which is offered for sale at a given price by one or more commercial firms. The data processing industry has grown primarily because its products have provided useful performance for the specified prices, and because new and improved products have regularly appeared. In studying products, we will first review the performance and price of specific units, looking at their principal and obvious individual features, independent of their usage in systems. Next, in Section 2.2, we will examine the larger, more difficult, and more important question of system performance, attempting to understand the factors which determine how the units, working together, function in typical operating situations. Finally, in Section 2.3, we will study some of the more mundane non-performance design characteristics of hardware products.

In the material which follows, performance refers to various quantitative measures with which the functional capability of a unit, system, or service are measured. Price is the purchase price for hardware, software, and supplies, and the monthly charge for services. As we shall see, it is often very difficult to establish useful performance measures for complex data processing products, just as it's difficult to find a meaningful measure of the performance of a newspaper or a teacher. We shall also see that, for many important products, far too little has been done in defining and measuring performance.

## 2.1 Unit Performance and Price ●

The impression I will convey by my review of the history of unit price and performance is of course dependent on the particular units I choose to describe. In each section I will begin by saying something about the criteria I used in making my choices. It would be delightful, but is of course impractical, to treat every product from every manufacturer. What I would like to be able to do is to choose only the important units; and where possible, I attempt to establish criteria for "importance", and then select units which meet the criteria. With regard to some classes of product, however, I have too little data to determine the relative importance of different products, and am reduced to making an arbitrary choice; or I have too little data about the products themselves, and am reduced to presenting the available data without regard to importance.

### 2.11 PROCESSORS AND THEIR INTERNAL MEMORIES ●

**Important Products.** Each of us has his own viewpoint as to which computer systems are most important. To a salesman, the important machines are those which were easy to sell and brought large commissions. A field engineer might say that his most important systems were the unreliable ones, on which he spent a disproportionate amount of time. The engineer is likely to favor the innovative systems, in which new components or new logical systems or new architectural features or new programming concepts were tried out for the first time. I argue that the importance of a system should be measured by the extent of its acceptance among users. And I propose to employ three measures of acceptance: number of systems in use; total value of systems in use; and total operations per second carried out by systems in use.

In Figures 2.10.1 to 2.10.3 the most numerous GP and mini systems are identified, and their populations plotted as a percentage of total systems in use in the U.S. each year. IBM's domination of the GP business, which we noted earlier when we analyzed and discussed computer companies (Section 1.3), is once again demonstrated. Individually the IBM 650 and 1401 machines accounted for roughly half of total installations at their peak years. No single machine has since been as pervasive, though some later systems have exceeded the 1401 in absolute number of installations—at the end of 1963, 5,200 IBM 1401's represented 45% of U.S. GP installations; by 1970, 8,400 IBM 360/20's represented only 17% of world-wide installations, for example. The mini class of machines show a similar pattern, with the Bendix G15 and Librascope LGP30 jointly accounting for 90% of installations in the early days, while the most popular mini in 1970, the PDP8-L, represented only 13% of all U.S. mini installations.

Though number of installations is one interesting and useful measure of importance, it has the obvious disadvantage that it neglects the cost or value of a system, giving equal weight to a System 3 and a 370/195. We can take price into account by looking at the installed value of each system model at the end of every year, and picking out those whose value is the largest fraction of total installed value. The result for GP systems is plotted in Figures 2.10.4 and 2.10.5. Once again we see how effectively IBM has designed and marketed its products. Furthermore, we find that an examination of installed value draws our attention to several machines—the Univac I and the IBM 7090, 7074, and 1460—which rank first or second in installed value, but much lower in number of installations.

Finally, it is instructive to envision the total GP computing power in use in the U.S., and to determine which models contributed the largest proportion of that total installed power in each year. We must begin with a measure of the power of each computer system, and with the census of end-year installations. For each machine we determine total installed capacity for a given year by multiplying its individual power by the number of systems in use. And we calculate total computing power in use by adding together all the individual capacities.

If we perform this calculation using Knight's measure of system performance (to be described below), we get the results shown in Figures 2.10.6 and 2.10.7. Using power as a criterion, we find several machines to be "important" which didn't appear in the lists of the most numerous or greatest installed value systems—the UNIVAC 1108, the CDC 6600, and the IBM 360/65, for example.

Incidentally, using the same measure of performance, we can list the most powerful machines at each point in time. The result is shown in Figure 2.10.8, where greatest power is measured in terms of operations per second on the top curve, and operations per dollar (i.e. computing speed divided by system rental price) on the bottom. Perhaps the most interesting aspects of this figure are the appearance of the commercially unsuccessful Philco machines in the early sixties, and the success CDC has had in recent years in designing powerful and cost effective systems.

In the discussions which follow, we will focus most of our

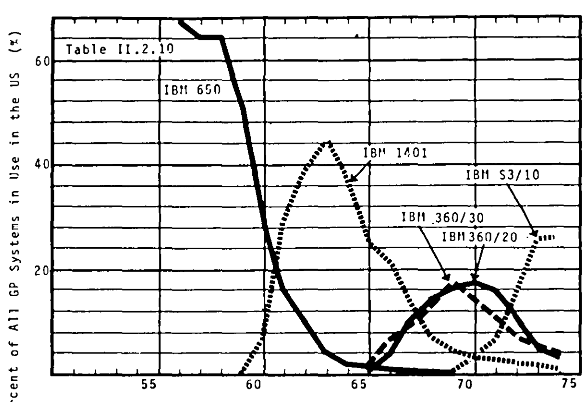



FIGURE 2.10.1 THE IMPORTANT COMPUTERS I .
G.P. SYSTEMS HAVING THE GREATEST NUMBER IN USE IN THE U.S.

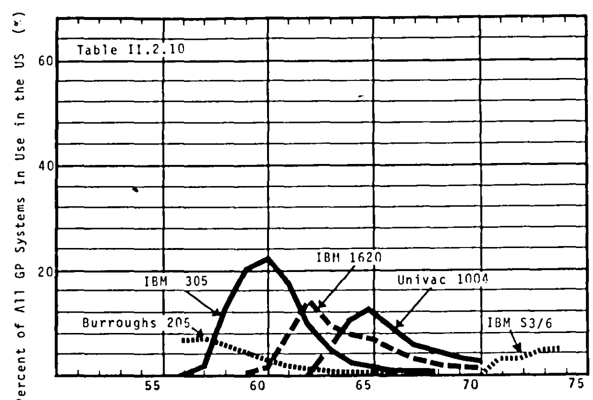



FIGURE 2.10.2 THE IMPORTANT COMPUTERS II.
G.P. SYSTEMS HAVING THE SECOND GREATEST NUMBER IN USE IN THE U.S.

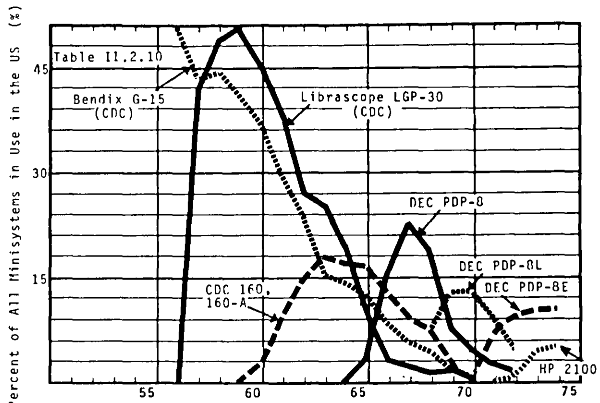



FIGURE 2.10.3 THE IMPORTANT COMPUTERS III.
MINISYSTEMS HAVING THE GREATEST NUMBER IN USE IN THE U.S.

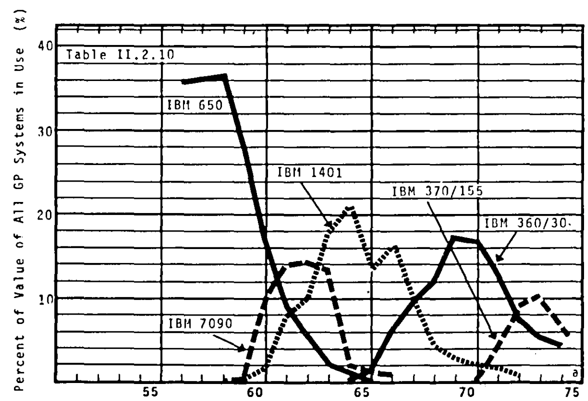



FIGURE 2.10.4 THE IMPORTANT COMPUTERS IV.
G.P. SYSTEMS HAVING THE GREATEST VALUE IN USE IN THE U.S.

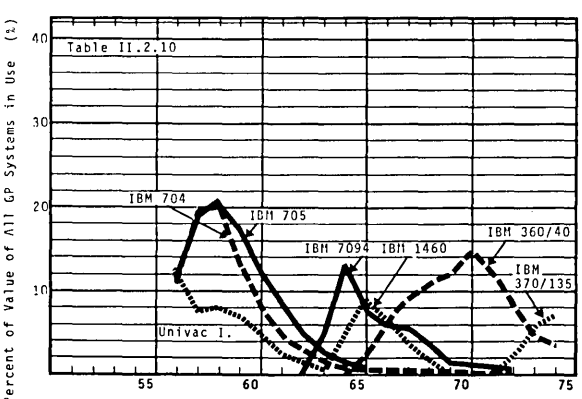



FIGURE 2.10.5 THE IMPORTANT COMPUTERS V.
G.P. SYSTEMS HAVING THE SECOND GREATEST VALUE IN USE IN THE U.S.

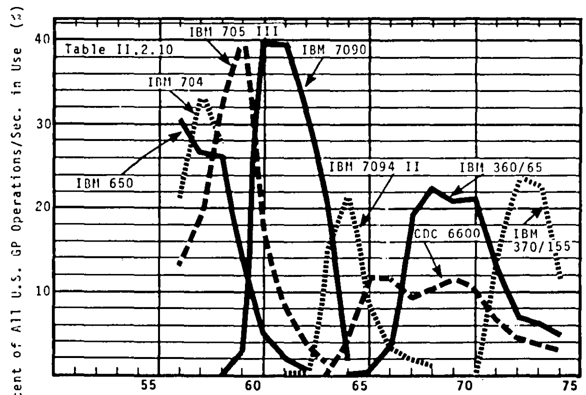



FIGURE 2.10.6 THE IMPORTANT COMPUTERS VI
GP SYSTEMS PERFORMING MOST OPERATIONS PER YEAR IN U.S.

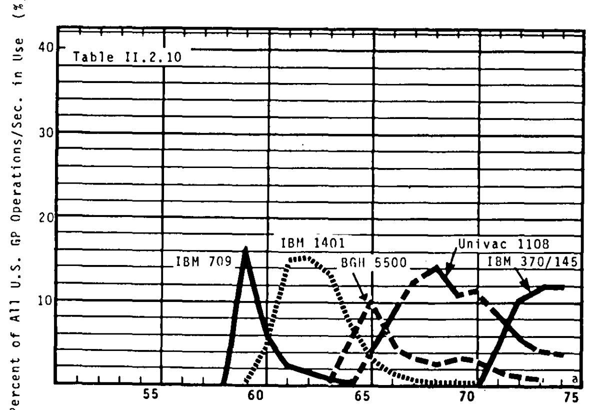



FIGURE 2.10.7 THE IMPORTANT COMPUTERS VII
GP SYSTEMS PERFORMING SECOND MOST OPERATIONS PER YEAR IN U.S.

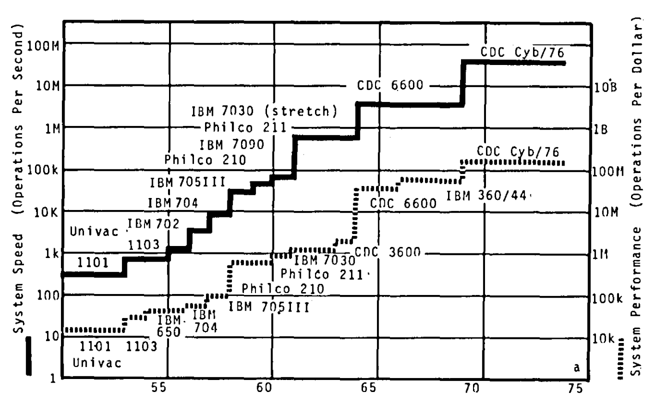



FIGURE 2.10.8 THE IMPORTANT COMPUTERS VIII
SYSTEMS WITH THE BEST PERFORMANCE IN EACH YEAR

attention on the systems identified in Figures 2.10.1 through 2.10.7, and will ignore the perhaps technically interesting but commercially less important models which appear only in Figure 2.10.8.

**Raw Performance** Having identified the systems which have been and are important by one criterion or another, let's proceed to characterize and record their price and performance. We will look at the raw performance of CPU's, internal memory, and the major peripherals in the next few pages before taking a look at the more difficult question of system performance.

The CPU is of course the control center of any data processing system, and presumably its performance is critical to the performance of the system it controls. It is, however, a most complex device and cannot be succinctly described without omitting something of importance. Although it is hard to pick a single parameter to characterize CPU performance, the best choice is probably addition time, including memory access; and that parameter is plotted in Figure 2.11.1 for the important systems. Note that the add times for the key processors 650-1401-360/30-370/135 show an improvement of over three orders of magnitude (5,200-230-30-4 microseconds) in the 17 years from 1954 to 1971—an average reduction of 33% per year. An AFIPS report (CEIR 66) published in 1966 estimated a "representative add time not including memory access" which is plotted as a dotted line in the figure. Since an add instruction requires at most two memory cycles plus a raw add time, it would appear that the AFIPS numbers are on the high speed side of "representative". But they certainly confirm that startling performance improvements have been commonplace in the industry.

Although many computer instructions are completed in the time required to perform an addition, typically there are others that take longer. Examples are arithmetic functions like multiplication, division, and square rooting, and logical operations like data-moving and table-lookup. Sometimes such functions are implemented in the hardware, and can be carried out with a single instruction. Sometimes they must be implemented with software. Their impact on processor performance obviously depends on the frequency with which they appear in the user's workload (a subject we will discuss in Section 2.21). But Figure 2.11.2 provides a measure of processor performance which takes multiplication into account, giving machine speed in operations per second for a program containing 95% add operations and 5% multiply operations. And Figure 2.11.3 shows how processor performance is affected by multiply time and by the proportion of multiplications (or by the time to perform any slow function and the frequency of occurrence of that function). For example, if multiply time were ten times addition time for some processor, and 10% of operations were multiplications, the figure shows that the processor's speed would be about 52% of its speed performing pure additions.

The two dotted lines in Figure 2.11.2 were drawn quite arbitrarily at a compound growth rate of 58.5% per year (a factor of 100 times each ten years). The bottom line traces the performance of lower-price-range processors like the IBM 1401 and 360/30. Note the IBM 650, however, does not lie anywhere near the line. The top line follows the more expensive units, from the IBM 705 to the Univac 1108. Lines representing this same growth also appear in Figures 2.11.5 and 2.11.6.

The next most important performance parameter to consider is memory speed, and Figures 2.11.4 and 2.11.5 show how that characteristic has changed over the years. Memory cycle time, defined as the average time between two successive accesses to random words, is very much a function of technology. The Univac I used a mercury delay line for internal storage, but its successors adopted the more economical magnetic drum, with a resulting large increase in cycle time as shown in Figure 2.11.4. Some early large machines used electrostatic storage, but the mainstream of computer technology seized the magnetic core as an optimal compromise between performance and cost, and the subsequent points in the figure show how core memory performance has improved over the years. The dotted line is comparable to the "representative add time" in Figure 2.11.1, and comes from the same AFIPS study (CEIR66).

The memory data transfer date shown in Figure 2.11.5 is the quotient of the memory width, in bits, and the cycle time in microseconds. The IBM 360/30, for example, retrieves data from memory in units of one eight-bit byte, and has a cycle time of 1.5 microseconds. The data transfer rate is therefore eight bits per 1.5 microseconds, or 5.3 bits per microsecond. Note that improvements in memory bandwidth have pretty much paralleled those in processor speed.

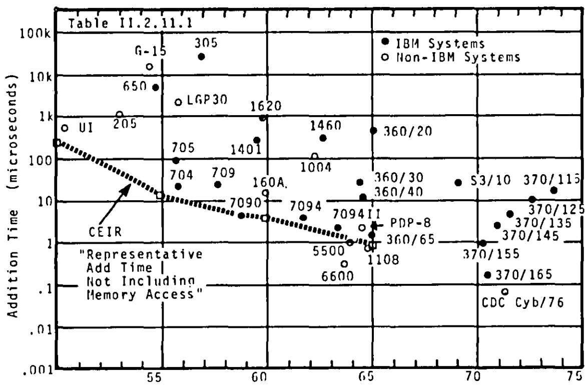



FIGURE 2.11.1 PROCESSOR PERFORMANCE I
ADDITION TIME

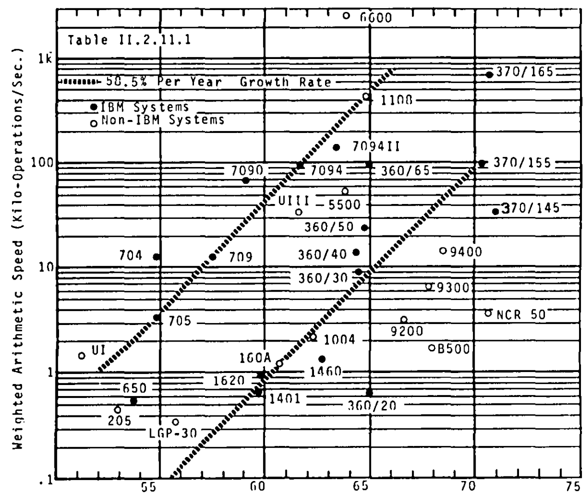



FIGURE 2.11.2 PROCESSOR PERFORMANCE II
WEIGHTED ARITHMETIC SPEED

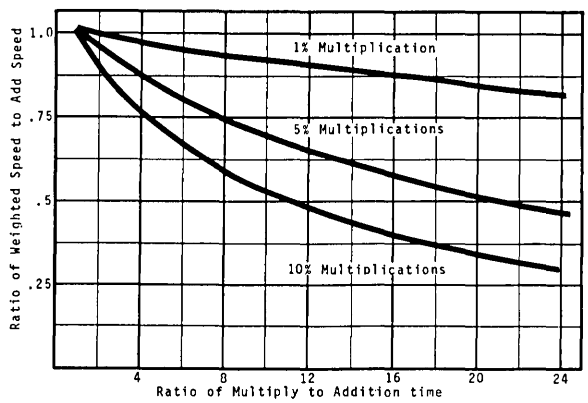



FIGURE 2.11.3 PROCESSOR PERFORMANCE III
EFFECT OF SLOWER OPERATIONS ON PROCESSOR SPEED

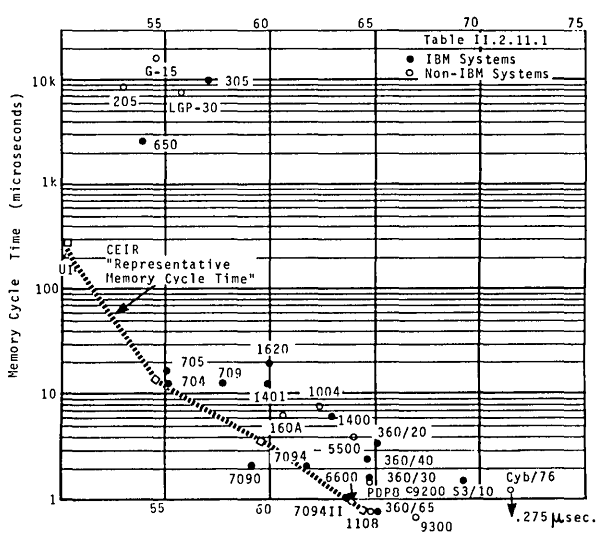



Figure 2.11.4 PROCESSOR PERFORMANCE IV
MEMORY CYCLE TIME

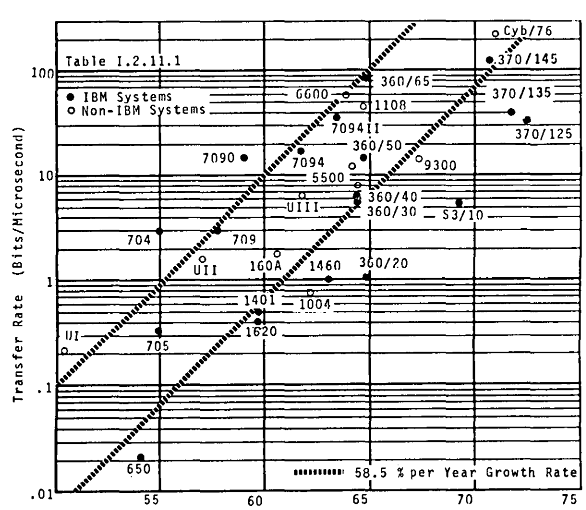



FIGURE 2.11.5 PROCESSOR PERFORMANCE V
MEMORY DATA TRANSFER RATE

**Knight's Performance Measure.** Various other individual performance measures could be recorded and plotted. However, probably none is as meaningful as the raw speed data of Figures 2.11.1 to 2.11.5. Another, somewhat more sophisticated measure attempts simultaneously to take into account arithmetic speed, memory size, memory word-length, and the degree of overlap permitted between the processor and the I/O system. This measure, devised by K. Knight as part of a doctoral thesis at the Carnegie-Mellon Institute, is defined in detail in Part II in connection with Figure II.2.11. It basically starts with an arithmetic speed which is weighted according to specified proportions of the various instructions, reduces that speed to allow for the non-overlapped input-output time required to handle data for the processor, and then multiplies the result by a memory factor which increases with increasing memory size, and gives extra weight to long words and to variable-word-length systems.

Knight actually defined and computed two performance indices, one labelled Commercial, the other Scientific, which differ only in weights assigned to various factors, including the instruction mix. And he published his indices, as applied to all computers designed up until 1968 (KnigK66, 68, 72). His measure of Commercial speed was used in the calculations identifying the important computers of Figures 2.10.6 to 2.10.8. A chronology of performance of all the various important computers is shown in Figure 2.11.6, and once again we see that an improvement rate of 59.5% per year compounded might be taken as a reasonable estimate of the advancements made in raw computer speed over the years.

While some technology improvements—faster circuits and memories—have made it possible to increase system speed, others—like the introduction of automatic wire wrap and integrated circuits—have simultaneously permitted reductions in system cost. The resulting improvement in operations per *dollar* (found by dividing Knight's Commercial speed index by processor-alone rental, and assuming a month contains 4 1/3, 40-hour weeks) is illustrated in Figure 2.11.7 and is even more spectacular than the increases in speed. Knight was particularly interested in the relationship between system performance and system price, and used his performance figures in a series of curve-fitting calculations. Assuming that the relationshiop between speed and rental in any year was of the form log S = logC + klog R where C and k are arbitrary constants, he found k fairly close to two. That is to say, for any given generation of computers, speed is proportional to the square of system rental, so that by doubling ones hardware expense one gets roughly four times as much capacity. This result, plotted in Figure 2.11.8, confirmed an early conjecture by H.R.J. Grosch, which has been widely known as Grosch's Law. The five dotted lines in the figure are Knight's statistical results for the five years shown. The 1971 line, with a slope substantially greater than that of the others (corresponding to an exponent of 1.52 compared with Grosch's 2.0) reflects a recent revision—see KnigK76. The various points plotted, representing price and speed of the more important computers, should serve to remind us that the 'Law' is simply an average, and that individual systems, and even families of systems from a specific manufacturer (note, for example, the IBM 360 family in the figure) fail to conform. The continuing improvement in performance measured in operations per *dollar* is indicated in Figure 2.11.8 by the rightward movement, from year to year, of the dotted lines.

**Memory Pricing.** With many early systems, only one or at most two memory sizes were offerred by the manufacturer. However, it soon became apparent that the internal memory capacity requirements of different users varied enormously, depending on the magnitude and character of their data processing workloads. Accordingly, second- and later-generation systems generally were designed so that the customer could choose from a range of memory capacities, or could have blocks of internal memory added to his system after it had been in operation for some time.

The price structure for processor and memory thus starts at some initial point, which buys a processor and minimal memory, and proceeds by increments as bytes of memory are added. The price structures for the important computers are reproduced in Figures 2.11.9 to 2.11.11, and the incremental price (the cost of adding a byte of memory to a system, found by dividing the incremental cost of a block of memory by the number of bytes included) is plotted in Figure 2.11.12. Comments:

1. Three different memory technologies are represented in these figures: The IBM 650 had a magnetic drum memory; the IBM 370/125, /135, and /145 have integrated circuit memories; and all the other systems have magnetic core memories.
2. The actual amount (and cost) of equipment which must be installed to effect an increase in memory size depends very much on the specific design of the memory. At one extreme, it may be possible to add capacity simply by adding basic storage elements—for example, by adding magnetic cores on plug-in modules. At the other, an increment in memory size may require not only such storage elements but also associated drivers, amplifiers, address registers, input-output registers, control circuits, power supplies, and cabinets. In planning his system, a supplier generally may decide to deliver some extra equipment with most installations—extra cabinet space wired for memory additions, extra power supply capacity—in order to achieve more uniformity in his manufacturing operations, and to reduce the installation cost of adding incremental memory when (and if) the customer orders it.
3. The data plotted is *price* information, of course, not *cost* information. It represents what the customer pays, not what it costs the supplier. And the relationship between the supplier's cost and price is very complicated. Hardware selling price generally may be a function of competitive conditions, inventories, expected user system configurations, the manufacturer's relative interest in selling or leasing his systems (which influences the ratio of sales to lease prices), product development costs, software development costs, and selling costs, as well as manufacturing costs. Some of this diversity is at least indicated in the figures. For example, referring to Figure 2.11.12, we can speculate that the unusual and similar incremental price curves for the IBM 1401 and System 3/10 memories is probably a reflection of actual costs: the first increment, at a relatively high price, includes hardware which makes the next increment relatively cheap; but to add a third increment it is necessary, in effect, to start over again. On the other hand, examining the price curves for the IBM 360/65 and 370 systems in Figure 2.11.11, one might conjecture that competitive factors played a part in pricing. The low initial price for the smallest 360/65 made it possible for that machine to compete on a price basis with low-cost machines from other manufacturers; but as a buyer found he must add memory to the basic system, he had to pay a high incremental price, and IBM's profit margin, which

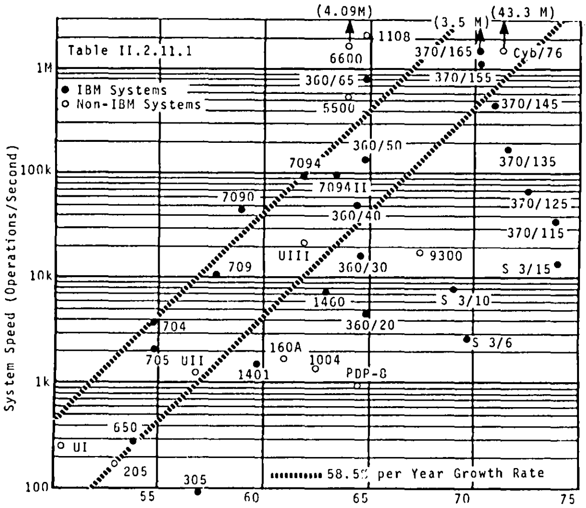



FIGURE 2.11.6 PROCESSOR PERFORMANCE VI
COMMERCIAL OPERATING SPEED (KNIGHT)

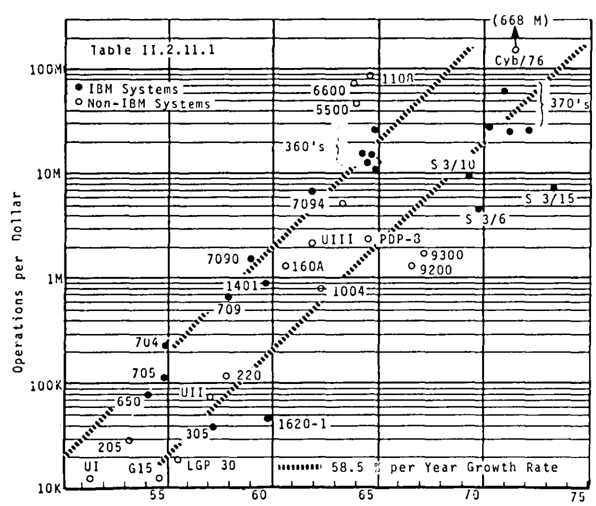



FIGURE 2.11.7 PROCESSOR PERFORMANCE VII
OPERATIONS PER DOLLAR

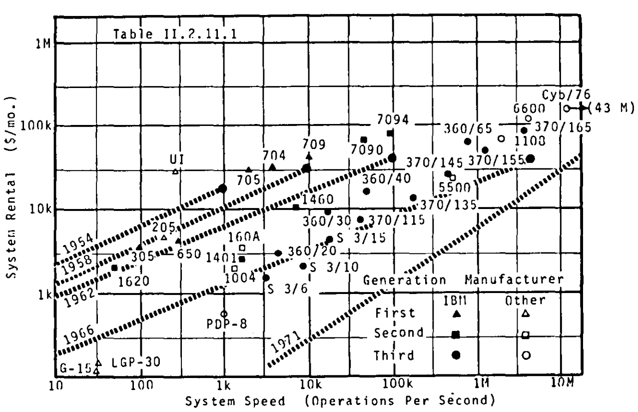



FIGURE 2.11.8 PROCESSOR PERFORMANCE VIII
COMMERCIAL OPERATING SPEED VS. SYSTEM RENTAL

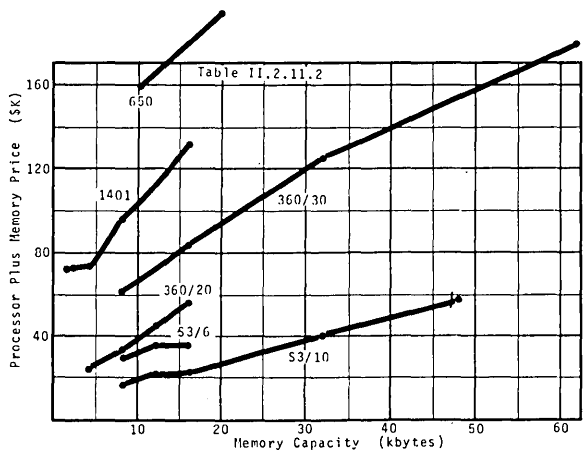



FIGURE 2.11.9 SYSTEM MEMORY CAPACITY AND PRICE I

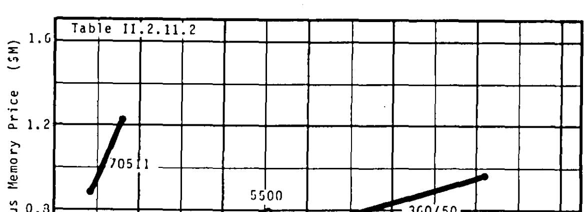



FIGURE 2.11.10 SYSTEM MEMORY CAPACITY AND PRICE II

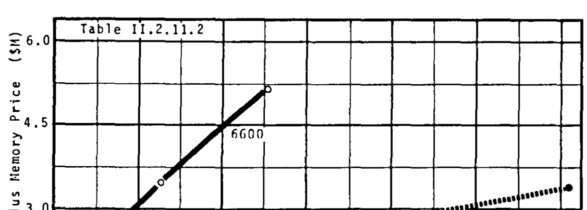



FIGURE 2.11.11 SYSTEM MEMORY CAPACITY AND PRICE III

was low for the small system, improved. For the 370 systems, independent memory manufacturers have alleged that IBM set the price of a basic system high and the incremental price of memory unrealistically low, so that competitors could not profitably offer plug-in memories to IBM users—as they did very successfully with IBM's 360 systems.

4. Figure 2.11.12 shows that incremental memory prices for magnetic core memories only dropped by a factor of about ten between 1960 and 1972—the IBM 1401 increment cost \$1.50 to \$5.00 per byte, the IBM 370/155 cost \$0.40 to \$0.50 per byte. It seems likely that core memory *manufacturing costs* fell by more than a factor of ten in that time: the cost model in Section 4.13 (see Figure 4.13.11) estimates a factor of more than 50. It therefore seems very possible that core memories, when initially introduced, had relatively low profit margins for the manufacturers; that subsequent improvements in magnetic core memory technology greatly reduced manufacturing costs; that IBM passed on only a portion of that reduction to users in the 360 machines, and thus greatly improved memory profitability; that other system manufacturers were therefore able to maintain relatively high memory prices and profits, since their common competitor was IBM; and that the situation changed, and the cost to the user improved, only when independent manufacturers began competing directly with IBM, offering lower-cost add-on memories.

We have spoken, and will continue to speak of "price" as if it were a fixed and immutable entity. In fact, prices change from time to time for various reasons, and Figures 2.11.13 to 2.11.16 show a sample of price history for a few of IBM's more important products. Each figure shows the price history of four products, the earlier ones on the left, the later on the right. Three prices are shown for each product: purchase price (solid line), rental price (dashed line), and maintenance price (dotted line). All prices are shown as ratios to the price given for the first year plotted—three horizontal lines would thus describe a product none of whose prices changed at all during the period covered. Comments:

1. IBM's prices have on occasion changed significantly. It is therefore wise to be cautious in basing plans on a given IBM price, without taking into account the possibility of a change.

2. Relative changes in purchase and rental prices are often used to encourage customers to purchase or to rent, depending of course on whether the purchase or rental price becomes relatively lower. IBM may wish to encourage purchases to increase cash income, to sell off an inventory in anticipation of introducing a new and more advanced product, or to counter the actions of competitors.

3. Changes in maintenance prices are probably based on actual maintenance costs. When IBM introduces a new product, it establishes a maintenance price based on the expected cost of maintenance— which in turn is based on expected reliability, maintenance time, parts inventory costs, and preventive maintenance requirements (see Section 4.4). As time goes on, actual costs are weighed against those expected, and maintenance price may be adjusted accordingly.

4. Maintenance is included in IBM's rental price—the maintenance price is of interest only to customers who have purchased IBM equipment and desire IBM service. One thus might expect that an increase in maintenance price would be accompanied by an increase in unit rental. Generally speaking, IBM does *not* tie rental and maintenance prices together in this fashion. In fact, the charts illustrate a key feature of IBM strategy: Wherever possible, keep monthly rental prices fixed and achieve financial, profit, or competitive objectives by changing purchase or maintenance prices.

## 2.12 PERIPHERAL EQUIPMENT ●

**Overview.** Before studying in detail the changes which have taken place in the price and performance of the more important classes of computer peripherals, it will be helpful if we look briefly at the spectrum of input-output and memory products. Three important parameters characterize a memory: cost per byte, typical unit capacity, and access time (elapsed time between a request for data and the availability of the data). These three properties are shown in Figures 2.120.1 and 2.120.2 for representative products from the principal memory technologies: flip-flops (used internally in the design of equipment), magnetic core and integrated circuit internal memories, and peripheral memories including moving-head and head-per-track files, data cells, and magnetic tape units. For each technology several points are shown, representing its state at five-year intervals as indicated by the characteristics of widely-used units. Lines connecting the points thus trace the pattern of technological progress. The general trend, of course, evident with each technology, has been for access time and prices to fall, and capacities to increase. Comments:

1. Changes of a factor of 100 in 15 years (an average 36% per year) in price per byte, access time, and maximum unit capacity have been commonplace. But the rate of change in memory technologies has not matched the rate in processor technology, as portrayed by Figures 2.11.1, 2.11.2, and 2.11.7, where changes of three and even four decimal orders of magnitude have occurred in fifteen years.

2. In peripheral equipment memory technology, the relative improvements in moving-head files have been outstanding. In 1955 the first moving-head-file cost three times more per on-line byte stored than a magnetic tape unit, and had an access time forty times that of a representative head-per-track file. By 1970 the price per byte had fallen to half that of the much improved newer tape units, and average access time was only eight times that of the improved head-per-track files. Meanwhile, technology of the much larger data cell stood still, and by 1970 one paid the same price per byte for a moving-head-file and a data cell, and had ten times better access time with the former.

3. Inasmuch as a half-dozen technologies are available to span a performance and cost range of seven to ten orders of magnitude, system designers have used a hierarchy of memories to obtain large effective storage capacities at reasonable cost in large systems. Magnetic tape, whose off-line storage cost is very low (see Figure 2.16.1) is used for back-up and long-term storage and is the primary storage device for many small systems. The moving-head file serves as the basic on-line bulk storage device. For intermediate-sized files which require frequent transfer to and from internal memory, the head-per-track file is inserted. And the *cache* memory (a fast-access, relatively small integrated circuit memory in which copies of frequently-used blocks of main internal memory are stored) is employed in some large systems to get the effective access time of a flip-flop memory with the cost and capacity of a magnetic core memory.

4. There is an often-noted access-time "technology gap" between the fastest rotating magnetic memory and the cheapest magnetic core memory. So far no technology has evolved with price, access time, and capacity characteristics

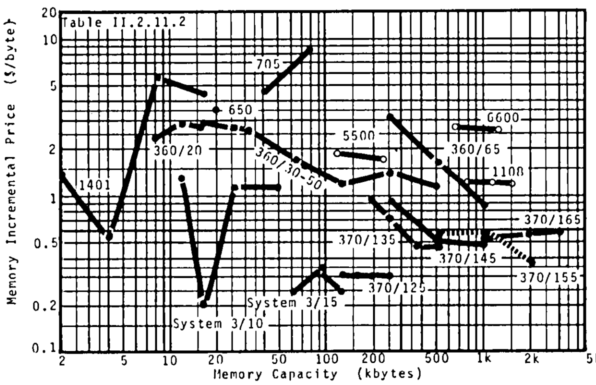



FIGURE 2.11.12 INTERNAL MEMORY PRICES VS. CAPACITY

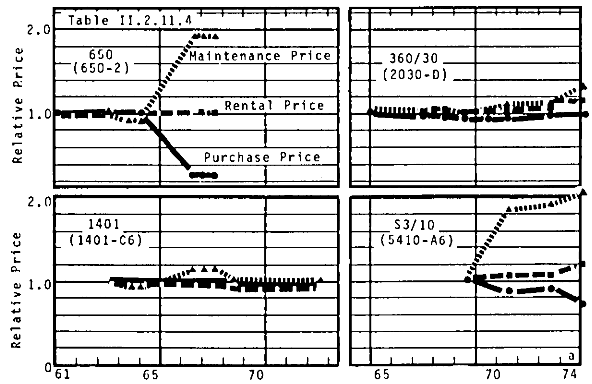



FIGURE 2.11.13 HISTORY OF IBM PRICING I
PROCESSOR PRICING RELATIVE TO A FIRST YEAR

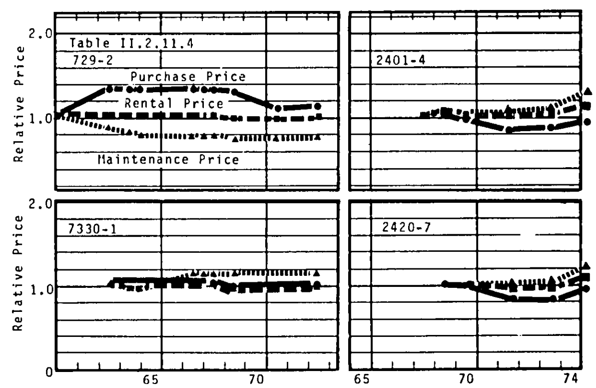



FIGURE 2.11.14 HISTORY OF IBM PRICING II
TAPE UNIT PRICING RELATIVE TO A FIRST YEAR

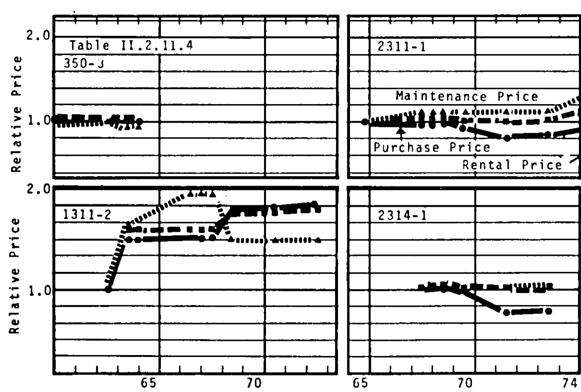



FIGURE 2.11.15 HISTORY OF IBM PRICING III
MOVING-HEAD-FILE PRICING RELATIVE TO A FIRST YEAR

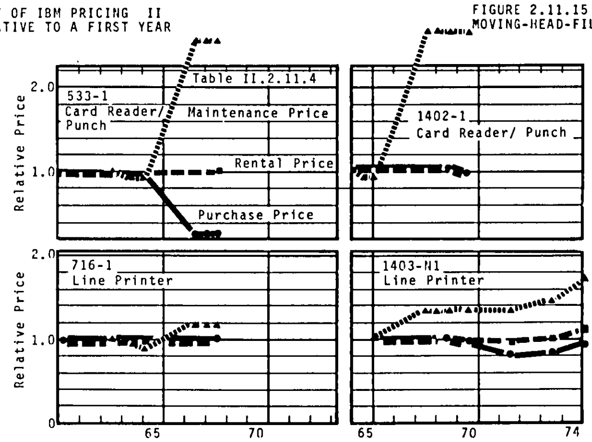



FIGURE 2.11.16 HISTORY OF IBM PRICING IV
UNIT RECORD EQUIPMENT PRICING RELATIVE TO A FIRST YEAR

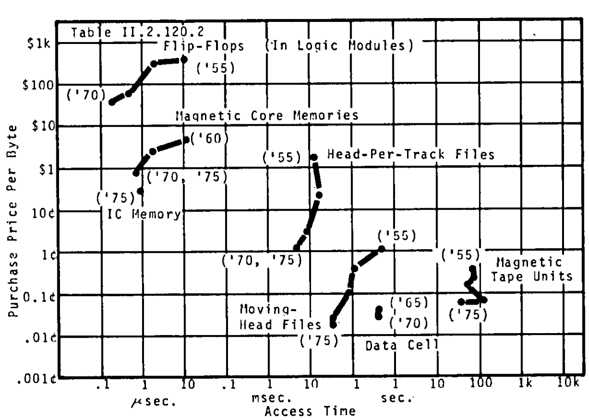



FIGURE 2.120.1 MEMORY TECHNOLOGIES I.
PRICE PER BYTE AND ACCESS TIME

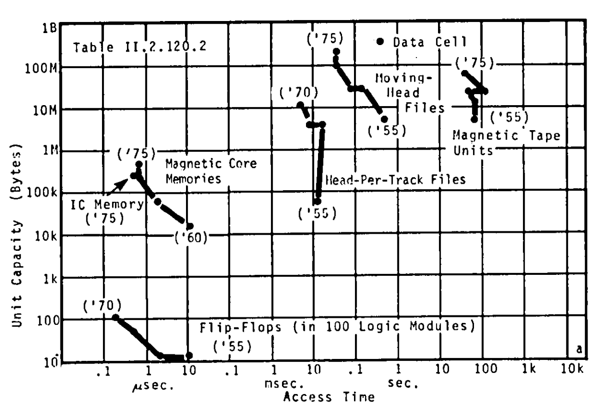



FIGURE 2.120.2 MEMORY TECHNOLOGIES II
MAXIMUM UNIT CAPACITY AND ACCESS TIME

lying in that gap. And in fact the price and capacity gaps are so narrow that a successful new technology cheaper than the core and flip-flop is likely to be as cheap as the head-per-track file—thus supplanting it and simply creating a new gap.

The important properties of input-output equipment are price and data rates, and in Figure 2.120.3 the characteristics of the principal peripherals and terminals are plotted. Each appears as a closed curve on the data-rate/purchase-price plane, with the understanding that most units commercially available in 1975 would appear as points within the appropriate curve. I have not plotted vectors showing trends in performance, as I did in the previous two figures, because, as we shall see later, improvements in I/O technology have not been as striking as those in memory technology. Comments:

1. Different I/O technologies offer a fairly continuous range of performance and price, from ten to a million bytes per second, mostly providing performance in the range $10 to $100 per byte-per-second (2.75 to 0.275 million bytes transferred per rental dollar, if we assume a monthly rental 1/44 of sales price, and that a unit is operated 40 hours per week, 4 1/3 weeks per month).

2. Card punches provide substantially less performance, in cost per unit speed, than do card readers, reflecting the technological problems involved in cutting holes in card stock. Line printer performance generally exceeds that of card punches, and is equivalent to that of card readers at high output rates.

3. The optical character readers really fall into two categories, as indicated by the two-lobe curve. Various specialized readers handling simple, regular documents and limited type fonts (e.g. print tapes from cash registers) lie within the upper, high-performance loop, while generalized page readers able to accomodate a variety of document sizes, formats, and fonts are representative of the lower one.

4. The computer-output-microfilm printer provides by far the fastest data rate, and the best performance in characters per rental dollar. However, the cost and inconvenience of the viewers required to read microfilm have inhibited its widespread acceptance—it is used only in special applications, at relatively few installations compared to line printers. (See Table II.1.22, lines 97-98.)

**Memory Peripherals.**

In Section 1.22 we observed that the principal memory products were moving-head files and magnetic tape units, with head-per-track files running a poor third. Let us now examine each of these technologies in turn.

**Moving-head files.** Moving-head-file technology has improved more spectacularly in the twenty-year history of the industry than has any of the other peripheral equipment technologies. The result has been a sharp decline in the price per kilobyte of on-line storage capacity, as shown in Figure 2.12.1, and a simultaneous but lesser decline in access time, as indicated by Figure 2.12.3. IBM's first moving-head files, the 350 and 355, employed large (24-inch diameter) disks and a single head which was moved automatically from disk to disk as well as from track to track once the proper disk was reached. The mechanism was complicated and expensive and the access time required to move the read-write heads was long, but the cost savings in heads and electronics led to a relatively low cost per kilobyte of $6 to $10, compared to $1000 per kilobyte for head-per-track files (see Figure 2.12.6). The 350 unit employed a recording density of 100 bits per inch on tracks spaced 20 to the inch, for a maximum density, not including the effect of between-record gaps, of 2000 bits per square inch, as shown by the dotted line in Figure 2.12.1. The 1405 units introduced for use with second-generation systems had very similar mechanisms, but achieved a higher effective storage density partly through increases in recording density and partly by a reduction in between-record spacing on the tracks. The result was an increase in storage capacity at little increase in price so that price per kilobyte fell to about $3.

Two important technology improvements were introduced by IBM in the early 1960's. First, with the 1301, additional heads were provided so it was not necessary for the mechanism to move a head from one recording surface to another. The result, as shown in Figure 2.12.3, was a reduction of average access time from 625 ms (for the 1405) to 132 ms. A simultaneous increase in both track and recording density permitted increased capacity, so that the cost per kilobyte remained about the same despite the fact that the mechanism itself cost more. Second, IBM introduced the 1311, and with it the concept of a removeable "disk pack" which could be purchased separately from the moving-head-file unit and which thus provided off-line storage in exactly the same fashion that magnetic tape reels provided storage for tape units. (The per-byte cost of storage on disk packs has, however, always been much higher than the corresponding cost of tape reels—see Figure 2.16.1). Recording density on the 1311 further increased, to 50,000 bits per square inch, but the disk pack was only 14 inches in diameter compared with the 24 inches of the fixed disks in older units. The resulting small capacity and low sales price encouraged its widespread use with small systems, though the per-byte price was substantially higher than that of the 1405 and 1301. In addition, as shown in Figure 2.12.3, access time specifications were relaxed, with the aim of reducing manufacturing costs and increasing unit reliability.

The next steps involved improvements and new products in support of the third generation System 360. The 2311 displayed twice the recording density of the 1311 on the same disk pack, and provided a high-power mechanism which cut average access time to under 100 ms. With the 2314 IBM introduced a double-size disk pack (20 recording surfaces compared to the 10 for the 1311/2311), still another density increase, and a modest improvement in access time. And the increased capacity by now permitted a price of about $1 per kilobyte—down a factor of ten in ten years, during which period access time improved by a factor of seven.

In the seventies, the improvements in density and access time continued, with the introduction of files to support System 370. The 3330 achieved a recording density of 800,000 bits per square inch, and a later version doubled even that. And the 3340 introduced another new concept—a disk pack including read-record heads—which permitted a still higher density.

We have focussed attention on the major IBM units, as indicated by the solid "IBM trend lines" shown in Figures 2.12.1, 2.12.3, and 2.12.4. (The history of the average unit in use is traced by the dashed lines in Figures 2.12.1 and 2.12.2). Three other factors might be noted. The first is that other manufacturers have been followers rather than leaders in this field. They have not had the resources to invest in this technology, and perhaps have not had the wisdom to foresee its importance. All manufacturers had moving-head-file units for sale by the early seventies (some much earlier), but their products have been imitative, not innovative.

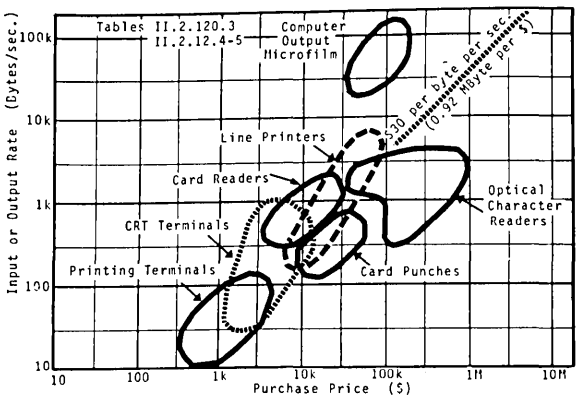



FIGURE 2.120.3 INPUT-OUTPUT TECHNOLOGIES (1975)

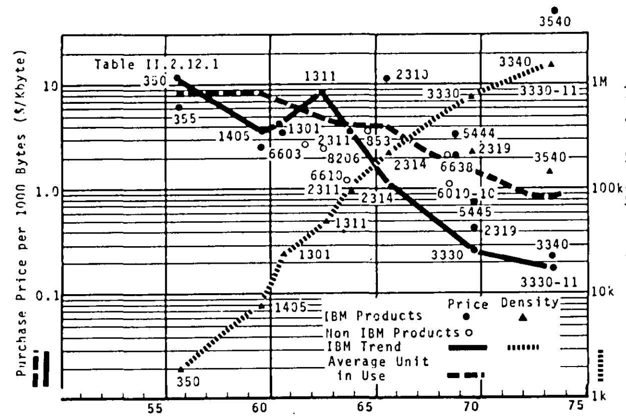



FIGURE 2.12.1 MOVING-HEAD FILES I
A CHRONOLOGY OF PRICE PER KILOBYTE AND STORAGE DENSITY

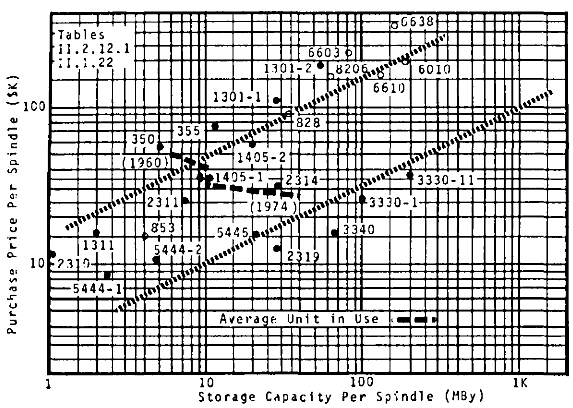



FIGURE 2.12.2 MOVING-HEAD FILES II.
PRICE AND STORAGE CAPACITY

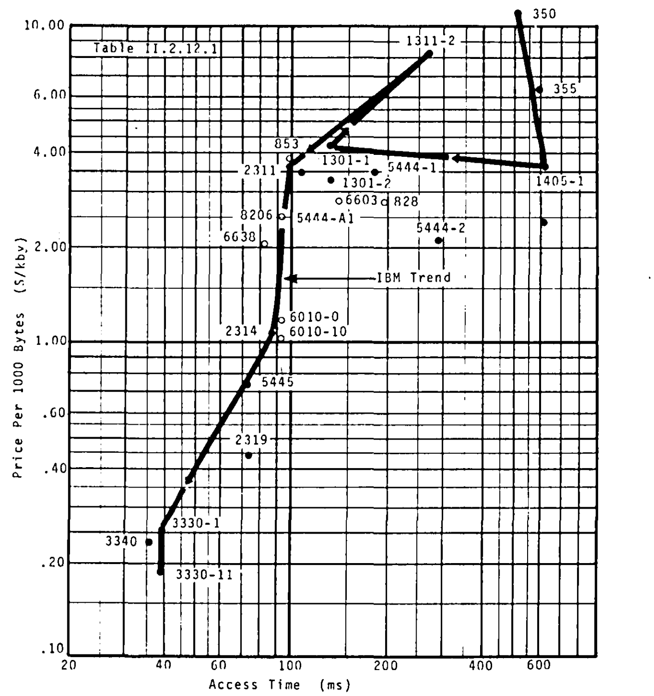



FIGURE 2.12.3 MOVING-HEAD FILES III
PRICE PER BYTE AND ACCESS TIME

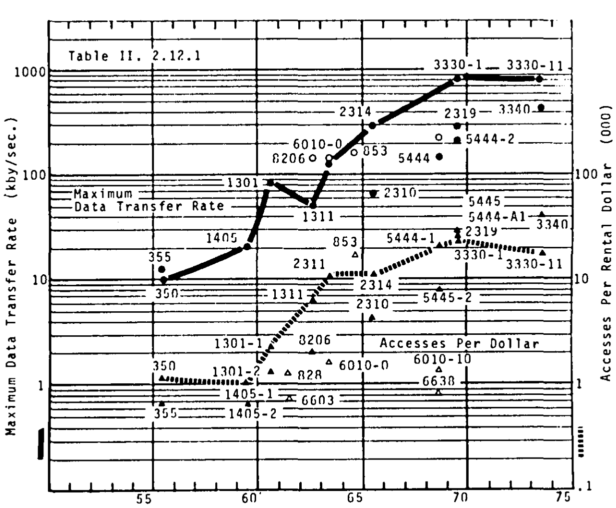



FIGURE 2.12.4 MOVING-HEAD FILES IV
TRANSFER RATE AND ACCESSES PER DOLLAR

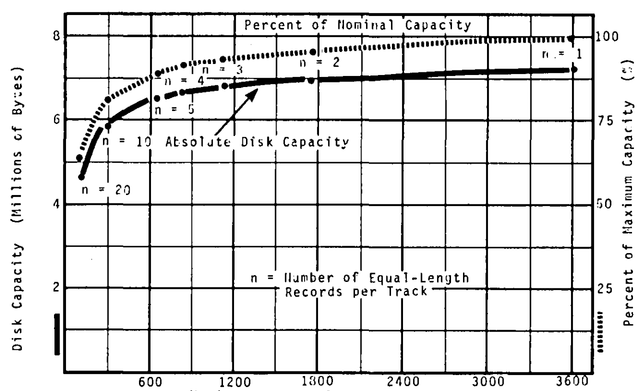



FIGURE 2.12.5 MOVING-HEAD FILES V.
IBM 2311 CAPACITY VS. RECORD SIZE

A second factor is the development of small capacity, low-priced systems to provide cheap storage capacity for small systems. The 5444 family of machines for the IBM System 3 provided capacities in the range of 2.5 to 5 million bytes, and the still newer "floppy disk" technology (where the storage medium is a flexible plastic platter with a magnetic coating), as represented by the IBM 3540, is even smaller and cheaper.

The third factor of interest is indicated by the dotted lines in Figure 2.12.2: moving-head-files obey a sort of "Grosch's Law" in the sense that a doubling in price paid more than doubles the storage capacity purchased. Both dotted lines express a square-law relationship between the variables—a doubling of price gives a quadrupling in capacity. The upper line is intended to approximate second-generation technology as exemplified by IBM's 1405's, 1301's, and 1311. The lower line approximates fourth-generation equipment: the IBM 5444's, 5445, 3330's, and 3340. Though we might quibble about the exponent used (second- generation systems would be better matched with an exponent less than two, fourth-generation systems with an exponent greater than two), it seems clear that the relationship is non-linear.

Though storage capacity, cost per byte, and access time are the principal performance measures for moving-head files, there are others which might be noted. Two of these are plotted in Figure 2.12.4. As radial head motion was sped up to reduce access time, the delay involved in waiting for a selected record to rotate into position under the head became more important, and consequently the rotational speed of the disks was increased. This together with increases in the number of bits per inch recorded along the disk surface has resulted in a great increase in the rate with which data is transmitted from and to the disk— from 10,000 bytes per second for the IBM 350 to nearly a million for the IBM 3330. And as access time has fallen, the number of accesses per rental dollar have increased by more than a factor of ten.

Finally, we must keep in mind that the data presented here on unit capacity and cost per byte is based on figures for *maximum* capacity. Actual capacity is generally a function of the way a unit is used, and of the flexibility in data layout permitted by unit specifications. Many early units required that data be stored in records of fixed length, so that if some specific application required smaller or longer records, programmers had to rearrange data into standard length records before storing them away. With newer units, variable length records are permitted. However, unit capacity is always quoted assumimg that the longest possible record is employed, and if the user elects to use shorter records, unit storage capacity is correspondingly reduced. These effects are shown in Figure 2.12.5.

**Head-per-track files.** The same improvements in recording density which reduced the cost per byte of moving-head files were applied to head-per-track files, with the result shown in Figure 2.12.6. The magnetic read-record heads and circuits represent a major portion of the cost of the memory, and as the number of bytes per head increased, the cost per byte fell. As is indicated in Figure 2.12.7, the reduction in per-byte cost was generally accomplished by increasing file capacity at a given price. Access time is determined by rotational speed, and mechanical considerations limit that speed to 10,000 revolutions per minute or less, so access time improvements have not been spectacular—see Figure 2.12.8. It is possible to reduce access time at a given rotational speed by supplying two or more heads per track, and then automatically choosing the head nearest the selected record, when a read or unit operation is required. The IBM 2305-1 employs that approach, but the additional heads required add substantially to per-byte costs. Accesses per rental dollar are shown by the dotted line in Figure 2.12.9.

Data transfer rates fundamentally are the quotient of bits per track and the time required for a rotation. However, designers have for various reasons reduced actual transfer rates by interleaving (reading or writing alternate records on a track), or have increased the rates by handling data in parallel (reading or writing in several tracks simultaneously). The range in transfer rates is indicated in Figure 2.12.9.

Where IBM has clearly been the leader in moving-head file technology, Burroughs has lead with head- per-track files. The Burroughs 475 was roughly contemporary with IBM's 1311 and 2311 *moving-head* files, and provided a comparable price per byte with a much better access time. And though Burroughs' head-per-track files have not been able to match price-per-byte of more recent moving-head files, they still compete favorably even with IBM's 2305's. Incidentally, note once again the non-linear relationship between price and capacity. The dotted line in Figure 2.12.7 shows that the Burroughs 9370's and 9372 roughly obey a square-law relationship. So also do the Univac 6015/6016, and the IBM 7320/2301.

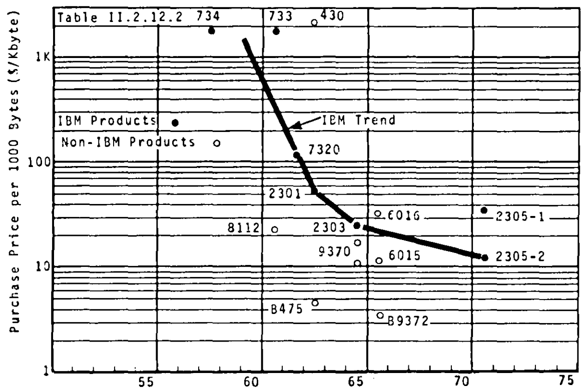



FIGURE 2.12.6 HEAD-PER-TRACK FILES I
CHRONOLOGY OF PRICE PER KILOBYTE

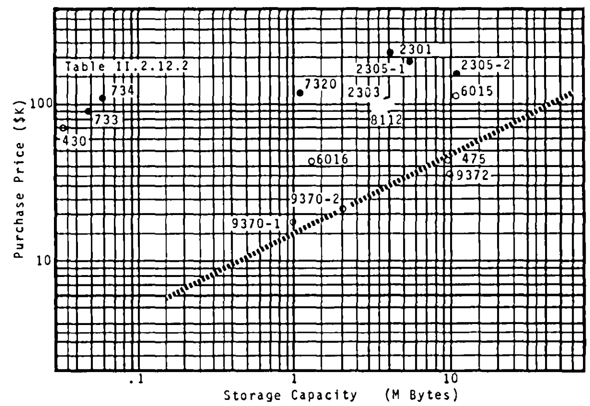



FIGURE 2.12.7 HEAD-PER-TRACK FILES II
PRICE AND STORAGE CAPACITY

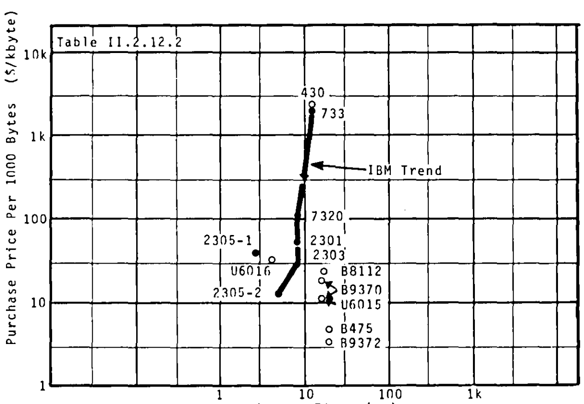



FIGURE 2.12.8 HEAD-PER-TRACK FILES III
PRICE PER BYTE AND ACCESS TIME

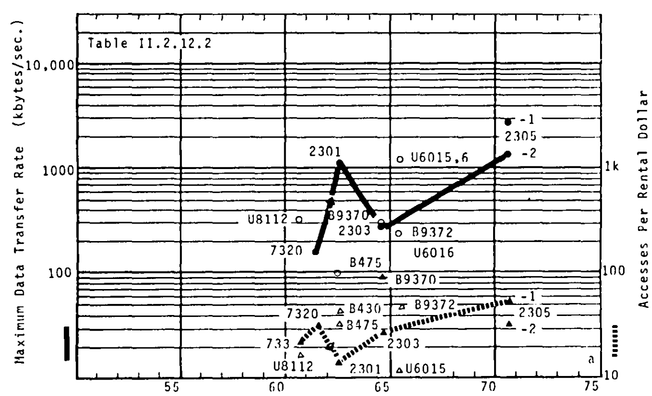



FIGURE 2.12.9 HEAD-PER-TRACK FILES IV
TRANSFER RATE AND ACCESSES PER DOLLAR

**Magnetic tape units.** Magnetic tape was recognized at a very early date to be potentially an excellent technology for mass storage, and most manufacturers introduced products which stored data on long thin ribbons of various materials and dimensions. However, IBM's success in producing and marketing systems put other manufacturers in a dilemma. Since most GP systems in use were (and still are) manufactured by IBM, competitors found themselves frequently selling to companies which already were using IBM equipment, including tape units. Such customers quite reasonably wanted to be able to transfer data from one system to another on some machine-readable media. The IBM punched card was from the first adopted as one standard medium for data transfer (though Univac used a different "standard"), but it was inconvenient—the cards themselves bulky, and card readers and punches slow and relatively unreliable. The other systems manufacturers were thus forced, for competitive reasons, to adopt the IBM tape as a standard, and to develop tape handlers which could read tapes written by IBM systems, and write tapes which IBM systems could read.

The characteristics of the principal tape units are recorded in Figures 2.12.10 to 2.12.14. Price per byte and recording density appear in the first of these figures, where the price and density of the leading IBM units are traced by solid and dotted lines, respectively, while the price of the average unit in use is shown as a dashed line. The early Univac I and Burroughs 548 units were of course not compatible with the IBM 727, which they preceded, and as late as 1962 Univac still employed non-compatible units (the Univac III tape). But subsequent development has followed IBM's lead. Various standard recording densities have evolved, starting with 100 bits per inch along the tape length and progressing through 556, 800, 1600, and 6250. Density across the one-half inch wide tape has remained fairly constant—first- and second-generation systems recorded seven tracks across the tape, and later systems nine, as the eight-bit (plus parity bit) byte became the standard way to store alphanumeric data. (Here again the industry followed IBM's lead.) Note that average on-line price per byte stored has dropped from about $3.50 to $1.50, and that the improvement has come about basically because average tape capacity has more than tripled, while average tape unit cost has remained fairly steady (Figure 2.12.11).

Maximum data transfer rate is the product of the tape speed, in inches per second, and maximum character density, in bytes per inch. Figure 2.12.12 shows how this performance factor has improved with time, and Figure 2.12.13 indicates that maximum character rate (rather than maximum capacity, which is a simple function of tape density) tends to vary in a square-law fashion with price. The upper dotted line in Figure 2.12.13 indicates such a relationship between the early IBM 727, 7330, 729-2, 729-4, 729-5, 729-6, and 7340. The lower dotted line represents the more recent IBM 3410-1, 3410-3, 3420-3, and 3420-9.

Finally, the relationship between tape reel capacity and record length is shown in Figure 2.12.13 for a variety of tape formats. The key parameters are tape density and the length of the inter-record gap, and the characteristics of units from an early Univac tape (250 bits per inch, 1.05 inch gap) to the latest IBM technology (6250 bpi, 0.3 inch gap) are indicated. For each, a black dot indicates the record length for which the tape is half as full as if it would be if there were a single record as long as the tape. Note that, for the new high-density IBM tape, the 1000-byte records which serve as a basis for our price-per-byte calculations limit capacity to only about one-third of maximum.

**Comparing Memory Technologies.** Before turning to a review of the evolution of card equipment and printers, it is useful to compare the three memory technologies directly. Looking first at Figures 2.12.1, 2.12.6, and 2.12.10, we observe that improvements in recording density, and hence price per byte, have been much greater in rotating memory than in tape technology. We also confirm, as we noticed in Figure 2.120.1, that moving-head file technology, originally much more costly per byte than tape technology, overtook the latter in the mid-sixties to provide the cheapest way of storing data on-line. Head-per-track memories run a poor third in price. In looking at Figures 2.12.2, 2.12.7, and 2.12.11, we are reminded that rotating memory technology has frequently been characterized by very large, very expensive (over $100,000) units, while most tape units have always sold for under $50,000. The fact that small systems need bulk memory has caused rotating memory developers to provide the smaller units which are, any given level of technology, more costly per byte than a big device would be.

Figures 2.12.3 and 2.12.8 contrast the substantial access-time improvements which have occurred in moving-head file technology with the much smaller ones in head-per-track files. (The "access time" to data on a magnetic tape unit can be regarded as the time necessary for the tape to move half its length at read-write or at rewind speed. That time has varied from thirty seconds to twelve minutes, with no particular trend apparent.) Finally, a comparison of Figures 2.12.4, 2.12.9, and 2.12.12 remind us again that improvements in moving-head files have outstripped those of the older technologies.

In concluding this section, it seems worth re-emphasizing that peripheral memory technology obeys a sort of Grosch's Law, just as does system technology in general. The dotted lines in Figures 2.12.2, 2.12.7, and 2.12.13 each have slopes of one-half (indicating that an improvement in performance by a factor of 100 requires a price increase of only a factor of 10) and each fit, at least moderately well, a set of points representing a group of devices available at a given time. In part this price-performance relationship reflects the fact that real costs are non-linear functions of performance—a high-data-rate magnetic tape unit, for example, may require a more complex read-write head and a faster drive motor than does a low-data-rate unit, but most other parts and assemblies will be very similar for the two units. In part the non-linearities come about simply as a result of pricing policy. To keep development and service costs low, and to achieve uniformity in its manufacturing operations, a company may use one unit, with minor modifications, to cover a performance range. The *cost* difference between low- and high-performance units is thus negligible, and prices are set to cover the cost of the simple unit and to encourage users to purchase or rent the more complex ones.

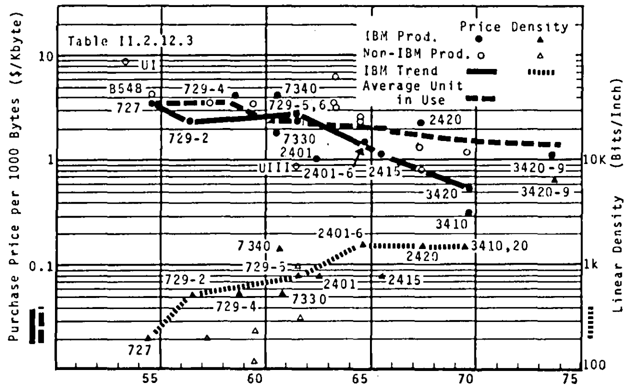



FIGURE 2.12.10 MAGNETIC TAPE UNITS I
CHRONOLOGY OF PRICE AND STORAGE DENSITY

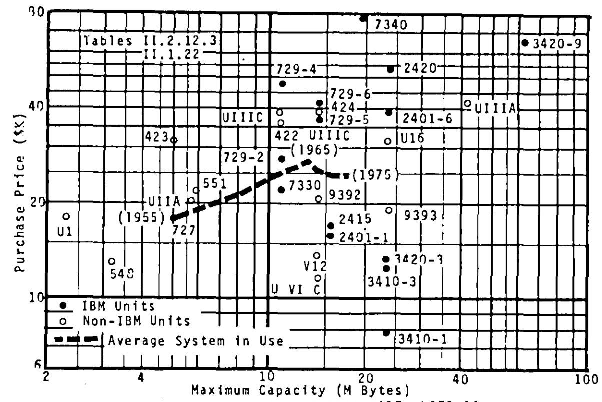



FIGURE 2.12.11 MAGNETIC TAPE UNITS II
PRICE AND STORAGE CAPACITY

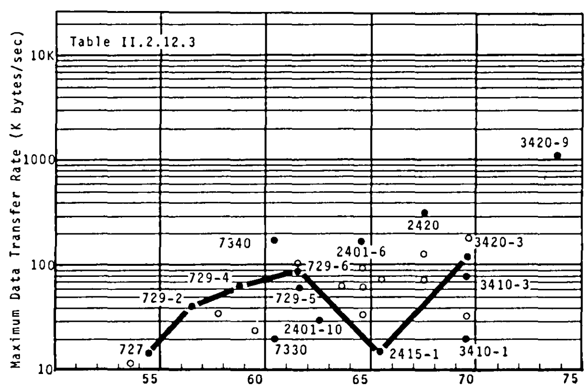



FIGURE 2.12.12 MAGNETIC TAPE UNITS III
CHRONOLOGY OF DATA TRANSFER RATES

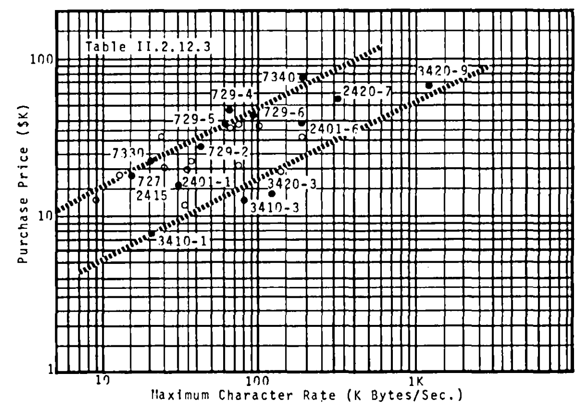



FIGURE 2.12.13 MAGNETIC TAPE UNITS IV
PRICE AND DATA TRANSFER RATES

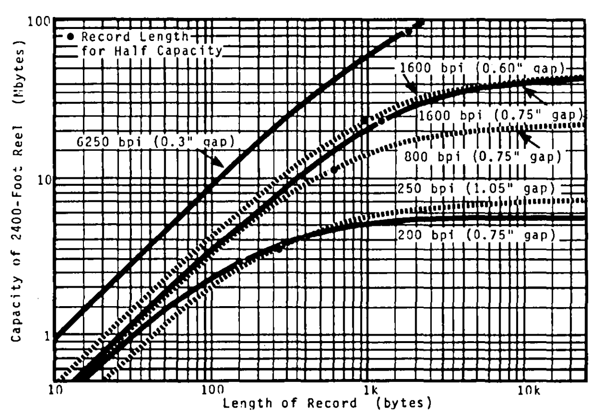



FIGURE 2.12.14 MAGNETIC TAPE UNITS V
STORAGE CAPACITY VS. RECORD SIZE

**Unit Record Equipment.**

**Line Printers.** The improvements in unit record equipment have not been nearly as spectacular as those which have occurred in the memory peripherals. Early printers employed a type bar or wheel in each print position. Each such printing element was independently moved until it presented the desired character to the printing surface. When all elements were in position, they were driven into the print ribbon and paper, and printing occurred. To increase printer speed, designers first turned to a continuously rotating drum whose axis was parallel to the lines on which data was to be printed. The character set to be printed was embossed around the circumference of the drum, repeated as many times along its axis as there were print positions. Opposite each such print position was an independently-driven print hammer, and during one revolution of the drum each hammer was activated at the instant that the proper character was opposite the hammer. Print ribbon and paper were positioned between hammer and drum, and print quality was affected by the length of time the hammer pressed the paper against the (moving) drum, and by the relative impact instants of the different hammers, which determined how straight the line of printing was on the paper.

More recently chain or train printers have been used, in which a character set is embossed on a strip which moves parallel to the line to be printed. Once again there must be a hammer for each print position, and the independently-driven hammers must be activated at the proper time as the chain or train is pulled past the paper.

These various changes have led to modest improvements in printing speed while prices have remained in a relatively narrow range, with the result that performance per dollar has improved. Line printer performance in output characters per rental dollar (assuming that each line printed is full of data and that the printer operates at full capacity 40 hours per week) has improved by a factor of about ten from the 1950's vintage IBM 407 to the 3211, as is shown in Figure 2.12.15. Much of the improvement has come about through increases in printing speed—the 3211 is almost 15 times as fast as the 407, but only cost 36% more, as is indicated in Figure 2.12.16. But the same figure shows that improvements have also come about through design changes which made lower prices possible. The IBM 1403, introduced in about 1960, was comparable in speed to the 720 at one-third the price. Once again the dotted lines show the nearly square-law relationship between price and speed. The upper line follows the performance of early printers— the IBM 370, 407, 716, and 720—and the lower one approximates the performance of the later 5203's, 1403's, and 2311.

Just as moving-head file and tape unit capacities (and data rates) are influenced by the layout of data on the media, so is printer speed a function of various printer operating parameters. The effective capacity of the IBM 1403 printer, for example, is a function of the type-chain used, the block (or page) size, the number of lines actually printed per block, and the printing density in lines per inch. The effect of these factors on printer speed is shown in Figure 2.12.17, for the 600- and 1100-line-per-minute (lpm) versions of this printer. Highest operating speeds are achieved when a numeric-only print chain is mounted on the 600 lpm unit, print density is set at eight lines per inch, and large blocks (66 lines in this example) are printed. When data is printed on every line of the block, printer speed is 1285 lines per minute. As the number of lines printed per page falls off, so does the effective printing speed—with half a page printed (33 printed lines followed by 33 blank lines) the speed drops to 1223 lpm, with 10% of the lines printed, speed drops to 922 lpm.

The speed of the 600- and 1100-lpm units printing both numeric and alphabetic characters falls off in a similar fashion with the number of lines printed per block. The figure also shows the effects of changing print density and of printing small blocks. The differences come about because of the printer's ability to slew—that is, to move print paper very rapidly past lines where no data is to be printed. If it were not for this slewing capability, effective speed would drop much faster with the percentage of lines printed per block: with 50% of lines printed, printing speed would be 50% of maximum instead of the 95% shown on the graph. But in addition slewing is more effective at the 8 line-per-inch density than at 6 lpi, for the mechanism slews paper at a fixed speed in inches per second, and thus bypasses more lines per second at high density than at low. And finally, the actual printing speed at a given density and lines-per-block is lower for small blocks than for large blocks because the printer has two slewing speeds depending on how many lines are to be passed. Thus for example if 13 lines are to be printed and then 53 passed (20% of a large 66-line block), the effective print rate will be 554 lpm for the 600 lpm printer operated at 8 lines per inch. But if we are printing one line and then skipping four (20% of a small 5-line block) on some small document or form, the printer can only slew at the slow rate and the effective printing speed is 521 lines per minute.

Printer performance is thus a very complex matter. Its complexity is even greater when one takes into account other matters not treated here, which nevertheless strongly influence system performance. One such factor is the degree of buffering in the printer controller, which helps determine how much time the processor spends servicing the printer. Another is the number of characters printed per line. I have found no statistics available on this parameter, which is exceedingly important because systems are often input-output limited (see Section 2.23) and it is *characters*, not lines, which must be printed. A final factor is the cost of printing paper (see Section 2.16). Printing density (lines per inch, characters printed per line, and lines printed per block or page) is a major factor in paper cost, and as we saw, (Figure 1.27.2), it costs more to provide paper for a printer than to rent the printer itself.

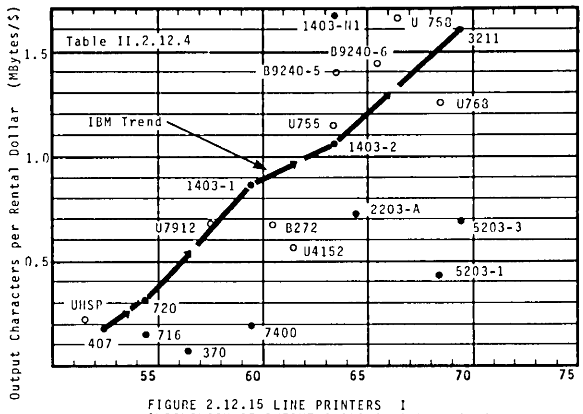



FIGURE 2.12.15 LINE PRINTERS I
CHRONOLOGY OF OUTPUT CHARACTERS PER DOLLAR

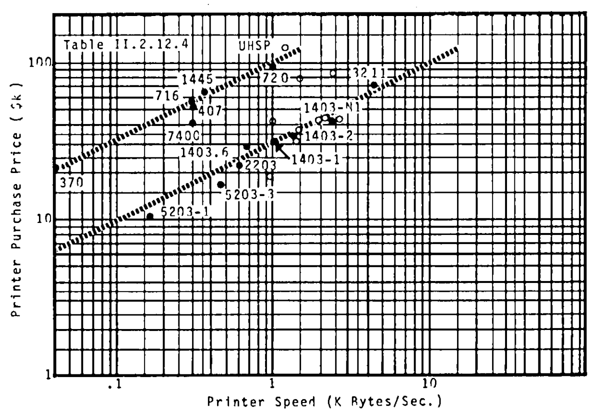



FIGURE 2.12.16 LINE PRINTERS II
PRINTER SPEED VS. PURCHASE PRICE

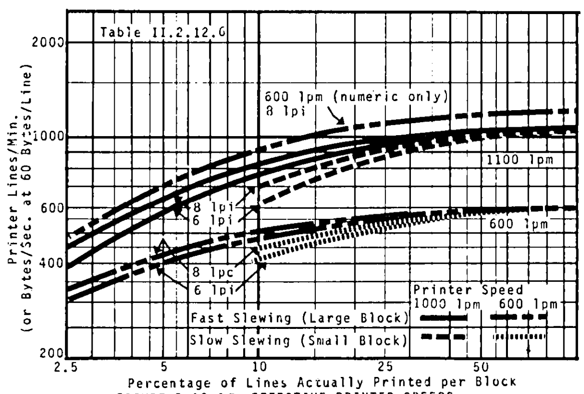



FIGURE 2.12.17 EFFECTIVE PRINTER SPEEDS
THE EFFECT OF LINE SKIPPING ON THE IBM 1403

**Card Readers and Punches.** Card equipment performance has changed less than that of any of the peripherals. The card punch mechanism has changed hardly at all, and the principal change in card reader technology has been the substitution of photoelectric hole-sensing equipment for the original wire brush which made an electrical contact through the card hole. Maximum reader speed has increased from 200 to 1200 cards per minute (cpm) and maximum punch speed from 100 to 500 cpm. The number of characters read or punched per rental dollar (assuming each card contains its full allotment of characters, and using the nominal operating speed in cpm) has improved by a factor of perhaps ten for card readers and two for card punches, as shown in Figure 2.12.18 A similar measure for the card reader/punch, based on the sum of reading and punching speed, has improved by a factor of three as shown in Figure 2.12.19. Plots of unit speed versus purchase price show a tendency toward the square-law effect we have seen in other peripherals. In Figure 2.12.20 the lower dotted line indicates that the Burroughs 911X card readers might have been priced with Grosch's Law in mind. The IBM 543, 7500, and 3505 readers similarly lie near a square-law line, though the IBM 711 and 2501 represent major discrepancies. Another square-law line is shown for IBM punches, but while it is perhaps reasonable in approximating a relationship between the units shown, it fails for various pairs of units which were simultaneously available, like the 323 and the 7550, or the 3525-P1 and the 3525-P3. It is even more difficult to attempt to apply a square-law formula to the reader-punch units shown in Figure 2.12.21.

There are various reasons for the seeming anomalies and inconsistencies in card equipment price and performance given in Figures 2.12.20 and 2.12.21. One explanation has to do with whether a user must buy a controller in addition to the basic unit. Comparing the three 96-character IBM reader-punches shown in Figure 2.12.21 (the two 5424's and the 2596), we find the 5424-A1 and -A2 require controllers costing $4200 and $5325 respectively, while the 2596 requires no extra equipment. In Figure 2.12.20 the Burroughs 91XX readers each require a $2590 controller. Table II.2.12.5 provides some information about the need for and cost of controllers, but the subject is complex–the 7603-1 controller required for the 7500-1 reader, for example, can be shared with a card punch or line printer, so not all of its cost should be ascribed to the reader.

Another reason for the inconsistencies has to do with performance differences which don't appear on the figures. One example is given in Figure 2.12.21: the user pays a premium price for the IBM 2520-B1 because that unit contains a 500 cpm card punch and it has proven to be expensive to achieve that speed. A second example has to do with the time it takes a reader or punch to start a read or punch cycle, once the processor requests an input or output. The actual operating speed of three units is shown in Figure 2.12.22 as functions of the computation time required per card. For short computation times, the three units operate at their rated speeds of 1333, 1067, and 400 bytes per second. The 2501-B2 reader is driven by a clutch which can engage at only one point in its 60 ms cycle. If the processor is able to initiate a new card-read cycle every 60 ms or less, the reader operates at its rated speed of 1333 bytes per second (1000 cards per minute). If it takes more than 60 ms but less than 120 ms for the processor to initiate a new read cycle, the reader speed falls by 50% to 667 bytes per second, for once a clutch cycle is missed, the reader must wait an entire clutch revolution before reading another card. The 3525-P3 punch, on the other hand, has four clutch points, and therefore, if the processor can't respond in its 200 ms cycle time but does respond in less than a quarter of a clutch revolution later (i.e. 50 ms later), punch speed only falls off by 20%, from 400 to 320 bytes per second. Finally, the 3505-B1 card reader has no clutch at all, and is able to start a new read cycle almost immediately whenever the processor issues a command. Card reading speed thus falls off continuously, rather than in discrete steps, as shown by the dotted line in Figure 2.12.22, and the performance of the 3505 exceeds that of the nominally faster 2501 if the processor cycle time is greater than 60 ms. This somewhat difficult-to-explain aspect of performance, then is a factor which contributes to the relatively high cost of the 3505 compared to the 2501, as shown in Figure 2.12.20.

## 2.13 DATA ENTRY EQUIPMENT

As we shall see in Chapter 3, the performance of a keyboard data entry system is limited by the physiological factors which constrain a human's ability to move his fingers in transcribing what his eye sees. An obvious solution to this problem is to replace the humans by automatic character-reading equipment. But designers have been unable to invent low-cost equipment capable of handling the variety of document types and of reading the variety of type fonts and handwritten characters the human handles and reads with ease. So character-reading equipment has always been expensive, (see Figure 2.120.3, and compare optical character readers with "printing terminals", which are roughly comparable to keyboard data entry devices), and is useful only in carefully-devised, high-data-volume applications.

IBM and Remington Rand (later Sperry Rand) were marketing card punching keyboard-operated devices for use with electromechanical data processing equipment before the fifties, and these devices were used, unchanged, to prepare cards which supplied data to the new computers. The designers of Univac tried something new: the Unityper recorded, on Univac-compatible magnetic tapes, data entered directly from a keyboard. But with early electronic technology it was prohibitively expensive to write large blocks of data on the tape. Tape recording density was thus low, and it was not economically feasible to design a key-to-tape device which would produce tapes compatible with what became the industry standard. Unityper faded, a product ahead of its time.

Data entry technology thus stood still until 1955, when Mohawk Data Sciences introduced the 1100, a key-to-tape device whose output was IBM-compatible magnetic tape. Though this device was much more expensive than the keypunch it supplanted (see Figure 2.13.1), it provided features and flexibility which permitted improvements in operator productivity, and was a resounding commercial success. The continuing drop in electronics costs has since made it possible for vendors to compete in the marketplace with minicomputer-based systems which servive many keyboards simultaneously and collect input characters on IBM-compatible disk packs, eliminating the tape merging operations necessary with key-to-tape systems. These key-to-disk systems, the first of which was Computer Machinery Corporation's CMC-9, were also successful. And in 1970 IBM finally introduced a new keypunch–the 129–which provided a critical feature the key-to-tape and -disk manufacturers were in effect supplying: local buffering (storage) of the current input record, which permitted the operator to correct a mistake on entry before the card was punched, and also reduced or eliminated the delay due to card-feed time between records. Finally, IBM's 3742, introduced in the U.S. in 1974, made it possible to record input data on a new medium—the floppy disk.

In summary, it appears that improvements in data entry equipment have come slowly as designers have found ways to improve, only slightly, the efficiency of keypunch operators. The result is that data entry costs have been increasing (with increased salary costs) as computational costs have fallen (see Figures 3.21.4 and 3.25.14).

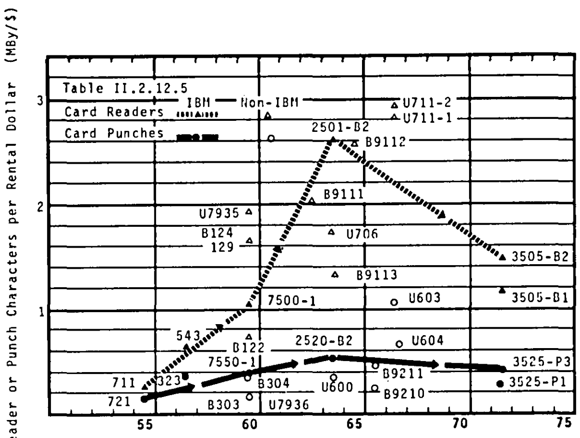



FIGURE 2.12.18 PUNCHED-CARD EQUIPMENT I
CHRONOLOGY OF INPUT-OUTPUT CHARACTERS PER DOLLAR

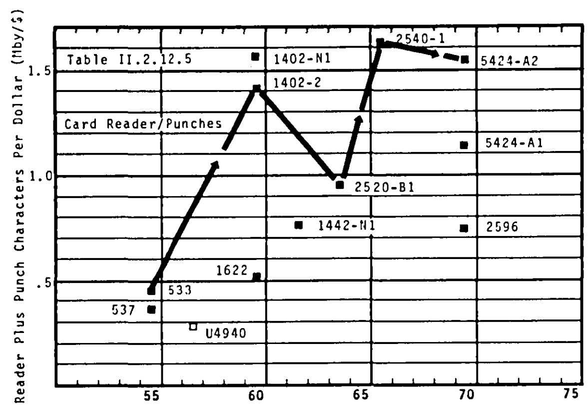



FIGURE 2.12.19 PUNCHED CARD EQUIPMENT II
CHRONOLOGY OF INPUT-OUTPUT CHARACTERS PER DOLLAR

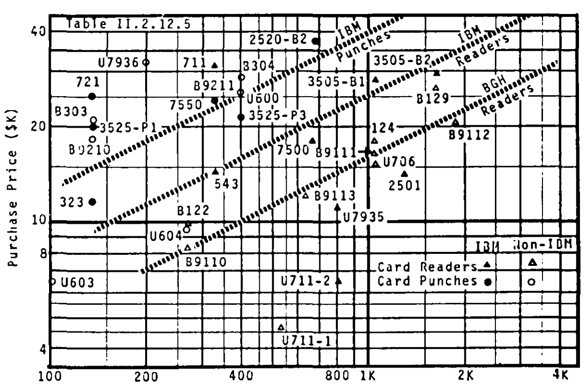



FIGURE 2.12.20 PUNCHED CARD EQUIPMENT III
CARD READER/PUNCH SPEED VS. PURCHASE PRICE

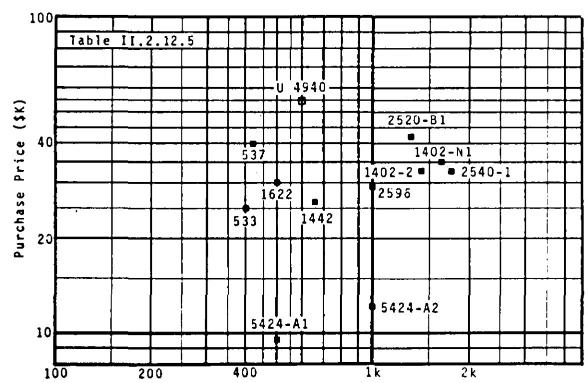



FIGURE 2.12.21 PUNCHED CARD EQUIPMENT IV
READER SPEED PLUS PUNCH SPEED VS. PURCHASE PRICE

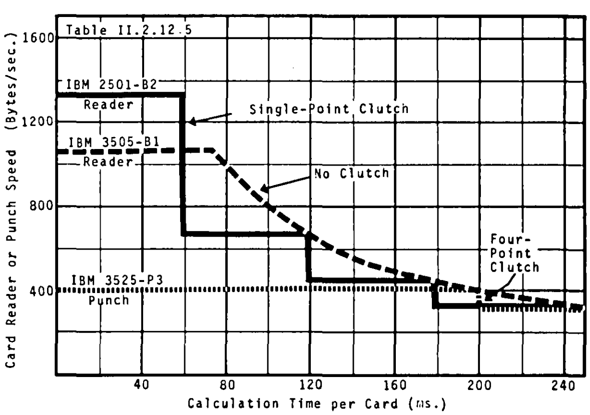



FIGURE 2.12.22 PUNCHED CARD EQUIPMENT V
EFFECT OF CLUTCH OPERATIONS ON OPERATING SPEED

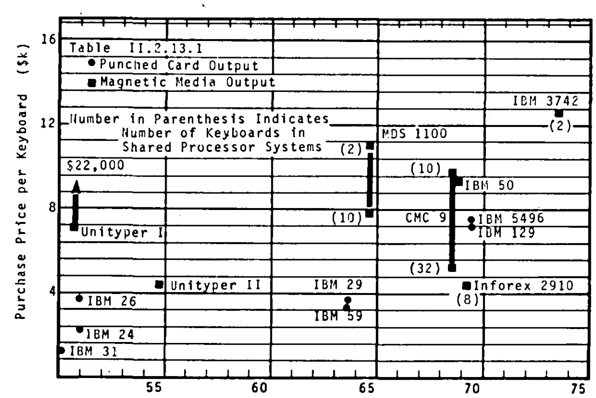



FIGURE 2.13.1 KEYBOARD DATA ENTRY UNITS
CHRONOLOGY OF PRICE PER KEYBOARD

## 2.14 DATA COMMUNICATIONS

The transfer of data from one location to another may be accomplished in a variety of ways—Table 3.0.1, in the next chapter, gives examples of the communication channels which are available. But most practical data communication in the United States makes use either of the telephone system or of the postal service. And because many computer applications require short delays in transmitting from place to place, wire communication is in many ways the more important of the two.

### Telephonic Data Communications

The earliest digital system to be tied to a telephone line was Bell Laboratories' early relay calculator, and the second probably was the SAGE air defense system. These early systems made use of transmission circuits which the communication common carriers (the telephone companies and Western Union) had established to provide telegraph service to users. However, the carriers were confident that there was a market for higher-speed facilities for use in transmitting data between computers, or between terminals and computers, and in 1962 AT&T first offered a combination of communications lines and interface equipment which permitted data transmission at 1200 to 2400 bits per second. These services made ingenious use of the existing telephone networks, which were of course designed to transmit voice communications. At each end of the line, digital signals were converted by devices known as data sets (sometimes called modems), into signals having properties suitable for transmission over voice channels. From that point on the telephone system treated data transmissions as if they were voice conversations, and at the other end of the line a second modem retrieved the digital message from the audio signals. In the mid-sixties additional facilities of this same kind permitted data transmission at rates up to almost 250,000 bits per second.

As one might expect, it is inefficient to use a voice network for the transmission of data, and by 1975 the telephone companies and a number of new companies known as specialized carriers began to offer services via equipment specially designed to handle digital data. AT&T's service, offered in a limited number of cities starting in December, 1974, was known as DATAPHONE ® Digital Service, and included facilities for transmitting data at 2400, 4800, 9600, and 56,000 bits per second. (DATAPHONE ® is a Service Mark of AT&T, and the service is popularly known as DDS.)

The data communication facilities provided are of two kinds: lines, and terminations. Lines are the transmission paths and circuits which connect one location to another; terminations are the special circuits needed at each end of the line to translate binary signals from the user's equipment into the kind of signal compatible with the circuits employed in the line. The terminations include data sets and line conditioning circuits. Monthly line costs are a function of line lengths and of the time the line is used. Monthly termination costs generally depend on the data rate handled. There is usually a one-time installation charge to be paid for installation of either a line or a termination. Neither the cost of the user's terminals, which serve as human-oriented input-output devices containing such things as keyboards, printers, displays, and card readers, nor the cost of the user's computer- communication interface is included in this discussion.

Looking first at lines, we find two offerings: private lines, and lines supplied via the dialed telephone network. Private lines are leased by the month, are usable full time, require payment of an installation charge, and of course connect two fixed designated points. Lines supplied via the switched network, often called Direct-Dial or DD circuits (not to be confused with DDS—DATAPHONE ® Digital Service), are used and paid for by the minute, and of course may connect any two points in the network any time a connection is established. Voice grade private lines and DD circuits are available between any two points in the U.S. The DDS system currently (1976) is available in a limited number of cities, and only as a private line service; AT&T does not yet make possible a switched connection via an all-digital system, though some specialized common carriers do.

The telephone companies' ability to handle increasingly higher and higher data rates has permitted remarkable reductions in data transmission costs over private lines, as is illustrated in Figure 2.14.1. Here we show the monthly system cost, including lines, data sets, and terminations for a 300-mile private line, divided by the number of bits which can be transmitted over that line in a month of 24-hour days. In the fifties the only available lines handled 75 or 100 words per minute, at a cost of about $2.00 per million bits. The higher-speed systems made available in the early sixties required larger monthly payments, but provided even larger capacities so the cost per million bits transmitted fell as low as ten cents. And then in the mid-sixties wide-band facilities became available which further reduced the cost to about one cent per million bits. The solid line follows the two-order-of-magnitude drop in system costs. However, the private line cost of a user with a minimum requirement for data transmission has changed very little over the twenty-year period, as shown by the dotted line in the figure; the 300-mile private line available today at lowest monthly cost has a capacity of 150 bits per second (almost 400 million bits per month) for a cost of about $1.35 per million bits, more than half the cost of the earlier 75 wpm circuit. Note that the three high-speed systems introduced in 1966, and the DDS system as well, are full-duplex systems—i.e. they permit simultaneous transmission in two directions. The other circuits are half-duplex, in which transmission is possible in both directions, but not simultaneously. Full-duplex lines typically cost 10% more than half-duplex lines.

If one has relatively few characters to transmit per month, it is cheaper to dial up a line whenever one has data to transmit than it is to hire a private line. However, as ones transmission requirements increase, there comes a point where the cost of the DD line equals that of the private line; for higher monthly data transmitting capacities, it will be cheaper to have the private line. This situation is illustrated in Figures 2.14.2 and 2.14.3, which show the monthly cost of interstate lines plotted against line usage in minutes per month. (Here we look at line costs only, and do not include termination costs.) The first of these figures shows the break-even points for 300-mile circuits under a variety of circumstances. The slanting, solid lines show the cost of dialed calls, which is of course proportional to the time the lines are used. The graph shows a range of costs, depending on how and when the calls are dialed. The most expensive usage would be calls placed during weekdays, where each call is only of one minute duration. If each call is long (ten minutes or more), the cost is given by the next solid line. Calls of intermediate length would have monthly costs lying between these two lines. The cheapest dialed rates are for night calls (originated between 11pm and 8am daily), as indicated by the other two solid lines.

The horizontal dotted lines in Figure 2.14.2 represent the fixed costs of private lines, and three different tariffs are illustrated. Voice grade lines are available under the "high-low" tariff: over 350 major cities are identified as "high-density" areas, and voice grade lines connecting such cities are relatively cheap; other cities are regarded as "low-density", and users must pay more for private lines connecting them. (However, two low-density cities can also be connected by linking each to a high-density city via low-density lines, and then linking the high-density cities with a low cost line.) The breakeven points, at which the costs of private and dialed lines are equal, appear as dots in the figure. Their locations depend on the duration and time of the dialed calls, and also on whether the cities involved are designated high or low density. The graph also shows the cost of a DDS private line operating at 4800 bits per second. However, as mentioned before, this service is available only in a restricted list of major cities. Furthermore, whereas the voice grade line costs the same no matter what bit rate it handles, the DDS charges vary with bit rate, so the breakeven situation is much more complicated than is indicated by this figure. Note that there is a wide range of breakeven times, from about 800 minutes (13 hours) per month for short day calls between high-density cities to some 7200 minutes (120 hours) for long night calls between small cities.

The breakeven point varies as a function of the length of the line as illustrated in Figure 2.14.3. Here we show the costs for high-density private lines, with DD costs based on long calls at day rates, and vary line length from 30 to 3000 miles. The breakeven points (solid dots connected by dashed lines) vary from about 1000 to 7500 minutes per month. The corresponding breakeven points for lines connecting *low-density* cities are shown as open dots connected by dotted lines. The breakeven times for low-density cities are generally higher than for high-density cities. Note that private line costs increase more rapidly with distance than do dialed line costs, with the result that the breakeven point occurs at higher values of line usage as mileage increases.

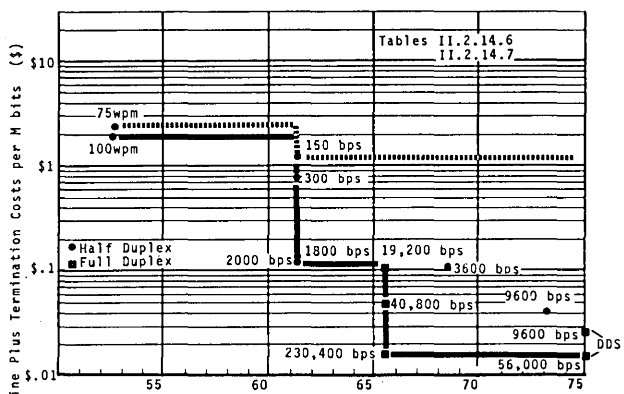



FIGURE 2.14.1 COMMUNICATION COSTS I
CHRONOLOGY OF SYSTEM COSTS ON 300-MILE PRIVATE LINE

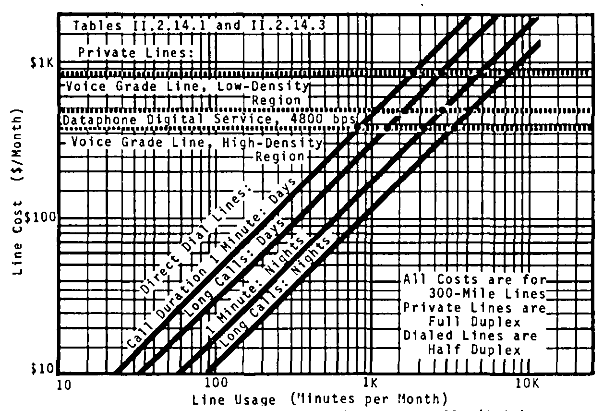



FIGURE 2.14.2 COMMUNICATION COSTS II (1975)
BREAKEVEN POINTS FOR DIALED AND PRIVATE LINES

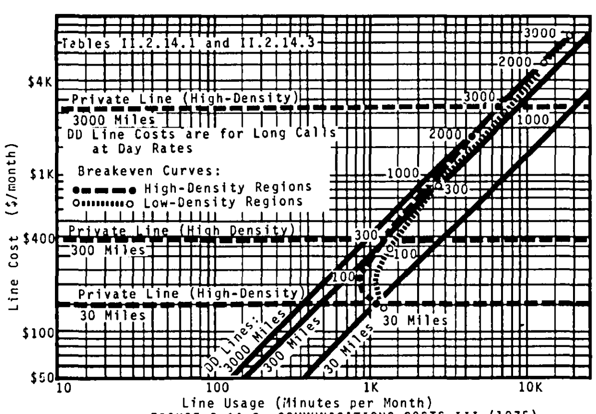



FIGURE 2.14.3 COMMUNICATIONS COSTS III (1975)
BREAKEVEN POINTS FOR DIFFERENT LINE LENGTHS

If we look at system costs (line costs, plus termination costs, plus installation costs amortized over a 12-month period) as a function of the number of bits transmitted per month, we find the DD lines most economical up to the breakeven point, and then the various private lines most economical, each up to its maximum capacity. The solid line in Figure 2.14.4 shows the monthly cost of various 30-mile systems. For transmission times up to about 1000 minutes per month (or 72 million bits at 1200 bps) a dialed line is more economical than a private one. Furthermore, at rates of one million bits per month or less, communication costs are dominated by the fixed cost of the data sets required. The upward curve of the left segment of the solid line in the figure reflects the fact that line charges become an increasingly important factor as transmission time increases. Incidentally, note that at capacities below about four million bits per month a 300 bps service is cheaper than the 1200 bps service—the low cost of the 103A data set more than makes up for the longer line time required to transmit the bits.

For capacities over the 72-million-bit breakeven point, private circuits are cheaper than dialed circuits. At 30 miles, a 1200 bps 202T data set on a high-density private line is most economical, up to the maximum capacity of the line. At traffic rates greater than that maximum (almost 3.2 billion bits, assuming one operates 24 hours a day seven days per week), one must employ either an additional line or a higher bit rate. The DDS service provides data rates of 2400, 4800, 9600, and 56,000 bps, and the fixed costs of those facilities are shown next, as steps in the graph, each step ending at its maximum capacity. The 56Kbps DDS system has a capacity of almost 150 billion bits per month, and for greater line speeds a Telpac circuit operating at 230,400 bps handles capacities up to 605 billion bits per month.

The cost curves for the 300- and 3000-mile systems are very similar to those for the 30-mile systems, as shown by the dashed and dotted lines in Figure 2.14.4. However, the breakeven points are higher for the longer distances, as we saw in Figure 2.14.3, and the comparatively high cost of long private lines makes it economical to use DD facilities at rates above 1200 bps. For example, with monthly capacities in the range 100 million to one billion bits on a 3000-mile line, a 208B data set carrying 4800 bits per second on a DD line is cheaper than a 2400 bps system, either dialed-up or private.

The curves in Figure 2.14.4 show monthly costs as a function of bits transmitted. System costs *per million bits transmitted*, are plotted for the same three distances in Figure 2.14.5. The various breakeven points shown in Figure 2.14.4 appear here as well. One particularly interesting fact shows up clearly on the curves: the high-bit-rate facilities are priced so that it is often cheaper to use two or more duplicate lower-speed systems than to lease a high-speed system. For example, for a capacity of 40 billion bits per month on a 300-mile system, it would be cheaper to use two 9600 bps systems than to employ the 56,000 bps system. And at 300 miles and over, multiple 56,000 bps DDS systems are always more economical than the 230,400 bps TELPAC system. In any particular situation, there may of course be system considerations which would lead one to specify a 230,400 bps system despite its higher cost; but if cost is the primary consideration, the lower-speed systems are to be preferred for long distances.

It should be emphasized that the data presented in Figures 2.14.1 to 2.14.5 attempts to simplify a very complex situation. Some of the factors which contribute to this complexity are worth mentioning.

1. The prices and performance of communications services are governed by tariffs controlled by various governmental bodies. For interstate communications the tariffs are controlled by the Federal Communications Commission (FCC), with the result that they are uniform over all the 48 contiguous states. But within any given state tariffs are established by state authorities, so that the same facility in two different states may have different rentals and installation costs. In fact, the same facility provided by two different telephone companies in the *same* state may have different rentals and installation costs. The data shown in the figures are interstate rates, though there is some local rate data given in the tables of Part II. Note that the tariffs are frequently changed, as new services are added, as prices are revised, and as competitive conflicts are resolved.

2. Specific costs are obviously a function of the particular cities to be served. As mentioned above, DDS serves a restricted (but growing) list of cities; the high-density tariff applies to a still larger list; and the low-density rates apply elsewhere. Combinations of high- and low- density rates may be used under certain circumstances to connect low-density cities, but the rules are complex.

3. Three or more cities can be connected together by a single private line by ordering a line which connects the cities and paying special termination (or "drop") charges in each of the cities, as well as the termination charges for the end cities. Under some circumstances each of the cities may have its own private communication channel on that line—a channel with a bit rate some sub-multiple of the bit rate for the line itself. Under other circumstances the station at one city will be a "master", determining which city may make use of the line. Once again the rules and tariffs are too complex to discuss here.

4. There is another AT&T tariffed service called Wide Area Telecommunications Service (WATS) which is economical to use under certain circumstances. It consists of a special price structure which permits unlimited use of the dialed network (DD) system over specified geographic areas. The rates are particularly attractive for long distances: for less than $1700 per month one can buy 240 hours of calls anywhere in the U.S., with additional time costing less than eight cents per minute. (Detailed rate information is given in Table II 2.14.2, columns 15 to 22.)

5. In most areas in the U.S., local dial telephone service is offered on a flat rate basis, such that an unlimited number of calls of unlimited duration can be made over a distance of several miles at a fixed and low monthly fee. Such circuits can be used to provide very low cost data transmission over those short distances. One large class of users is the customers of various time-sharing services who tie up local dialed lines for hours at a time, connecting their terminals to a computer. The telephone system was designed to handle many calls, each of relatively short duration, and the growing use of computer terminals has led to proposed changes in the tariff which may eliminate or curtail flat rate services.

6. The system prices shown here include the monthly cost (and amortized installation costs) of AT&T data sets. In practice, similar data sets are offered for sale by a number of private companies at prices which, suitably amortized, would be substantially lower than AT&T prices. For short lines, where data set costs are an important portion of the total, this alternative can substantially reduce total costs. In addition, independent data set manufacturers have often

supplied equipment not available from the telephone company—in mid-1975, for example, they offered data sets capable of transmitting 9600 bps on the DD network, where AT&T sets could not transmit more than 4800 bps.

7. The data presented so far covers tariffs of the traditional common carriers—in particular AT&T and the associated Bell System companies. In the late sixties a group of so-called "specialized common carriers" received FCC permission to compete with the Bell System in prescribed situations. Though it is not possible here to cover all these carriers, it seems worthwhile to discuss one of them, as a way of adding another dimension to the picture of communication system complexity.

The Data Transmission Company (Datran) provides communication services via an essentially all-digital system, just as AT&T's DDS system does. Datran's private line service, exactly comparable to DDS, was first available in December, 1973, and a switched system provided first service in early 1975. The switched system is unique: it makes connections between calling and called stations in one to three seconds, compared to 11 to 17 seconds for the telephone company's DD network; it offers a minimum charge of one cent per call, which corresponds to a connect time of one to ten seconds, depending on the bit rate used and the calling distance—the DD network minimum is sixteen to forty cents for a one-minute call; and it guarantees that monthly charges will not be higher than a specified maximum comparable to Datran's private line costs, so that a user with traffic near the breakeven point for private and dialed lines will not incur heavy expenses in a month when his data communication traffic is heavy.

Datran's pricing structure is similar to that of the telephone company. Typically there are fixed monthly termination costs, one-time installation costs, and monthly line costs which are a function of line length. Table 2.14.1 presents a summary of prices for AT&T's high- and low-density private lines, DDS private lines, and DD switching (dialed) system. Datran's private line system Dataline I, and its switching system Datadial are also shown in the table. The first entry on the table is the line cost, where that cost is independent of bit rate. The hi-low and DD service, as we have seen, use the existing voice network for transmission, and the user pays for a voice channel on which he can transmit any bit rate (depending on the data set used) up to 9600 bps. The DDS and Datran systems, on the other hand, are all digital, so line costs depend both on distance and on bit rate. Incidentally, the formula shown for DD line costs is empirically derived, and is good for long calls (over ten minutes each) and distances greater than about seventy miles.

Other entries in the table give formulas for total monthly cost as a function of distance (D, in miles) and time (T, in minutes, for the switched systems only, of course). For example, we can compare the cost of 2400 bps service using Dataline I and the high-density rate between two cities 1000 miles apart as follows: high-density line costs are $978 ($128 + $850), to which must be added $123 for a total of $1101 per month; Dataline I costs are $187 + $360, or $547. Naturally, these rates apply only to the specific cities served by Datran or identified as "high-density" areas in the AT&T tariff—and the AT&T service covers a much wider geographic area than does the Datran service.

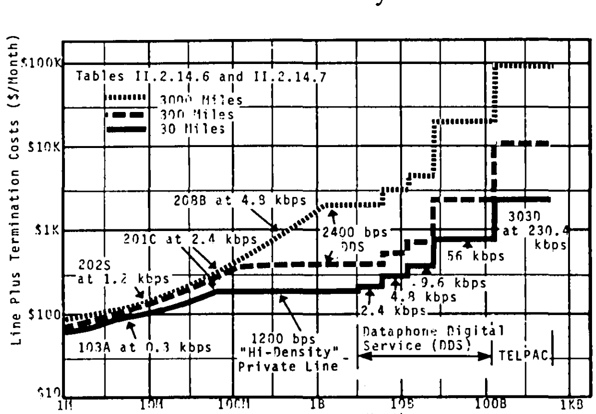



FIGURE 2.14.4 COMMUNICATION COSTS IV
MONTHLY SYSTEM COSTS VS. TRANSMISSION CAPACITY

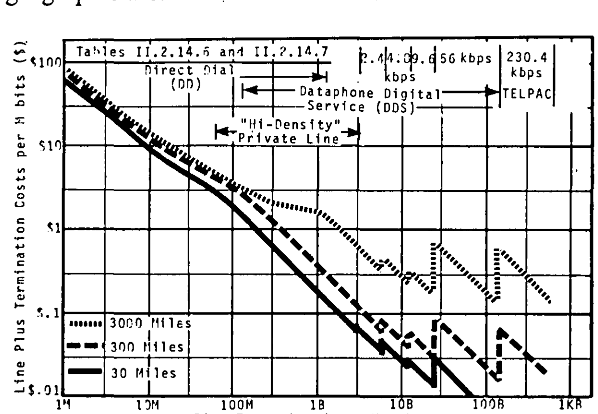



FIGURE 2.14.5 COMMUNICATION COSTS
SYSTEM COST PER MILLION BITS VS. TRANSMISSION CAPACITY

**TABLE 2.14.1 1975 SYSTEM PRICES FOR DATA TRANSMISSION ($/Month)**

| | ATT | | | | Datran | |
|---|---|---|---|---|---|---|
| | High Density | Low Density | DDS | DD | Dataline I | Datadial** |
| Line | 128 + .85D | 88 + 2.5D | - | T(.07 + .095 logD)* | - | - |
| 300bps | 44 + Line | 44 + Line | N/A | 54 + Line | N/A | N/A |
| 1200bps | 32 + Line | 32 + Line | N/A | 78 + Line | N/A | N/A |
| 2400bps | 123 + Line | 123 + Line | 201 + .60D | 117 + Line | 187 + .36D | 285 + .00015DT |
| 4800bps | 275 + Line | 275 + Line | 261 + .90D | 257 + Line | 249 + .54D | 313 + .0002DT |
| 9600bps | 545 + Line | 545 + Line | 331 + 1.30D | N/A | 312 + .81D | 333 + .0003DT |
| 56Kbps | N/A | N/A | 594 + 6.00D | N/A | 553 + 3.60D | N/A |

N/A = Not available. Sources: Tables II.2.14.1, II.2.14.2, II.2.14.6. D = Distance in miles. T = Time in minutes per month.

* Approximate formula for long calls and D greater than 70 miles. Log is to the base 10.

** Datadial monthly charges are guaranteed not to exceed a monthly maximum no matter how many calls are made. The maxima are: For 2400 bps, $285 + $0.75D; for 4800 bps, $393 + $0.75D; for 9600 bps, $493 + $0.90D

The cost of the various private-line alternatives are compared graphically in Figure 2.14.6, for 2400 and 9600 bps service. Comments:

1. As mentioned before, two cities in "low density" areas can be connected to nearby high-density cities which are then connected at high-density rates. The typical cost of connecting two low-density cities using the AT&T hi-low tariff is therefore somewhere between the costs shown by the curves in the figure.

2. AT&T's 2400 bps DDS service is cheaper than service under the hi-low tariff for all distances. However, for 9600 bps service it is cheaper to use voice channels for service if the cities to be connected are high-density cities separated by more than 760 miles. (The corresponding breakeven point for 4800 bps service is 2840 miles.)

3. Datran's Dataline I service is cheaper than any AT&T service for all bit rates at any distance.

We can also compare the costs of dialed lines as proviced by AT&T and Datran, with the results shown in Figure 2.14.7. Here we plot monthly costs vs. connect time per month for three different line lengths: 250, 1000, and 2000 miles. The dashed curves represent costs of the Datadial service, with its guaranteed maxima. The solid curves represent AT&T's DD prices, assuming daytime rates and long calls; and the bar-dash curves show a maximum rate based on private lines between high-density cities. Comments:

1. For very low monthly usage, DD is cheaper than Datadial because the DD fixed costs are slightly lower.

2. For usage less than the breakeven point and distances less than 2000 miles, Datadial is cheaper than AT&T's DD service. For distances greater than 2000 miles, the DD system has the cost edge. Furthermore the DD advantage becomes greater at long distances because Datadial charges are proportional to distance while DD charges are (approximately) proportional to the log of distance.

3. For usage beyond the breakeven point, Datadial is cheaper at all distances. Furthermore, as was mentioned above, a user operating around the breakeven point is protected, in high-usage months, by Datran's automatically-invoked maximum charge. There is no corresponding AT&T maximum: a customer must either use DD service or lease a private line.

4. The AT&T rates shown assume each call lasts ten minutes or longer. If each call lasts one minute, the DD costs increase markedly, and the DD/private line breakeven point occurs earlier. Calls shorter than a minute still are subjected to the one-minute minimum charge, so the per-minute cost is even higher. The Datadial curves, on the other hand, are applicable as long as each call costs more than $.01—in other words, as long as calls are longer than 12, 3, and 1.5 seconds, respectively, for the 250-, 1000-, and 2000-mile lines.

The only performance factor we have discussed so far is bit rate. Another extremely important one is reliability. The telephone companies have always been reluctant to establish very stringent specifications on service reliability, though communications companies have been active in measuring and characterizing data errors for some years. AT&T studies have shown, for example, that 80% of all calls transmitting 2000 bps at moderate distances on the switched (DD) network have error rates less than one error in 125,000 bits transmitted. (BalkM71). Seventy-two percent of the errors counted occurred during five percent of the calls, and 22% of the calls (each 30 minutes in duration) had no errors at all—when connections are good, they are very, very good, but when they are bad, they are horrid. Finally, the studies show that errors occur in bursts. With a burst defined as a collection of one or more bits beginning and ending with an error and separated from neighboring bursts by 50 or more error-free bits, then 80% of the bursts on 2000 bps lines were less than ten bits long and contained fewer than three errors.

These statistics refer to dialed lines (private line reliability is better), and of course to a network which was designed to handle voice, not digital, communications. AT&T's new DDS system, planned for data transmission, was designed to meet the following reliability objectives: 99.5% of one-second intervals should be error-free; circuits are available at least 99.96% of the time, station- to-station. The first objective seems not very impressive, for it permits a cluster of bad bits every 200 seconds. (The study referred to in the previous paragraph indicated a probability of about 1/3 that there would be at least one error in every 200 seconds when transmitting at 2000 bps.) The 99.96% availability goal is much more stringent: it permits only 3.5 hours of down-time per year. Datran's error rate specification is much tighter than AT&T's—one bad second every 2000 (33.3 minutes) instead of one every 200. But Datran has no availability specification.

Competition, from specialized carriers, data set manufacturers, and others, has benefitted users of data communications. Commercial data sets have been less costly than those supplied by AT&T, and often have provided features the telephone companies didn't offer. Datran and the other specialized carriers offer services equivalent to AT&T's at lower prices, with lower error rates, and in addition offer services and features not available from the telephone companies—for example, Datran's all digital high-speed Datadial service, with its one-cent minimum call and its maximum monthly charge.

On the other hand, we must keep in mind the obligations the common carriers have, and the limitations of the specializer common carriers. The former are primarily in the business of handling voice communications, and are obliged to provide uniform service to every community in the U.S. at relatively uniform prices. The specialized common carriers have been able to limit their investment in communications equipment to those "backbone" communication lines where there is very heavy, and therefore potentially profitable, data communication traffic. Where they require long lines pending construction of their networks, or where they must connect outlying customers to their central facilities, they lease service from the common carriers. In evaluating the comparisons made in Figures 2.14.6 and 2.14.7, we must keep these facts in mind—and must also remember that the specialized carriers are new and are finding it difficult to achieve profitability.

**Postal Data Communications.**

The mails are used to transmit bulk data as well as general correspondence. Punched cards, computer listings, microfilm records, and magnetic tapes are commonly transmitted by mail from one location to another over both short and long distances.

Unfortunately, while the performance of telephonic communications has improved enormously over the years, and the cost has dropped or at least held steady in the face of inflation, the performance of the postal service has remained constant or deteriorated, and its costs have escalated. The net result is indicated in Figure 2.14.8, where the first-class postage cost of mailing data on (line printer) continuous forms, magnetic tape reels, and microfiche cards is shown as a function of time. Comparing the results with the costs of telephonic data communications, shown in Figure 2.14.1, we note that postal costs are generally lower than telephone costs (note telephonic costs are plotted in cost per million *bits*, while postal costs are per million *bytes*) but are increasing. Furthermore, the reductions shown in telephonic costs came about as a result of the initiative of the common carriers in developing new services; the improvements possible in postal costs have come about because of extra-postal initiative–through the development of microfilm, the improvements achieved in magnetic tape recording density, and the development of photocopying equipment which both reduces the size of line printer pages and copies them on both sides of a page. Even taking into account the 1976 increase of postal rates to thirteen cents per ounce, it is cheaper to mail continuous forms than to transmit characters over dial-up lines, unless the amount of data to be transmitted per month is relatively large–over 100 million bytes per month, say, at 30-mile distances (see Figure 2.14.5). And even at the very highest monthly data rates, it is cheaper to mail magnetic tapes than to employ high-speed DDS or Telpac Services over long distances, and cheaper to mail microfiche than to use telephonic private lines at any distance.

Obviously, raw data transmission costs are only one factor to be considered in choosing a data communication system. The other critical considerations are transmission delay and system reliability. First-class mail, which moves via air these days on long hauls, generally takes two or three days between pick-up and delivery, with pick-up available at most twice per day. Telephonic communication delay is measured in fractions of a second, and is available continuously. And postal reliability is variable: there is little chance of losing stray characters in a package (as is common in telephonic communications), but there is a good chance that an extra day's delay will occur, and a not-inconsiderable chance that the package will be forever lost.

Nevertheless, there are a variety of circumstances when the low cost of postal communications makes it the obvious choice for data transmission.

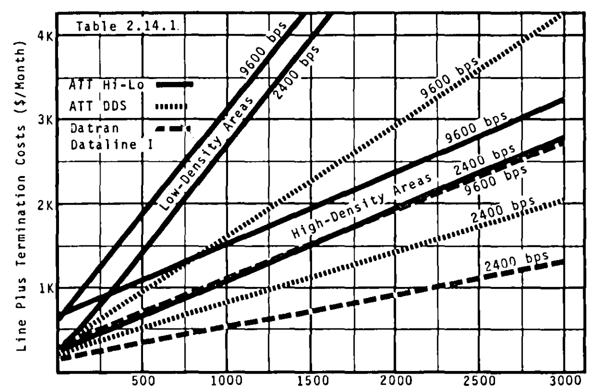



FIGURE 2.14.6 COMMUNICATION COSTS VI
PRIVATE LINES FROM ORDINARY AND SPECIALIZED CARRIERS

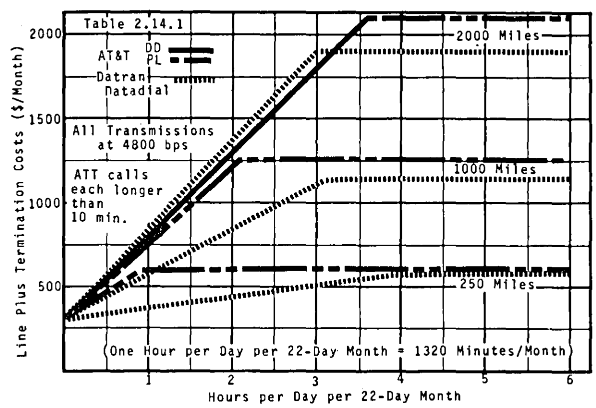



FIGURE 2.14.7 COMMUNICATIONS COSTS VII
DIALED LINES FROM ORDINARY AND SPECIALIZED CARRIERS

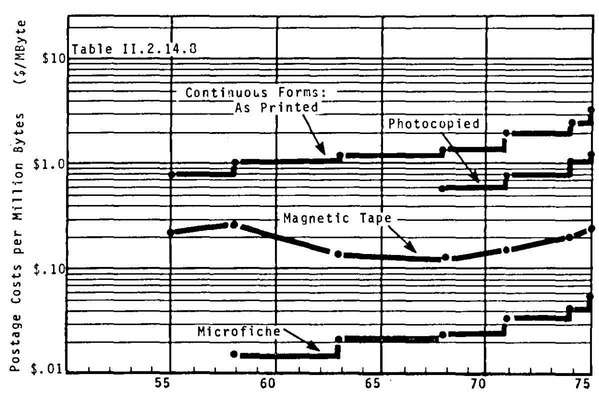



FIGURE 2.14.8 POSTAL COMMUNICATION COSTS
CHRONOLOGY OF FIRST-CLASS POSTAGE COSTS

## 2.15 PROGRAM PRODUCTS ●

A variety of programs are offered for sale to computer users. Some are available as independent products, and some as components whose price is included in the total price of a system. Some are offered for sale by system manufacturers, some by independent software firms, and some by the users who develop them.

Three classes of program can be distinguished. The first class is designed to help computer operations, the latter two to help computer programmers. Operations Aids include Operating Systems, System Simulators, System Generators, and Performance Analyzers, among others. Of these, the most important is of course the Operating System, whose purpose it is to monitor and optimize system performance. The price of an Operating System is generally included in the price of the associated hardware, and its performance cannot sensibly be discussed without discussing System Performance, which we will consider in Section 2.23.

Of the two classes of software designed to help the users' programmers, one, the Applications Packages, contains programs aimed at solving some specific problem or handling some specific application-oriented task for a class of customers. Payroll programs, civil engineering (surveying) programs, and inventory control programs are examples of such products. They exist in great variety, and are offered by software houses, by the system manufacturers, and by some users. Often they must be modified in some way to meet the specific requirements of a user-buyer. There seems to be no useful way of classifying or describing this heterogeneous class, and I will not treat it further.

The last category of software products is the Programmer Aid. This family of products is designed to reduce programming costs in some way—by providing standard programs for common data processing or computing functions (e.g. matrix inversion, sorting, computing logarithmic or trigonometric functions, etc.); or by translating some standard procedure-writing format into machine language (e.g. assemblers, compilers, report generators, etc.); or by mechanizing some aspect of the programmer's job (e.g. programs which generate program testing materials or flow charts).

Of the Programmer Aids, the programs which translate procedures into machine instructions have been by far the most important, and are used in every computer installation where programming is carried out. In the remainder of this Section, we shall attempt to discover which of these aids is most important, and will present some data on their performance.

**The Important Products.** Despite the fact that virtually every computer installation uses Programmer Aids, there seems to be very little data available on the relative usage of various products. In Figure 2.15.1 I present an estimate of the relative use of different aids by domestic GP installations. The "use" of such aids could be measured in a large number of ways: by the proportion of existing programs written using each aid; by the proportion of lines of object code written; by the proportion of code currently being written; by the proportion of time programmers spend writing code; or by the proportion of machine time used running application programs created by each of the different aids. The very limited data I have been able to find on this subject (see Tables II.2.15.1) suggested the distribution shown in Figure 2.15.1, which I believed to be a fair estimate of the proportion of programmer time spent working with the use of the named aids. I have too little information to guess how the curves might change if they were based on proportions of lines of code in use, or of machine time. Comments:

1. Initially all programming was done in machine language, and the Assembler in its various forms was the only translator used. In the late Fifties FORTRAN was developed, and FORTRAN compilers were designed for some first generation machines. Its use spread rapidly, especially in installations which were more interested in scientific calculations than in business data processing. In the meanwhile, users and manufacturers had recognized that a different sort of language would be needed for data processing applications, and as a result the COBOL language was developed, and COBOL compilers were made available for second generation machines. Although many business applications continued to be written in assembly language (IBM's Autocoder in particular was very prominent), the use of COBOL grew and it soon overtook FORTRAN in importance. Today apparently about half of all programmer man-hours are spent using COBOL.

2. Work on COBOL specifications was begun in 1959, and the first compilers were in operation in 1960. In 1963 IBM and SHARE, the IBM users' group, formed a study to define a language which would "encompass more users (than FORTRAN) while still remaining a useful tool to the engineer." (SammJ69). The resulting very general-purpose language was named PL-I, and the first compiler was released in 1966. It has not yet been widely adopted by manufacturers other than IBM.

3. Sometime in the early sixties, IBM noticed that many application problems could be solved if a tool were available with which one could specify the desired *format* of system inputs, system files, and output reports. As a result, the Report Program Generator (RPG) was developed, and it became possible to "write programs" by filling out a set of forms. Programs to translate data from such forms into computer procedures were made available with IBM's third-generation machines and their success has led other manufacturers to develop similar systems.

4. Jean Sammet (SammJ72) estimated that over 200 higher levels languages were developed between 1952 and 1972. She lists 164 of them as being used to some extent in the middle of 1971. These languages, along with other aids which do not fall within the definition of "language" are included in the "miscellaneous" portion of the graph. One language in particular deserves special mention. ALGOL, used very infrequently in domestic applications, is apparently fairly widely used abroad, especially in Europe.

5. IBM's influence is as important in the development of software products as it has been in hardware development. FORTRAN, RPG, and PL-I were all developed by IBM and have subsequently become "industry standard" programming aids, in one way or another.

6. By the late sixties and early seventies it had become common for users to employ an average of 2.5 or 3 languages at each computer site. COBOL, FORTRAN, RPG, and assembly language each were in use at more than one-third of all sites. (See Tables II.2.15.1 for additional detail.)

**Performance.** In evaluating a Programmer Aid such as a compiler or report generator, we must consider the factors which contribute to programming and operating costs. Although the concepts involved are presumably applicable, more or less, to any Aid, we will concentrate attention on the performance of compilers, which are, as we have seen, the products most widely used.

In Table 2.15.1 I summarize various factors, some qualitative or subjective and some more or less quantitative and measureable, which affect the costs of programming and operating data processing systems. Note that some factors are a function of the characteristics of the language which forms the basis for the compiler—for example, the COBOL features which facilitate the reading and writing of data files on magnetic tape units and random access storage devices make that language particularly useful for data processing compared to FORTRAN, whose input/output features are very primitive. Other factors are attributable to a specific compiler written to translate statements in the language for a specific machine.

Jean Sammet (SammJ71) has provided a useful framework for evaluating the language features, though her article was not intended to provide a quantitative comparison of any particular languages. One explicit comparison, reported in the literature, has been carried out and is described by Figure 2.15.2. In an experiment, seven applications programs were written by seven experienced programmers. Each wrote two programs for his application, one in the PL-I language, and the other in another language. Records were kept of the number of statements in each of the 14 programs, and the programmer time required to code and debug each program. The graph shows programmer time along the vertical axis, and the number of statements in the program along the horizontal axis. A particular program written in some language by an individual programmer can thus be represented by a point on the graph. I have plotted a total of eleven pairs of points: seven pairs describe the fourteen programs written by the seven programmers (I have identified these pairs by connecting them with dotted lines); three pairs compare an average PL-I program with the corresponding average Jovial, FORTRAN, or COBOL program (they are connected together by dashed lines); and the last pair compares the average of the other seven PL-I programs with the average of the other seven programs (these two points are connected by a solid line). It is, of course, foolish to draw any definitive conclusions from this data. The sample is extraordinarily small. The seven programmers were all inexperienced in the use of PL-I. And some of the differences pictured—especially debugging time—may be a function of features of the compilers used rather than features of the languages. I will nevertheless venture three comments:

1. PL-I generally seems to require fewer statements to implement a procedure than any of the other three languages tested.

2. The four programs written to compare PL-I and Jovial actually implemented a single data management problem. The results for those four programs thus illustrate the very large difference that can exist between two different programmers. Note that they both implemented the application in PL-I using about 450 statements, but that one required almost twice as much time as the other. And note that the one who was slower with the PL-I program spent less time on his Jovial program, though it contained more statements than that of his competitor.

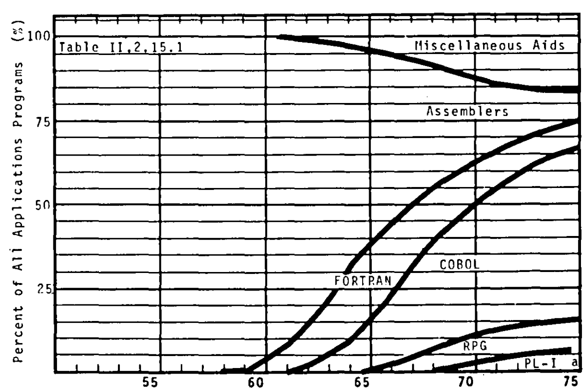



FIGURE 2.15.1 PROPORTION OF APPLICATION PROGRAMS WRITTEN USING DIFFERENT PROGRAMMER AIDS

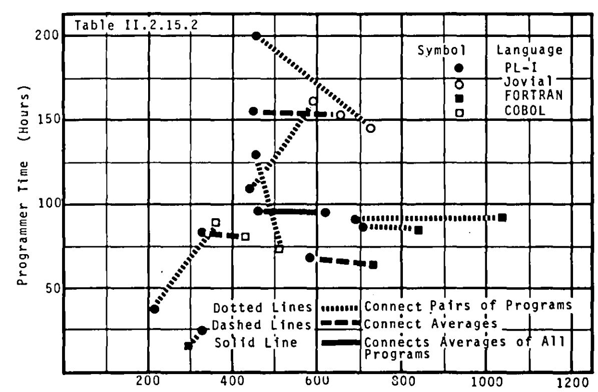



FIGURE 2.15.2 PROGRAM LANGUAGE PERFORMANCE COMPARISON SEVEN PROGRAMS EACH WRITTEN IN TWO LANGUAGES

## TABLE 2.15.1 LANGUAGE AND COMPILER PERFORMANCE ●

| Contributors to Programming Costs | | Contributors to Operating Costs | |
|---|---|---|---|
| Language Features | Compiler Features | Language Features | Compiler Features |
| Ease of | Debugging Aids | Environmental Independence | Memory Occupied |
| Reading | Documentation Aids | Machine Independence | By Compiler |
| Writing | | Operating System | By Object Program |
| Debugging | | Independence | Speed |
| Maintenance | | On-Line vs. Batch | Of Compiler |
| Learning | | Independence | Of Object Program |
| Documentation | | | |
| Generality | | | |
| Naturalness | | | |
| Simplicity | | | |
| Succinctness | | | |
| Relevance to Application | | | |

3. The differences, in languages and programmers, translate directly into large differences in the cost of application programming and of ones ability to set and meet programming schedules. We will return to this subject in Section 2.21, when we discuss system workloads, and in Section 4.2, when we discuss software development costs. But it is a pity that a subject so important to the industry as language performance has received so little quantitative and analytical attention.

Let us next look at operating costs, as contrasted to programming costs, and at the aspects of compiler performance which affect such costs. Once an application program is written, it contributes to operating costs by requiring computer time for two reasons: for production runs—the reason the program was written in the first place; and for recompilations, necessary to correct errors or to add new features in the original program. The relative importance of production efficiency and maintenace efficiency of a compiler obviously depends upon the application. If a program is written for some one-time calculation, production run time may be much less important than compiling time. On the other hand, if many production runs are planned and little maintenance is required for an application, one would be willing to devote a great deal of time to compilation if the resulting run-time program were very efficient. One measure of run-time efficiency is the number of machine instructions which are generated by a compiler for each instruction written in the source language. A small ratio implies (but of course does not guarantee) low running costs both because little memory is required to store the program, and because the program is relatively short.

Figure 2.15.3 provides some insight into the variability of this ratio for the COBOL language over sixteen different applications totaling more than 450,000 source instructions. The programs implement a variety of data processing applications, and cover a broad spectrum of program size—one of the Burroughs 5500 applications contains 195,000 source instructions, and the three CDC programs range in size from 3,570 to 11,410 source instructions. The average shown is for the 16 *applications*, giving equal weight to the small and large programs.

In a British study (WichB72) four ALGOL programs were each compiled and executed on five different computers using, of course, five different compilers. Average figures on the resulting compiled code, expressed as ratios to code for the ATLAS computer, are given in Table 2.15.2. Note the 6:1 ratio between the largest and smallest compiled code, as measured in bits, and the (nearly) 2:1 ratio in number of instructions executed.

Turning now to compiling time as opposed to run time, we can get some feeling for the differences between various compilers, and for the relationship between compiling speed and computing system speed, by studying Figure 2.15.4. Here is plotted the compiling speed, in statements per minute, of 28 compilers on 23 different computers as a function of computer speed in thousands of operations per second. For each computer system, we show two or three measures of computer speed: two of them are Knight's commercial and scientific performance measures (KnigK66,68); the other is additions per second. A given computer-compiler thus shows up as a horizontal line representing the compiler speed, connecting three points representing the three possible measures of computer system speed. Comments:

1. It would seem reasonable that compiling speed should be proportional to system speed. In fact, in a completely buffered system where input and output are overlapped with computation, compiling speed should be directly proportional to raw computer speed. The three dotted lines correspond to what one might call compiling "efficiencies" of 1,800, 6,000 and 60,000 equivalent computer operations per COBOL statement. Since the COBOL language is well-defined and is implemented on Von Neuman machines whose order codes do not differ significantly from system to system, it should be possible to establish, with some measure of confidence, a good figure for the average number of machine operations required per statement compiled. I speculate that that figure lies between 1,000 and 3,000 operations per statement.

2. Obviously there is substantial variability in apparent efficiency of the compilers shown. Why should some systems seems to require 60,000 operations to compile a COBOL statement, while others need only 1800? The principal reasons seem to be differences in system input/output capabilities, differences in the experience of compiler writers, differences in the way compiling speed is measured, and differences in the compiler's ability to generate "fast" run-time code.

We can also look at compiler performance by taking into account the monthly rental of each system along with compiling speed, and calculating the hardware cost of compiling 100 COBOL statements. The result is shown in Figure 2.15.5 for the same group of compilers and systems pictured in the previous figure. If we assume that compiling speed is directly proportional to system speed (as I postulated in connection with the previous figure); and if we further assume that a computer's speed is proportional to the square of its cost (Grosch's Law); then the hardware cost of compiling 100 statements should be inversely proportional to system monthly rent, and the points in Figure 2.15.5 should fall on a downward-sloping line like one of the dotted lines shown in the figure.

In this figure, I have identified, by name, only the systems whose characteristics lie on the boundaries of the performance range. I have also distinguished four Burroughs 5,000 systems which differ from one another only in memory size. Note that, for those systems, a 20% increase in monthly rental improves compiling speed by more than a factor of 20 (see Table II.2.15.3), and the cost of compilation by almost a factor of 20. The improvement was obtained simply by increasing the size of internal memory.

The compilers whose characteristics are described in Figures 2.15.3 to 2.15.5 and Table 2.15.2 were written between the early sixties and the early seventies. In that period of time there have been major changes in system hardware, and thousands of new compilers have been written. Comparing the 1962-1963 data of Figures 2.15.4 and 2.15.5 with the 1970 data of Table 2.15.2, we might conclude that ten years of progress still leaves us with substantial performance differences from one compiler to another. However, the samples are small and the performance measures inconsistent. And despite the obvious critical importance of compiler performance, despite the fact that compilers which were "free" in the early sixties must now be leased, there are still no standard measures of compiler performance, and users pay monthly fees for products whose performance is completely unspecified.

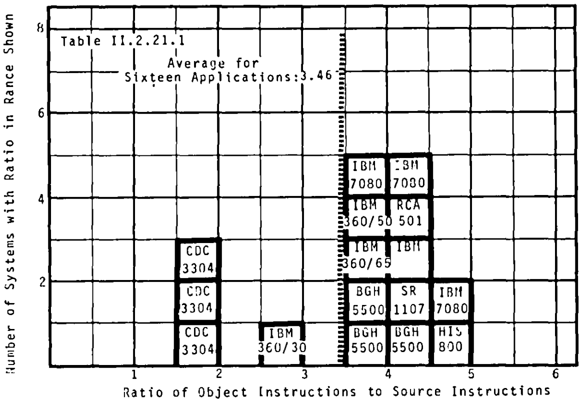



FIGURE 2.15.3 COBOL COMPILER PERFORMANCE COMPARISONS OBJECT/SOURCE INSTRUCTION RATIOS FOR SIXTEEN APPLICATIONS

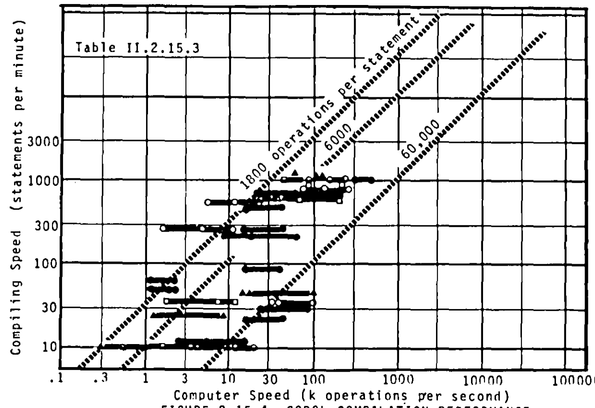



FIGURE 2.15.4 COBOL COMPILATION PERFORMANCE ON A VARIETY OF COMPUTERS I.

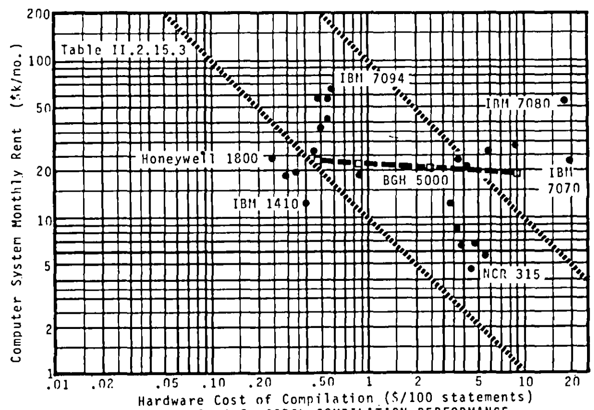



FIGURE 2.15.5 COBOL COMPILATION PERFORMANCE ON A VARIETY OF COMPUTERS II.

### TABLE 2.15.2 COMPARATIVE PERFORMANCE OF FIVE ALGOL COMPILERS

| | ATLAS | Univac 1108 | XDF9 | ICL 1907 | BGH 5500 |
|---|---|---|---|---|---|
| Number of Instructions Compiled | 1.0 | .41 | .78 | .65 | .63 |
| Size of Compiled Code (bits) | 1.0 | .31 | .35 | .32 | .16 |
| Number of Instructions Executed | 1.0 | .83 | 1.50 | .94 | .96 |
| Execution Time | 1.0 | .28 | 3.50 | 1.20 | 1.80 |

Source: WichB72 (Wichmann, B.A., "Five ALGOL Compilers," *The Computer Journal, 15*, 1, Feb., 1972.)

## 2.16 MEDIA •

A medium is a material on which data may be recorded. The media to be discussed here are computer-related media which are transportable—which can be moved from place to place independent of the equipment which does the recording. Transportability is important for two reasons: for human-readable media (continuous forms and microfilm rolls), it makes it possible for computer-generated data to be used, examined, or transferred by people; for machine-readable media (punched cards, forms printed in special type, magnetic tapes, disk packs), it provides a low-cost way to store data, and permits information to be transferred from one computer installation to another.

When a user purchases media, he must name or imply a specification which the media must meet for the recording equipment to work properly. If cards are too thick or printing paper too stiff, or magnetic coatings have flaws, the corresponding peripheral equipments may not record data reliably. When such specifications are adopted by the computer industry generally, they are called standards. Standards exist for all the media discussed here, and have three advantages: they encourage competition among media suppliers by enlarging the market for each standard medium; they encourage competition among equipment suppliers by permitting the development of new equipment without the necessity of also developing a medium (and the encouragement of competition is desirable in both these areas because it leads to reductions in price and improvements in performance); and finally they permit information interchange between two users who operate systems designed by different manufacturers at different times. This latter function was particularly important before the common carriers offered data communication facilities.

The cost and capacity of the principal media are plotted in Figure 2.16.1. The punched card was the original machine-readable medium and is still widely used. Its price per byte stored has changed very little over the years, though the introduction by IBM of the high-density (96-character) card in 1970 permitted a modest reduction. Magnetic tape manufacturing costs have fallen, and simultaneously recording density has increased with a resulting considerable improvement in the performance of tape as a medium. Disk packs were introduced most recently, and price per byte stored has fallen substantially, mostly because of increases in storage density on the magnetic surface, but also in part because of the effects of competition on disk pack prices (see Section 1.27).

It has proven difficult to assemble a history of the price of human-readable media, and so we show 1970 and 1975 prices only for a line printer sheet and a microfilm roll. Note that their prices per byte are comparable, low, and not substantially different from the 1600 bpi magnetic tape. Line printer continuous forms are the most costly media from the point of view of a typical computer user, and form prices are a function of many factors, the principal ones being form size and number of parts (a two-part form provides an original and *one* carbon copy, a three-part form two carbon copies, and so on). Figure 2.16.2 shows some typical prices as of 1972. Note that an n-part form generally costs *more than* n times the price of a one-part form, for the simple reason that one must buy carbon paper as well as printing paper with the multi-part forms.

## 2.2 System Performance and Usage

As we have seen, it is relatively easy to discuss and even to measure the performance of a line printer or a card reader. The central processing unit, with its variety of commands, registers, interrupts, data structures, and potential for parallel or interleaved operations, was much harder to describe quantitatively, though in Section 2.11 we used some fairly simple measures to trace the history of CPU performance.

When one or more imperfect CPU's are connected to a variety of fallible peripherals and terminals, are made to function with available software, are programmed, operated, and maintained by ordinary people with their human foibles and idiosynchracies, in typical data processing departments where imperfect procedures are improperly followed, on data collected in unexpected formats rich in illegal characters, carrying out a mixture of calculations dictated by the seemingly random requirements of commerce—under these circumstances we have what is called an electronic data processing *system*. And in this section we will discuss system performance, and will attempt to quantify some of the factors which affect it.

To approach the performance question with the proper perspective, let us study the general Data Processing System diagram of Figure 2.20. It is applicable to any organization, large or small, and specifies that a system comprises three ingredients and two functions. The ingredients are: data, including both organization records and procedures, and in particular including the procedures which specify what is to be done with the organization's data; people, who create and follow the procedures; and equipment operated by those people. The functions are Data Processing Management, which prepares new procedures in response to the organization's new processing requirements; and Data Processing Operations, which implements the procedures. As is implied by the diagram, DP Management might receive a request from the organization for a new inventory control system. It would supply the organization with a description of the new computer equipment and personnel required to perform this new job, and would prepare programs to implement the job and manual procedures for computer operators, keypunch operators, and terminal users (as appropriate). DP Operations would install the new equipment, hire and train the new people, assemble or compile the new programs, and in due course accept, process, and output inventory control data. Although the diagram is applicable to General Motors, with its tens of millions of dollars worth of computer equipment and thousands of data processing employees, it is also intended to accomodate a small firm whose data processing is done by a part-time bookkeeper with an adding machine.

I start by claiming that the performance of this (and any) data processing system is best measured by the cost of following management's directions regarding the organization's data; and that the best system will be the one whose cost over a period of time is lowest.

By stating the performance criteria in these general terms, I hope to accomplish two ends. I mean to remind the data processing user and the computer system designer, first that they had best keep in mind *all* the costs involved in processing data; and second that there are a host of alternatives available, only a fraction of which require the use of an electronic computer. Some of these alternatives will be examined in Chapter 3, where we look at applications in more detail.

Having used Figure 2.20 to draw attention to the most general Data Processing System, let me now return to the original subject of this section: the study of that subset of systems which contain one or more electronic computer. How should we measure the performance of such a system? What are the factors which affect "the cost of following management's directions regarding the organization's data"?

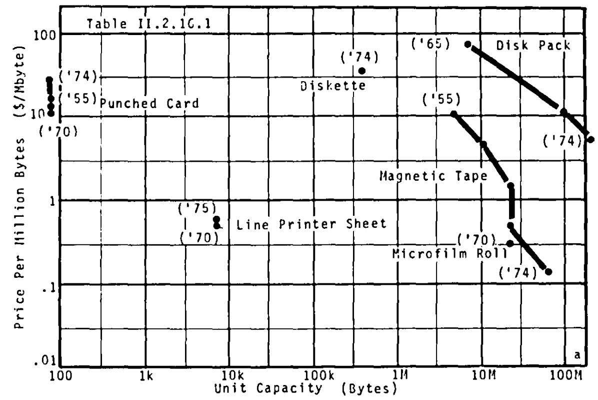



FIGURE 2.16.1 MEDIA TECHNOLOGY
PRICE PER MILLION BYTES AND CAPACITY

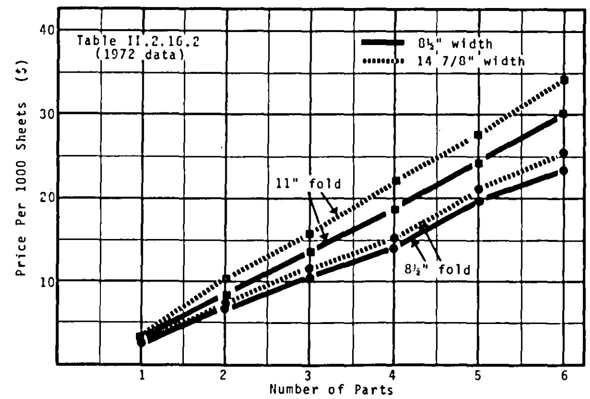



FIGURE 2.16.2 STANDARD CONTINUOUS FORMS
PRICES FOR DIFFERING SIZES AND NUMBER OF CARBONS

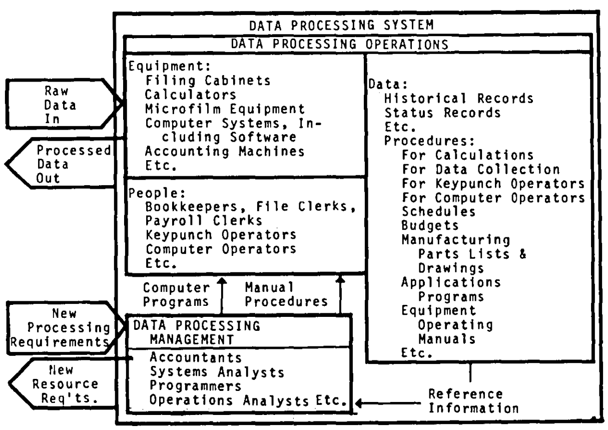



FIGURE 2.20 THE GENERAL DATA PROCESSING SYSTEM

Some of the factors, and presumably the most important ones, have been characterized (GrocJ72) under the categories of Accessibility, Usability, and Manageability as shown in Table 2.20.1. Each user planning a data processing system must be interested in these system attributes, and must in effect list them in order of their importance to him. Different users will obviously create different lists, depending on their problems. The petroleum engineer seeking a computer for process control has limited interest in the capabilities a system may have for accounting for its resources, but is very interested in the purchase price of the system and the cost of the environment it requires. The manager of a new time-sharing service, in contrast, is *very* interested in resource accounting and in the software a vendor supplies with his system, and is less concerned about system price or installation costs.

System suppliers should also be interested in these attributes. In fact, suppliers have been slow to appreciate the complexity of their product and the importance of Accessibility, Usability, and Manageability. For a long time, computer hardware was designed with the objective of maximizing operations per second, not jobs per hour. Software was designed principally to provide a multitude of facilities, and the contributions (positive and negative) software can make to Reliability, to Evolvability, to Maintainability, and to Controlability were ignored or overlooked.

The situation seems to be improving now, though it may be difficult to prove that this is so. Certainly manufacturers today provide software having maintenance and accounting features unthought-of in 1960. But it is extraordinarily difficult to evaluate the influence each factor in Table 2.20.1 has on "the cost of following management's directions regarding the organization's data". It is for that reason that, earlier in this chapter, I compared the problem of measuring data processing system performance with that of measuring the performance of a newspaper or a school teacher.

Two of the factors in Table 2.20.1 are obviously of critical importance to performance (however one defines it), and are directly related to hardware and software characteristics, so that they can be evaluated with some objectivity. They are system Capacity and Maintainability. In Section 2.23 we shall review the history of system design, attempting to examine in detail and quantitatively how these attributes have developed with time. However, there are two aspects of system usage which affect performance and which we will therefore examine first. Both are identified in Figure 2.20. The first, to be covered in Section 2.21, is Processing Requirements—the characteristics of the data which is to be manipulated and of the calculations which are to be carried out. The other, covered in Section 2.22, is People—their abilities, capacities, and attributes. After discussing these two subjects, we will much better be able to deal with the questions of system capacity in Section 2.23.

## 2.21 PROCESSING REQUIREMENTS (Workloads) ●

Just as the performance of a ditch digger depends on the consistency of the ground he works, and the performance of a washing machine on the weight, size, and dirtiness of the load of clothes it receives, so is the performance of a Data Processing System critically dependent on the characteristics of the jobs it must process. In this section we will describe and discuss the work to be done, and will review the available statistics on data processing workloads.

Workloads consist basically of two different kinds of functions: the *preparation* of data processing procedures; and the *execution* of those procedures and of others supplied from outside the system. In Table 2.21.1 I provide some examples of these two functions, as carried out by the system of Figure 2.20. Note that in general it is the function of Data Processing Management (including Programming, if the system includes a computer) to prepare procedures, and of Operations to carry them out. However the examples in the table bring out a very important point: the preparation of a procedure is really itself a kind of *execution* of a procedure—a translation of data from one form to another. The system analyst translates a management requirement into flow charts, the programmer translates the flow charts into COBOL statements, and a machine in Operations translates COBOL statements into machine language instructions. All three functions could be categorized as "executing" functions; and we distinguish them because procedure-preparing functions constitute the most complicated, expensive, troublesome, and little-understood half of the data processing workload.

If the procedure writers and procedure executors are comparable to the ditch digger and the washing machine, then the workload examples of Table 2.21.1 correspond to particular ditches and specific loads of washing. How can we describe these workloads? An immediate and obvious answer is that they are difficult to describe, for two reasons: because they are very complex (the procedure-preparing functions in particular usually require that human valuations and judgments be made); and because they are extraordinarily varied. However, the difficulty of the problem, while it may in part explain the fact that there seems to be little available data on data processing requirements, does not, in my own opinion, excuse what seems to be our neglect of a critically important aspect of computer science.

**Procedure Preparation.** As was indicated above, it is the procedure-preparing function which gives a data processing system user the greatest problem. In Section 1.25 we pointed out that the burdened salary costs of systems analysts and programmers are comparable to hardware costs, and in Section 3.25 we will see that those costs account for over 25% of total user costs. (I know of no comparable analysis of the procedure-preparing costs of the many small organizations which do not yet operate computers, or which employ computer services.) But cost is only one problem. Computer users often find that, despite their large investment in marvellously fast equipment, regular reports on business operations are not available until weeks after the close of a reporting period. Furthermore, they often complain that the scheduled time necessary to implement a new requirement is too long; that such implementations often are not even complete in their scheduled times; and that when completed they often are not what user management wanted.

Computer system designers recognized these problems at an early date, and have through the years provided a long series of software solutions: the programming languages discussed in Section 2.15. The design of such languages, and of the assemblers and compilers which translate individual procedures written in these languages into programs which will run on specific computers, is presumably based on some understanding of the nature of the procedure-preparing workload. Unfortunately, there is little evidence that either the language-designer or the compiler-writer has worked with any quantitative understanding of this workload (see, for example, KnutD71).

### TABLE 2.20.1 MEASURES OF SYSTEM PERFORMANCE

| | | | |
|---|---|---|---|
| | **Accessibility** | | |
| **Availability** | | **Approachability** | |
| **Reliability**<br>Mean Length of useful up-time.<br>Probability that output data is correct. | **Capacity**<br>Jobs carried out per hour.<br>Number of simultaneous time-sharing users allowed.<br>Probability of successful log-in by time-sharing user.<br>Number of simultaneous batch processing tasks processed. | **I/O Devices Provided**<br>Types of terminals and peripherals offered by the manufacturer. | **I/O Devices Available**<br>Terminals and/or peripherals on-site.<br>Waiting-time for use of peripheral or terminal. |
| | **Usability** | | |
| **Facilities Available**<br>Languages.<br>Debugging aids.<br>Documentation for operators and users.<br>Editing facilities.<br>Large data base facilities. | **Response Time**<br>Turnaround time, for batch jobs.<br>Real-time response to time-sharing user request.<br>Time between receipt of specification for a new processing job, until first execution of that job by the system. | **Flexibility/Adaptability**<br>Types of users accomodated and variety of use provided for.<br>Ease of making changes, or doing new jobs. | **Human Interface**<br>Time required to learn the system.<br>User/operator "feel".<br>Operations complexity. |
| | **Manageability** | | |
| **Cost**<br>Equipment cost.<br>Environment cost.<br>Communications costs.<br>Operations costs, including supplies, utilities, etc.<br>Start-up, costs for a new job, including analysis, programming, documentation, check-out, etc. | **Controlability**<br>Ability to account for resources and users.<br>Audit capabilities.<br>Access control mechanisms.<br>Printing control mechanisms. | **Evolvability**<br>Unused capacity available.<br>Maximum hardware additions.<br>Ability of software to accomodate any hardware combination.<br>Ability to modify software. | **Maintainability**<br>Mean time between system failures, whether due to hardware, software, or operations.<br>Mean length of down-time due to failure. |

### TABLE 2.21.1. EXAMPLES OF DATA PROCESSING SYSTEM WORKLOADS

| Preparation of data Processing Procedures | Execution of Data Processing Procedures |
|---|---|
| Accountant writes a procedure for bookkeeper, file clerk, payroll clerk, etc. describing how to debit and credit accounts, how to file documents, how to compute payrolls, etc. | Bookkeeper, file clerk, payroll clerk, etc. do bookkeeping, filing, keypunching, payroll calculations, etc. in accordance with the accountant's procedures, and with equipment procedures (for calculator, accoounting machine, etc.) as appropriate. |
| Analyst prepares a flow chart describing how a new data processing requirement is to be satisfied. | Programmer writes a COBOL application program in accordance with flow chart, and with the COBOL programming manual. |
| Programmer writes a COBOL application program. | Computer system performs compilation, preparing a machine-language program in accordance with the COBOL program and with the COBOL compiler program. |
| Computer system prepares a machine-language program. | Computer system processes the data in accordance with the machine-language program, and with the procedure implied by the hardware system's logic design. |
| Operations analyst writes a procedure detailing how the computer operators will handle job priorities during and after change-over to a new Operating System. | Computer operators control sequencing of incoming jobs in accordance with the procedure, and with the procedures given in the manual for the new Operating System. |

If we look at the very general procedure-preparing function—that which accepts new processing requirements from User Management and produces various manual procedures and/or computer programs for Data Processing Operations, along with new resource requirements for User Management (see Figure 2.20), we might specify the workload as suggested in Table 2.21.2. Comments:

1. The task shown is extraordinarily broad in scope, extending from the Management decision regarding a new requirement (but not including that decision) to the inputs to Data Processing Operations, and including *all* the procedures which must be prepared—for computer and keypunch operators, data collectors, forms designers, etc., as well as for a computer. By identifying such a task, I want to bring out two points: that the solutions to some problems (e.g. misunderstandings about the requirements) are unlikely to be found if we confine our analysis to the functions too close to the computer; and that it may be possible to employ computers more broadly in procedure-generation if we understand better everything which must be done.

2. The workload parameters shown are solely a function of the jobs to be done, not of the system provided to do them. Put another way, the parameters are independent of which computer is used to handle the job, or in fact of whether a computer is used at all.

3. The actual "values" of the parameters shown presumably vary widely from one organization to another and from one function to another. However, the extent of the variation can only be determined by measurement—by collecting data. Presumably an individual organization could analyze its existing and incremental data processing operations over a period of time and could develop a statistical picture of its workload. A computer Users' Group could sponsor a study or gather useful information by questionnaire. But today there seems to be little published statistical data on workloads, as we shall see in a moment.

4. The very useful systems and products which have been developed and which still are being developed to prepare procedures—the languages, on-line systems, fixed-format systems, data management systems, etc. discussed above—have generally been developed by individuals, committees, or organizations which have *not* had available a workload description of the kind discussed here. Upon reading the history of language development (e.g. SammJ69, RoseS72), one is struck by the number of languages which exist, and by the modifications which have been made to even the successful ones. What accounts for the success of languages such as APL and BASIC, and of the report generators like RPG and MARK IV, unless it be that they solve user problems neglected or overlooked by designers who had no clear picture of the problems earlier systems were suppose to solve? Would all these types and varieties of language be necessary, and would so many changes in specification have occurred, if we had a better understanding of the workload we were trying to handle? I can sympathize with the developers of FORTRAN, and even COBOL, for they planned those languages at a time when the whole field was very new. But what workload description did the designers of PL/I use? What assumptions are being made today by Data Management System designers regarding the size, structure, and access requirements of user files? If workload data bases exist, they are difficult to locate. Even when technical papers are published on workloads (e.g. FerrD72) the emphasis is usually on workloads as a tool to be used in measuring the performance of existing systems, not as a tool in the design of higher-level systems. As a result, the tendency is to focus on the workload that today's computers see, not the total workload as seen by a Data Processing Organization.

Some statistical data is available for some of the workload parameters listed in Table 2.21.2. I have found nothing on the first item, having to do with the statement of requirements, though it appears that some research has been initiated on the general subject of formalizing application specifications (LiskB75). There is some data on file requirements and input/output data requirements, which we will discuss next. In addition, there is some information on processing requirements at the procedure *execution* level. We will discuss that data later, and will comment on its relationship to procedure preparation.

A series of studies was conducted by the U.S. Army and Air Force of a total of 38 applications in the general category of "Management Information Systems," and including such things as payroll, inventory control, and personnel systems. Many of the applications are duplicated at more than one site. A report describing the results of these studies presented data, in standard format, on some workload characteristics (see Tables II.2.21.1 and II.2.21.2). Figures 2.21.1 to 2.21.5 show how certain parameters were distributed among the various applications. The number of input characters read per month and the number of output characters produced are shown in the first two figures. (The report did not indicate how many times per month each program was run, so it is not possible to tabulate I/O characters per run). Note that, on the average, the number of output characters substantially exceeds the number of input characters. Figure 2.21.3 shows that the average ratio of output to input characters is greater than five, with a median about 2.3.

Most of the systems referenced data bases, stored on cards, tape, or disks. The distribution of data base size is shown in Figure 2.21.4, and of record size in Figure 2.21.5. Only 10% of the systems required no data base, and over half had files in the range of ten to 100 million bytes. Record size is generally small, with a median of only 150 bytes—more than a third of the files contained records of less than 100 bytes, though none was smaller than fifty.

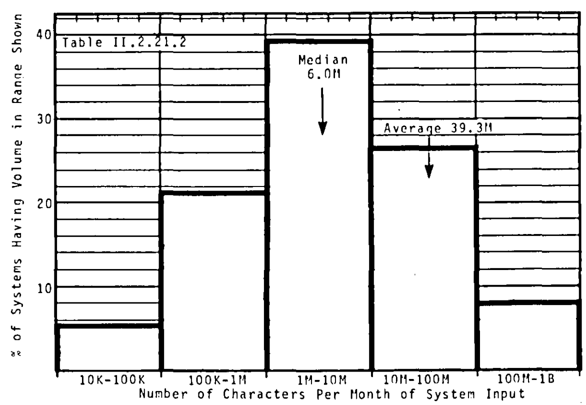



FIGURE 2.21.1 WORKLOAD CHARACTERISTICS I.
VOLUME OF INPUT CHARACTERS

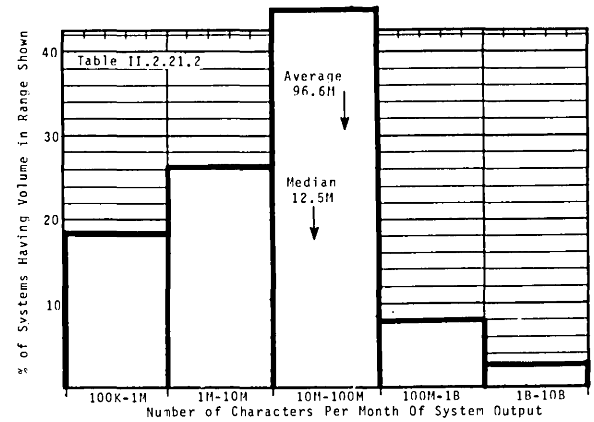



FIGURE 2.21.2 WORKLOAD CHARACTERISTICS II.
VOLUME OF OUTPUT CHARACTERS

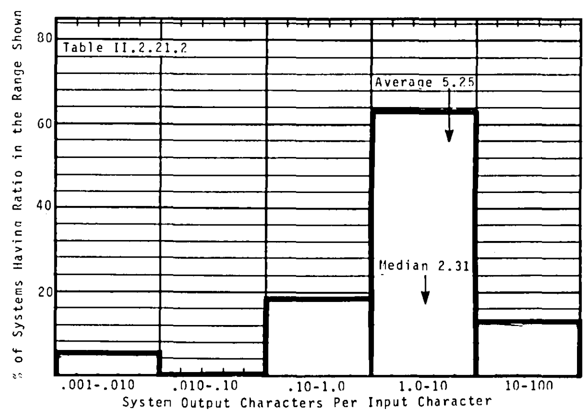



FIGURE 2.21.3 WORKLOAD CHARACTERISTICS III.
RATIO OF OUTPUT TO INPUT CHARACTERS

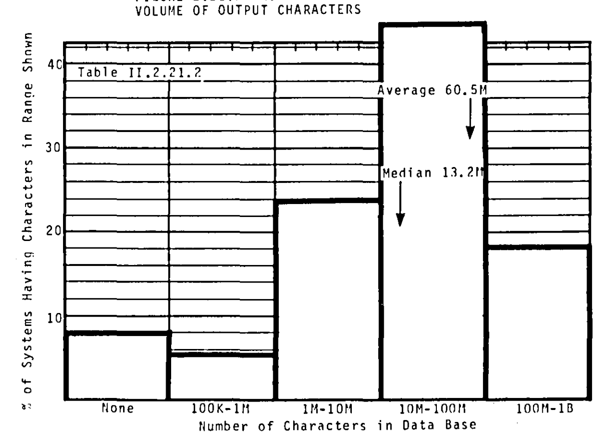



FIGURE 2.21.4 WORKLOAD CHARACTERISTICS IV.
SIZE OF DATA BASE

## TABLE 2.21.2 WORKLOAD SPECIFICATIONS: SYSTEM ANALYSTS' PROCEDURE PREPARATION

| Input | Output | Workload Parameters |
|---|---|---|
| New processing requirements from User Management | 1. New Resource requirements to User Management, if necessary.<br>2. New manual procedures to Data Processing Operations.<br>3. New Program to Data Processing operations. | 1. Form and format of statement of requirements. (Completeness, consistency, ambiguity)<br>2. Relationship of new task to existing ones. (Commonality of files, input, output, or processing.)<br>3. File requirements. (Number of records, fields per record, characters per field. Updating frequency required, and expected percentage of total records modified per update. Expected growth or shrinkage rate of file.)<br>4. Data Types. (Integers, complex numbers, arrays of data. Range and precision required for numeric data. Number of distinct symbols required for non-numeric data.)<br>5. Input data characteristics. (Location and nature of the "transaction" generating the data. Amount of data per transaction, and expected frequency of transactions.)<br>6. Output data requirements. (Required frequency, turnaround time, and priority of reports. Format required. Amount of data per report. Geographical location where reports will be used.)<br>7. Processing requirements. (Relative frequency of occurrence of arithmetic operations, mathematical functions—e.g. sine x—or operations—e.g. matrix inversion—and logical procedures—e.g. sorting.) |

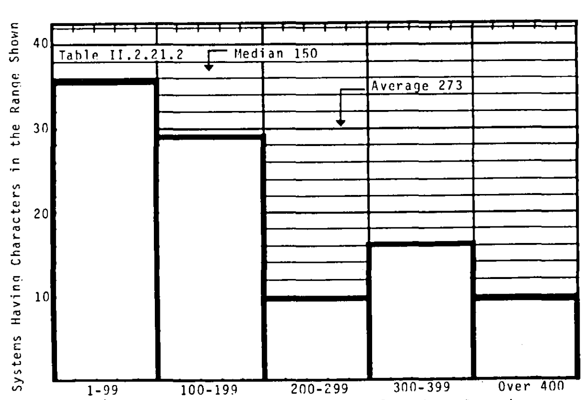



FIGURE 2.21.5 WORKLOAD CHARACTERISTICS V.
SIZE OF RECORDS IN THE DATA BASE

Three other studies reported on input and output characters *per job* at three universities. Results are summarized in Table 2.21.3, and compared with the Army-Air Force data which of course is not strictly comparable because it represents monthly figures for production jobs. The university data represents both research and instructional jobs, some successful, and some unsuccessful due to program or input-output errors. The average number of input and output characters per job are remarkably close for two of the universities, but are a thousand times lower than the *monthly* I/O rates for the Army-Air Force jobs. The average ratio of output to input characters, however, was comparable.

### Procedure Execution

As was indicated in Table 2.21.1, one can regard many system workloads as either being procedure-preparation or procedure-execution. Table 2.21.2 describes facets of procedure preparation which have not yet been mechanized—the work of the Systems Analysts and programmers. The workload specifications shown in the last column of that table apply to the job itself, and are intended to be independent of the way that job is implemented (though of course the specific data summarized in Figures 2.21.1-5 and Table 2.21.3 was measured in connection with specific implementations).

Let us now shift our attention to procedure execution as performed by computers. Table 2.21.4 describes the workload in this context. Note that workload characteristics are similar to and (for a given application) a function of the workload parameters of the job as seen by the systems analyst. For example "Processing Requirements" as seen by the systems analyst (Table 2.21.2) includes the relative frequency of occurrence of arithmetic operations as necessary to handle the function. The workload parameters for an assembly or compilation or for the running of an object program (both shown in Table 2.21.4) similarly include the frequency of use of arithmetic statements in the source code, and the frequency of occurrence of arithmetic instructions in the running program. But note the latter parameters are influenced by the language used, the programmer's experience, and the computer's instruction list as well as by the application itself.

There is some data, though not as much as one would like to see, on workloads in this somewhat different context. With regard to language features used, a lucid and entertaining article by Knuth (KnutD71) presents what seems to be the first data on the characteristics of actual applications programs, and specifically FORTRAN programs. Knuth and his colleagues selected a sample of 440 programs written at Lockheed Corp. computer center, and another 50 collected at Stanford University. All of these were analyzed on the basis of the statements appearing in the listings—a static analysis of interest to compiler designers as a description of the source code workload. In addition, a random subset of 24 programs was analyzed dynamically, and the investigators counted the frequency with which each statement occurred during a *run* of the program. The results are shown in Tables 2.21.5 and 2.21.6. The Lockheed programs contained an average of 436 statements and 120 COMMENT cards. (The non-COMMENT cards averaged 48 blank columns per card.) Roughly half the statements were assignment statements, and almost 70% of *those* were of the trivially simple form A = B. More than half of the DO loops contained only one or two statements and less than half contained other nested DO loops. Addition and subtraction occurred (statically) more than half again as frequently as multiplication and division. Knuth suggests one generalization with respect to the static characteristics: "Compilers spend most of their time doing surprisingly simple things."

**TABLE 2.21.3 WORKLOAD CHARACTERISTICS—A COMPARISON**

| | | University of: | | | | | | | Army/A.F. |
|---|---|---|---|---|---|---|---|---|---|
| | | Washington | Michigan | Manchester | | | | | MIS |
| Number of Jobs | | 1588 | 4436 | | | | | | * |
| Averages Per Job | | | | | | | | | |
| Compute Time | secs | | | 0.5 | 3.3 | 32. | 310. | 1200. | |
| Program Length | kwd | 17.9 | 11.16 | | | | | | 97.7 |
| Input Characters | kBy | 17.92 | 16.24 | 2.8 | 7.0 | 12. | 14. | 9. | 39,300. |
| Output Characters | kBy | 100.3 | 98.3 | 3.6 | 12.8 | 40.0 | 57.6 | 56.0 | 96,600. |
| Total I/O Char. | kBy | 118.2 | 114.5 | 6.4 | 19.8 | 52. | 72. | 65. | 135,900. |
| Per Instruction | kBy | 6.6 | 10.26 | | | | | | 2,008. |
| Output Char./Input Char. | | 5.60 | 6.05 | 1.3 | 1.8 | 3.3 | 4.1 | 6.2 | 5.25 |
| Computer Operations/Char. | | 84.6 | 417.5 | 26.0 | 55.6 | 205. | 1435. | 6153. | 1480 |

Source: See Tables II.2.21.3 and II.2.21.4
*Input/Output character counts shown in this column are *monthly* figures, averaged over 38 Army/Air Force Management Information systems.

**TABLE 2.21.4 WORKLOAD SPECIFICATIONS: COMPUTER SYSTEM PROCEDURE EXECUTION**

| Input | Output | Workload Parameters |
|---|---|---|
| 1. Program written in assembly or higher-level language | 1. Object program ready to run on specific system. | 1. Language features used. (Relative frequency of use of data types, operators, commands, declarations, etc.) |
| 2. Data to be processed by a given object program, using a given data base. | 1. Update of data base. 2. Reports, notices, or tabulations for use in other systems | 1. File requirements. (Number of blocks, records per block, fields per record, characters per field. Storage medium employed. Expected percentage of total records modified per update.) 2. Input data characteristics. (Amount of data per transaction processed, and number of transactions per run.) 3. Output data requirements. (Format required, |

**TABLE 2.21.4 WORKLOAD SPECIFICATIONS: COMPLETE SYSTEM PROCEDURE EXECUTION (Continued)**

| Input | Output | Workload Parameters |
|---|---|---|
| | | output media specified, and amount of data per report.) 4. Processing characteristics. (Length of program. Operating properties of program, including the proportion of time spent executing various subsets of the entire code, and the relative use of different instructions and features of the machine. Number of instructions executed per input-output character handled.) |

**TABLE 2.21.5 A STUDY OF FORTRAN PROGRAMS I: THE DISTRIBUTION OF STATEMENT TYPES**

| Statement Type | Static Statistics 440 Lockheed Programs (Number) | (Percent) | Stanford Programs (Percent) | 24 Sample Programs (Percent) | Dynamic Statistics 24 Sample Programs (Percent) |
|---|---|---|---|---|---|
| Assignment | 178 | 41 | 51 | 51 | 67 |
| A = B | 121(1) | | | 23(1) | 23(1) |
| IF | 64(2) | 15(2) | 8(2) | 10 | 11 |
| GO TO | 57 | 13 | 8 | 9 | 9 |
| CALL | 34 | 8 | 4 | 5 | 3 |
| CONTINUE | 21 | 5 | 3 | 4 | 7 |
| WRITE | 18 | 4 | 5 | 5 | 1 |
| FORMAT | 17 | 4 | 4 | | |
| DO | 17 | 4 | 5 | 9 | 3 |
| DATA | 10 | 2 | 0.3 | | |
| RETURN | 8 | 2 | 2 | 4 | 3 |
| DIMENSION | 8 | 2 | 1 | | |
| READ | 1 | 0.3 | 1 | 2 | 0 |
| Other (4) | 40 | 8 | 11 | 1 | 0 |
| Total (2) | 473(2) | 108%(2) | 103%(2) | 100% | 104% |

Notes:
(1). The trivial assignment type A = B represents 68% of total assignment statements for the combination Lockheed-Stanford programs, less for the 24 sample programs.
(2). The entry "IF ( ) Statement" counts as both an IF and a Statement. Therefore the totals add to more than 100%, and to more than the total number of statements in the average Lockheed program. Not counting these duplicates, the average Lockheed program contained 436 statements.
(3). The Lockheed programs each contained an average 120 COMMENT cards and 31 CONTINUATIONS.
(4). Each of the statements included in the "Other" category occurred with a frequency less than 2%.
(5). Source: KnutD71

**TABLE 2.21.6 A STUDY OF FORTRAN PROGRAMS II: STATIC CHARACTERISTICS OF LOCKHEED AND STANFORD PROGRAMS**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Length of DO Loop** (i.e. Number of Statements) | | | | | | | |
| Length | 1 | 2 | 3 | 4 | 5 | >5 | | |
| Percent | 39.0 | 18.5 | 9.5 | 7.0 | 13.0 | 13.0 | | |
| | | **Depth of DO Loop Nesting** | | | | | | |
| Depth | 1 | 2 | 3 | 4 | 5 | >5 | | |
| Percent | 53.5 | 23.0 | 15.0 | 5.5 | 1.5 | 1.5 | | |
| | | **Complexity, (1) of Assignment Statements** | | | | | | |
| Complexity (1) | 0 | 1 | 2-4 | 5 | 6-7 | 8 | 9 | |
| Percent | 68.0 | 17.5 | 1.7 | 3.0 | 2.6 | 3.0 | 0.6 | |
| | | | **Occurrence of Operators and Constants** | | | | | |
| Operator | + | - | * | / | ** | = | Standard Function | Constant |
| Percent (2) | 9.5 | 5.4 | 6.5 | 2.5 | 0.58 | 47.5 | 2.1 | 26.0 |
| Ratio (3) | .22 | .12 | .15 | .057 | .013 | 1.08 | .048 | .59 |
| | **Occurrence of Indexed Variables** | | | | | | | |
| Indices | 0 | 1 | 2 | 3 | 4 | | | |
| Percent | 58.2 | 30.5 | 9.7 | 1.2 | 0.2 | | | |

Notes:
(1). Complexity is computed by counting one point for each + or - sign in a statement, five for each *, and eight for each /.
(2). There were a total of 190,103 operators, standard functions, and constants. This line shows the percentage each is of that total.
(3). There were a total of 83,304 assignment statements. This line shows the ratio of number of operators to number of statements.
(4). Source: KnutD71

The dynamic statistics are not strikingly different from the static ones (see the last two columns, in Table 2.21.5). Assignment and CONTINUE statements occur more frequently, and DO statements less frequently— but note that the sample is fairly small. The dynamic tests were, however, especially useful in helping programmers improve the performance of their code, and more data from Knuth's paper is supplied in connection with a discussion of programmer performance in Section 2.22.

With regard to the other workload parameters shown in Table 2.21.4, some data on files and on input/output requirements has already been covered in Figures 2.21.1 to 2.21.5. Processing characteristics have been studied from a number of points of view, over the years, and some statistics have been published. Both the Army-Air Force report and two of the university studies, previously discussed, gave information on program length, for example, with the results shown in Figure 2.21.6 and Table 2.21.3. These same studies also provided data from which one can estimate the number of basic CPU operations (instructions) carried out per input-plus-output character. (These estimates were made by multiplying the given processor time by processor speed, and dividing by the sum of input and output characters processed. Part II gives details on the calculations.) The results for the Army-Air Force study is shown in Figure 2.21.7, and for the university studies as the last line in Table 2.21.3. Note that about half the samples lie in the range of 100 to 1000 operations per character; virtually all of them fall in the range between 50 and 5000 operations per character.

It would appear that this ratio is an extremely important parameter for use in characterizing workloads. As we shall see in Section 2.23, it helps determine whether a particular system is limited by processor speed or by input-output capacity in handling a given application. We will define the ratio more precisely, and evaluate the data shown in the present tables and figure, when we make use of it in the later section.

Looking in more detail at processing characteristics, we find various kinds of data have been collected mostly by development organizations interested in evaluating the effect of new hardware features on system performance. One interesting parameter is the number of sequential memory references made by a processor in the course of executing a program. What are the average number of instructions carried out between "jumps" (commands which transfer program control to a memory location not immediately after the jump command itself)? How often are two successive data words accessed from successive memory locations? Table 2.21.7 answers these questions for three programs run on the IBM 7094 computer. The first two columns show, for each program, the average number of instructions executed between jumps, and the standard deviation from that average; the second pair of columns provides similar data on successive data words read from or written into memory (ignoring the intervening memory references for instructions); and the third pair supplies similar data for the mixture of data and instruction references. Note the relatively small number of commands executed between jumps, and the fact that the chances are against two successive memory references from successive memory locations, taking both data and instructions into account.

Though the sample is small, this data seems to indicate that programs don't exhibit much "locality"— while executing programs—the computer's memory address register would appear to change very frequently from one portion of memory to another. But another experiment, examining memory references from a broader point of view, shows that programs in fact *do* display considerable locality. Figure 2.21.8 shows the results of an experiment which examined a stream of 60 million address references (instructions and data) in 20 customer applications programs running on IBM 7000 series machines. The experiment simulated the running of these programs on a hierarchical memory system of the kind shown in the figure. A processor requests instructions and data, as determined by the programs, from a local store of given size. If the requested information is there, well and good. If it is not, a block of data (of given size smaller, of course, than the size of the local store) containing the desired information along with other data and instructions, is read from a backing store, replacing an equal-sized block in the local store. The simulation was carried out over samples of 200,000 memory references, and the average ratio of bits transferred between backing and local store to bits transferred between local store and processor, was computed. And the simulated experiment was repeated for various sizes of local store and block transfer.

This experiment was designed to evaluate the cache memory—a very-high-speed but small local store inserted between processor and main (magnetic core) memory to improve performance by reducing average memory access time. Because programs *do* display locality, the cache memory is viable, assuming that its characteristics are suitably chosen. For example, if a 2048-byte local store is loaded with 16-byte blocks, then only ten bytes need be transferred from backing store for every hundred bytes used by the processor. There therefore exist sections of program which access a less-than-2048-byte subset of total program words ten times for every time they access some program word outside the subset. Compare this result with a "straight-line" program which contains no loops and accesses data adjacent to the instructions. In such a program each byte would be transferred once from backing store for each use by the processor, and the ratio b/c would equal unity, independent of the size of blocks and local store.

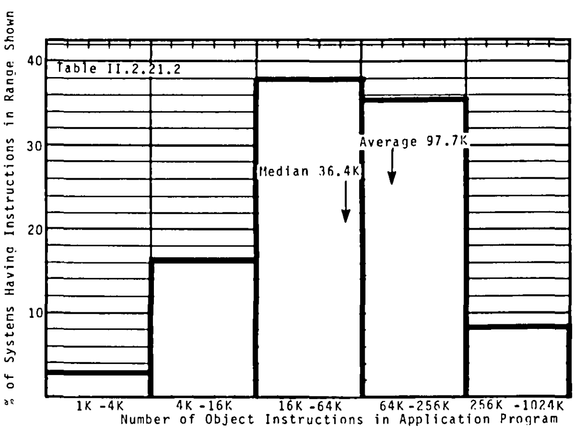



FIGURE 2.21.6 WORKLOAD CHARACTERISTICS VI
SIZE OF APPLICATION PROGRAMS

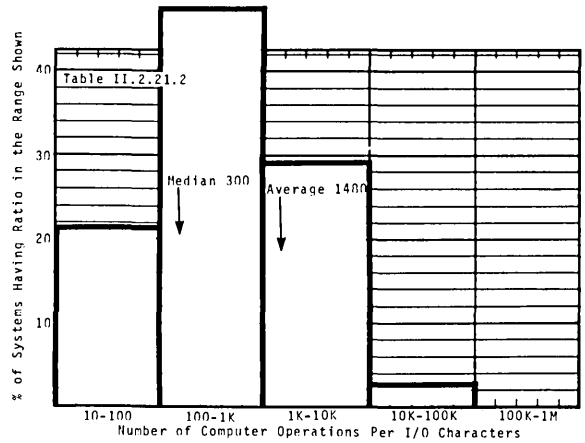



FIGURE 2.21.7 WORKLOAD CHARACTERISTICS VII.
COMPUTER OPERATIONS CARRIED OUT PER I/O CHARACTER

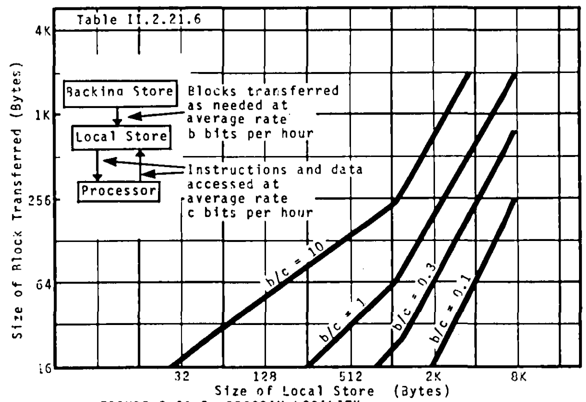



FIGURE 2.21.8 PROGRAM LOCALITY
RELATIVE TRANSFER RATE BETWEEN LOCAL & BACKING STORE

## TABLE 2.21.7 SEQUENTIAL MEMORY REFERENCES BY THREE PROGRAMS

| Program Number | Instructions In Sequence Mean | S.D. | Data Words In Sequence Mean | S.D. | Tot. References In Sequence Mean | S.D. | Number of References In Sample |
|---|---|---|---|---|---|---|---|
| 1 | 14.44 | 13.7 | 1.05 | .27 | 1.08 | .29 | 83856 |
| 2 | 4.52 | 8.8 | 1.04 | .30 | 1.09 | .37 | 190608 |
| 3 | 3.78 | 3.7 | 1.38 | .63 | 1.33 | .86 | 1392 |

Source: SissS68. See Part II

One set of measurements which has been reported at various times has to do with the relative frequency of use of various types of instruction. Occasionally one hears reference, for example, to "the Gibson Mix," which presumably is an estimate or average of instruction usage. In fact, there seems to be no paper by a Gibson on this subject, though several authors mention Gibson Mixes. Table 2.21.8 shows some of the figures which have been reported. Comments:

1. There is not much agreement between the various studies, even the two described as "Gibson Mixes". Note for example that the proportion of arithmetic commands executed ranges from nine to sixty percent.

2. Multiplication and division, generally the slowest instructions in any computer because of their complexity, typically represent one to eight percent of executed commands. The exception is a matrix multiplication application, where almost 16% of the commands are multiplications.

3. Roughly 10% to 30% of commands executed are branches (jumps), conditional or unconditional. This high proportion is what one would expect for we have seen (Table 2.21.7) that the mean number of instructions executed in sequence lies in the range 3-15.

One final compilation of data on instruction execution appears in Table 2.21.9. For six specific classes of program and a total of over ten million instruction executions, it shows the proportion of instructions making various types of memory reference, and also shows the ratio of data to instruction words. Note that there were 30% to 90% more memory fetches than memory stores, that branches averaged about a third of all instructions, and that about as many words referenced were instructions as were data words. These results are, however, heavily influenced by the number of registers in the hardware. Part of the experiment was rerun using a machine having more registers, with the result that register-type instructions increased by from 40% to 360%, with a corresponding decrease in other types.

The workload parameters we have discussed thus cover a wide range from those which are very machine- dependent (e.g. proportion of register references) to those completely independent of the system used (e.g. ratio of output to input characters, size of data base). The crucial parameter "operations per character" shown in Figure 2.21.7 probably falls between these two extremes. Ideally we would like to define some set of standard, machine-independent information-processing functions, and be able to characterize a particular workload in terms of functions required per input-output character. For any given machine we then might know how many computer operations are required per function, and could thus deduce the computer operations required per character for that particular job on that particular system. But in the absence of better definitions and data, I shall assume that all systems require the same number of computer operations per information-processing function, and therefore that operations per character is a good workload measure.

## 2.22 HUMAN PERFORMANCE

Computers are tools used by and for people. Computer room operators load and unload media, and handle exceptions of various kinds. Programmers and Systems Analysts prepare procedures. Clerks and keypunch operators supply data to the system. Scientists and engineers solve problems at computer terminals. Managers read computer tabulations. In all these activities the speed and accuracy with which a human can perform some perceptual or manual function is therefore of some importance, and in this section we will examine some of the available data on human performance.

**Input-Output Properties.** We have five senses, and therefore presumably could input information via taste, touch, and smell, as well as sight and hearing. In practice, of course (except for those who read Braile) we make use of sight and hearing to acquire data, and typical input rates are shown in Table 2.22.1. An average rate for reading and understanding normal text is around 200 words per minute or 20 bytes per second. However, training and practice in "speed reading" leads to very substantial performance improvements, and rates ten times the average are not uncommon. The audio input rates shown are copied from the "talking" rates in the second part of the table, assuming of course that humans hear what is spoken. It seems likely that the peak audible input rate might be much higher than that shown, but I have not found reports of any experiments aimed at measuring hearing rates, for high-speed (presumably machine-generated) audio information.

Human output rates are shown in the next portion of the table, based on audible and mechanical signals. (The human body employs electrical signals internally, but so far there have only been very primitive attempts to use them to control data output channels.) Speech is the fastest means of transmitting data, with a peak rate of 300 words per minute reported. The stenotype machine was designed to transcribe speech and obviously has an equivalent output rate, though it requires a specially-trained operator. The written, "pencil" output rates, on the other hand, are typical of the untrained person transcribing arbitrary, non-textual material. They are thus comparable to the keypunch rates shown earlier in the table. Note that the use of mark-sense forms inhibits input speed, though presumably a mark-sense reading device is simpler, cheaper, and more reliable than a hand-print character reader.

Actual rates, of course, may vary widely from those shown in the table, depending upon individuals and circumstances. But it is interesting to reflect on the mismatch between input and output rates, and on the potential advantage of speech as an output channel (see TurnR74).

**Computer Operator Activities.** The salaries of computer operators represent a non-trivial fraction of the total cost of operating a computer system, and their capabilities and functions should be kept in mind when we are designing equipment or programs, and planning computer facilities. Table 2.22.2 shows the result of an analysis in the late sixties of operator activity in twenty-five Univac installations. Comments:

1. The operator spends more than a third of his time at the processor console, the median time spent there being about a minute. Since nearly half of operator idle time is spent at the console, it seems likely that the operators return there when there are no operator functions to be performed. (Perhaps the only chairs in the computer room are at the console.)

2. About a sixth of the operator's time is spent moving between units.

3. The operator is inactive almost half the time.

Careful layout of the computer room, with the console centrally located and the busy peripheral units nearby, can pay off in reduced "moving" time. Furthermore, the large

**TABLE 2.21.8 RELATIVE PROPORTION OF INSTRUCTION TYPES EXECUTED (Gibson Mixes)**

| Reference: Mix Type: | ArbuR66 | SmitM68 Gibson | Matrix Mult. | SoloM66 Float. Sq. Rt. | Field Scan | KnigK68 Sci. | Comm. | BellC71 Gibson | RaicE64 | CresM63 |
|---|---|---|---|---|---|---|---|---|---|---|
| Transfer Data | 28.5 | (19.3) | (27.2) | (22.2) | (9.6) | | | 25 | 47.5 | 20 |
| Load | | 10.4 | 21.2 | 20.6 | 9.0 | | | | | |
| Store | | 5.2 | 6.0 | 1.6 | 0.6 | | | | | |
| Move | | 3.7 | | | | | | | | |
| Arithmetic | (17.1) | (24.6) | (51.0) | (31.8) | (17.9) | (28) | (26) | (10) | (9.0) | (60) |
| Add/Subtract | (9.5) | (17.9) | 35.4 | 17.5 | 17.9 | (20) | (25) | (6) | (8.5) | 55 |
| Fixed | | 10.4 | | | | 10 | 25 | 6 | 8.0 | |
| Floating | 9.5 | 7.5 | | | | 10 | | | 0.5 | |
| Multiply/Divide | (7.6) | (6.7) | | | | (8) | (1) | (4) | (0.5) | (5) |
| Fixed | | .6 | | | | | | | 0.3 | |
| Floating | 7.6 | 6.1 | | | | | | | 0.2 | |
| Multiply | (5.6) | (4.2) | 15.6 | | | 6 | 1 | 3 | | 3 |
| Divide | (2.0) | (2.5) | | 14.3 | | 2 | | 1 | | 2 |
| Logic | | (4.7) | | (15.9) | | | | | (14.5) | |
| Shift | | 3.4 | | 15.9 | | | | | 7.5 | |
| Miscellaneous | | 1.3 | | | | | | | 7.0 | |
| Branch | (13.2) | (18.1) | 21.8 | 28.6 | 45.8 | | | 30 | (12.5) | 20 |
| Conditional | 13.2 | 9.6 | | | | | | | 7.5 | |
| Unconditional | | 8.5 | | | | | | | 5.0 | |
| Index/Increment | 22.5 | 33.4 | | | 22.2 | | | 24 | 13.5 | |
| Miscellaneous | 18.7 | | | 1.6 | 4.5 | 72 | 74 | 11 | 3.0 | |

Source: See Part II. Note: The parenthetical figures are subtotals, shown for comparative purposes. But in each column, the numbers not in parenthesis sum to 100%.

**TABLE 2.21.9 RELATIVE PROPORTION OF INSTRUCTIONS HAVING VARIOUS TYPES OF MEMORY REFERENCES**

| | Units | FORTRAN Execution | String Proces. | Simu-lation | List Proces. | FORTRAN Compil. | COBOL Execution | Average (All) |
|---|---|---|---|---|---|---|---|---|
| Instructions Traced | M | 4.02 | 0.28 | 1.29 | 1.13 | 1.74 | 1.89 | 10.35 |
| Percentage of Instr. | | | | | | | | |
| Fetch in Memory | % | 36 | 38 | 28 | 26 | 28 | 28 | 29 |
| Store in Memory | % | 20 | 23 | 27 | 25 | 22 | 15 | 22 |
| Use Registers Only | % | 11 | 15 | 20 | 19 | 14 | 14 | 15 |
| Branch or Jump | % | 33 | 24 | 25 | 32 | 36 | 43 | 34 |
| Data Words: Instr. Words | % | 57 | 61 | 55 | 49 | 54 | 45 | 51 |

Source: See Part II.

**TABLE 2.22.1 HUMAN INPUT/OUTPUT RATES (Bytes per Second)**

| | Average Rate | Peak Rate |
|---|---|---|
| **Input** | | |
| Reading Print | 20. | 200 |
| Hearing (Conversation) | 15. | 30 |
| **Output** | | |
| Talking (Conversation) | 15. | 30 |
| Keyboards | | |
| Typewriter | 6.6 | 12 |
| Keypunch | 2.3 | |
| Ten-key | 8. | |
| Stenotype | | 30 |
| Pencil | | |
| Handwriting | 1.5 | 4 |
| Handprinting | 1.0 | |
| Marking (Note 2) | .3 | |

(1). Ten words per minute are assumed equal to 60 bytes per minute or one byte per second.

(2). "Marking" refers to putting pencil marks on a pre-printed form opposite selected numbers or letters. The forms may later be read automatically with mark-sensing equipment.

(3). The main sources were Table 3.21.1, TurnR74, and DevoD67. It seems surprising that Human Factors reference books generally do *not* contain data on human input-output rates.

**TABLE 2.22.2 ANALYSIS OF HOW OPERATOR TIME IS SPENT AT A LARGE-SCALE COMPUTER CENTER**

| Unit | Percent of Total Time: Total at the unit (%) | Inactive at the unit (%) | Active at the unit (%) | Median Time Spent (sec.) |
|---|---|---|---|---|
| Console | 35 | 21. | 14. | 62 |
| Work Tables | 17 | 5. | 12. | 6 |
| Card Readers | 13 | 3. | 10. | 14 |
| Magnetic Tape Units | 9 | 1.5 | 7.5 | 9 |
| Printers | 4 | 1.5 | 2.5 | 9 |
| Card Punches | 1 | .5 | .5 | |
| Other Units | 7 | 3. | 4. | |
| Subtotal | 86 | 35.5 | 50.5 | |
| Moving Between Units | 14 | 9.5 | 4.5 | 3 |
| Total | 100 | 45. | 55. | |

Source: See Notes in Part II.

amount of inactive time suggests that a careful scheduling of functions might reduce the number of operators necessary. On the other hand, the experimenters collected no data on the proportion of system time lost waiting for operators. We generally assume that time is negligible. If it is not, one might improve throughput and reduce total costs by *adding* operators or by taking other steps to reduce the time the system waits for operator action.

**Time Sharing Terminal Users.** People are spending a small but increasing fraction of their lives at keyboards "talking" with computers. System designers, who write programs and develop equipment to provide services through keyboards, and users, who one way or another pay for the time people spend "talking", are thus both interested in the dynamics of this activity.

One form of terminal user organizes and executes computations on time-sharing systems, and various measurements have been made of the user-computer interaction. Figures 2.22.1 and 2.22.2 summarize the situation: the first defines the terms used, the second gives typical times.

In these applications, a typical session may last an average of twenty-three minutes, and may consist of forty interactions each of thirty-five seconds' duration. An interaction starts with a five-second period during which the user thinks—decides what he will do next. That "think time" is followed by an input time which typically lasts fifteen seconds and spans the period from the time the first key is struck to the instant the last character of a request is entered. The computer is now the bottleneck, and the next segment of time is an idle period while the user waits. (The typical idle time is shown as one second. Its duration is, however, critically dependent on how heavily the system is loaded—it can be much longer.) The interaction ends with a fourteen-second computer output time, beginning with the first character received at the terminal and ending with the last one. The user's input time typically includes his entering ten characters, one at a time. The computer's output time typically includes some ninety characters, in three "bursts" with 2.5 seconds between bursts. (Table II.2.22.1 in Part II contains specific data on various systems. The reader who reviews that data will get some feeling for how these "typical" figures vary from system to system.) Comments:

1. If a session time typically lasts twenty-three minutes, much longer ones are quite common. Often the user of a terminal is connected to the computer via the public, switched communication network, where typical holding times for ordinary voice conversations are much shorter. The widespread use of the public network for data services is of some concern to the telephone companies, whose equipment was not designed to handle large numbers of long calls.

2. The user's *effective* "think time" is much longer than that defined by the figures. In fact, the user can begin to plan his next entry during the computer idle time, and can make plans which take into account the computer's current reply during the computer output time. (Other writers have used a definition of think time which encompasses output time.)

3. The ratio of nine output characters to one input character is high compared to the workloads we examined in Section 2.21.

Of course, many terminal users have characteristics quite different from those of time-sharing users. A user of a text-editing terminal, for example, typically may input a hundred characters—a typewritten line— for every character he receives from the computer. And his "think time" may be very short because he is copying material from a manuscript, so that he can start typeng a second line as soon as he finishes the first. To take another example, the typical "session" of the user of a stock market quotation terminal consists of a single interaction, including a two- to four-character request (of a stock price, by its official symbol) and a five- to thirty-digit reply from the computer.

The timing shown in Figure 2.22.2 is therefore simply to be regarded as an example of the kind of interaction which can be expected between user and computer. But the definitions employed should be useful in analyzing other applications; and the data gives us *some* insight into how these interactions take place.

**Programmer Effectiveness.** As we saw in Section 1.25, U.S. programming costs are over $10B per year and rising. Studies which help us understand how programmers and systems analysts work are thus potentially very valuable, for they could lead to reductions in that enormous annual expense.

We have already looked at one topic which is in part influenced by the characteristics of programmers as individuals: Tables 2.21.5 and 2.21.6 showed that programmers tend to use only the simplest language features when they write FORTRAN programs. Table 2.22.3 summarizes the results of five studies which supposedly compared the effectiveness of programmers working at terminals in a time-sharing mode with their effectiveness when programs were assembled, compiled, and debugged in a batch mode. One would expect that the quick turnaround and real-time interaction of time-sharing would facilitate and speed up the programmer's work.

The five experiments didn't all measure common aspects of the programmer's job, as is indicated in the first part of the table. The SDC studies, at one extreme, concentrated only on debugging time. The IBM study included both analysis and programming time, and the Stanford study (which actually compared two *batch* operations differing only in turnaround times—a few minutes for the "time-sharing" system compared with a few hours for the "batch") even included keypunch times. One way to compare the results is to compute the ratios of average man-hours for the time-sharing mode to average man-hours spent when working in the batch mode for each experiment. The next-to-last line in the table shows that ratio, and the last line displays a similar ratio for computer time.

It is difficult to draw any conclusions regarding batch and time-sharing operations from these experiments. Two of the five indicate that the batch mode is more efficient than the time-sharing mode as far as man-hours are concerned, and three of the five favor the batch mode with regard to computer time. But the experiments provided one set of measurements which both help explain the uncertain results, and give us some feeling for the nature of the programming problem. For four of the five experiments, the table shows the measured range of differences between individual programmers. Note that some programmers require fourteen times as many man-hours and eleven times as much computer time as others, working on identical jobs. The smallest ratios recorded were four to one.

This great variability observed between the performance of different programmers is widely known. Weinberg, for example, (WeinG71, p.135) refers to differences of as much as thirty-to-one between programmers on small projects. But in the past, all too often our response has been something akin to, "Programming is an art and there is nothing we can do to improve the efficiency of the artist." Thus Weinberg (p.134) argues "not every day is a good one for coding", and advocates that the programmer turn to something else when he feels one of those days coming on. More recently we have been taking a more scientific–as contrasted to psychological– view of the programming task, and have tried to understand the differences between good and bad programs. We are as a result developing new techniques and rules to help the inexperienced or weak programmer. ("Structured Programming" is a primary example of this work.) As we make use of research of this kind, we will not eliminate programmer errors, inconsistencies, and bad habits, but we should reduce them and thus improve the performance level of all programmers.

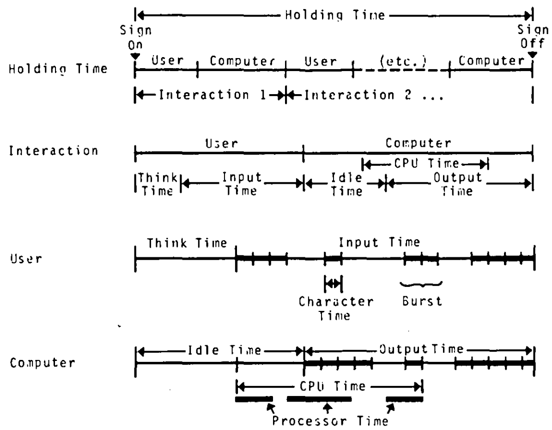



FIGURE 2.22.1 TIME SHARING USER CHARACTERISTICS I DEFINITIONS OF TERMS

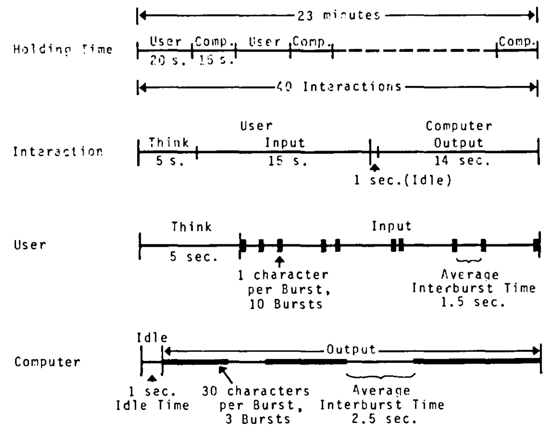



FIGURE 2.22.2 TIME-SHARING USER CHARACTERISTICS II SOME TYPICAL DATA

## TABLE 2.22.3 COMPARING PROGRAMMER EFFECTIVENESS ON TIME-SHARING VS. BATCH OPERATIONS

| Location of Study: | SDC | | MIT | | SDC | | IBM | | Stanford | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TS | B | TS | B | TS | B | TS | B | TS | B |
| Man-Hours | | | | | | | | | | |
| Debug | 5.0 | 9.6 | | | 19.3 | 31.2 | | | | |
| Problem-Solving | | | 15.5 | 19.3 | | | | | | |
| Analysis Time | | | | | | | 51.0 | 38.3 | | |
| Programmer Time | | | | | | | 94.5 | 45.6 | | |
| Program Prep | | | | | | | | | 7.33 | 6.75 |
| Keypunch Orig. | | | | | | | | | 1.82 | 1.80 |
| Prepare New Run | | | | | | | | | 5.18 | 4.88 |
| Total | 5.0 | 9.6 | 15.5 | 19.3 | 19.3 | 31.2 | 145.5 | 83.9 | 14.33 | 13.43 |
| Computer Time (min.) | 2.43 | 8.20 | 7.13 | 1.25 | 12.45 | 9.13 | 92* | 101* | 1.97 | 1.23 |
| Elapsed Time (days) | | | | | | | 29.5 | 46 | 3.0 | 3.7 |
| Range of Individual Differences in: | | | | | | | | | | |
| Man-Hours | 8:1 | 7:1 | 7:1 | 4:1 | 14:1 | 9:1 | 4:1 | 4:1 | | |
| Computer Time | 5:1 | 4:1 | | | 11:1 | 8:1 | | | | |
| T.S. : Batch Ratios | | | | | | | | | | |
| Man-Hours | 0.52 | | 0.80 | | 0.62 | | 1.73 | | 1.07 | |
| Computer Time | 0.30 | | 5.70 | | 1.36 | | 0.91 | | 1.60 | |

*Note: For the IBM experiment, computer times are not comparable. The batch system N2 is implemented on a 1.4 microsecond 7094-2, while the time-sharing system is on a 9.2 microsecond 7094-1.

## 2.23 COMPUTER SYSTEM PERFORMANCE ●

We are now at last in a position to consider the critical performance factors discussed in connection with Table 2.20.1: system Capacity and Maintainability. What data is available describing how these attributes have evolved over the history of the computer industry? Given the knowledge we now have of the workloads computers must handle and of the people who use computer systems, what can we deduce about Capacity?

**System Capacity.**

In discussing CPU performance in Section 2.11, we started with the simplest possible measures (addition time, memory access time, memory capacity) and then discussed successively more complex measures which have been invented in an attempt to take into account the complexity of what a processor does. We also looked at K. Knight's performance measure, which represented an early and ambitious attempt to measure system performance. These measures made it possible for us to compare the relative "speed" of different processors, measured in an equivalent number of operations per second.

But as we pointed out in Section 2.20, the data processing capacity of a system is a function not only of its hardware components, but also of the workload it is to handle and the personnel who operate and program it. In the next few pages we will describe the history of system capacity in this context, first using a more or less empirical approach based on a set of standard benchmarks, and then examining simplified mathematical models of system operation.

**Benchmarks.** If a potential buyer of computer equipment could take his application and run it on each of the systems he is evaluating, he could make a rational decision based on the time (and therefore cost) of handling his specific workload. Although that approach is feasible in some systems, it is not practical for many others—partly because the user cannot characterize his present workload accurately, partly because the workload will change and grow with time, and mostly because it is impractical to install and check out a complete set of application programs on even one system as part of a procurement cycle.

As a result, the idea of a set of benchmarks is attractive. A *benchmark* is a standard, well-defined task of a type often found in data processing installations. If a large enough set of such tasks were available, a prospective buyer could choose a subset similar to his expected workload and compare the performance of several systems each processing that subset.

In the early 1960's, the Auerbach Corporation established a small set of benchmarks, and until recently regularly published its estimates of the performance of all the important competitive systems, measured by the time required to solve each benchmark. In setting up the benchmarks, Auerbach first defined a number of "standard" equipment configurations ranging from simple card-oriented systems through a variety of magnetic tape and disk systems. For each computer evaluated, they first established the rental price for a pertinent set of the standard configurations. They then wrote programs for each configuration and for the appropriate benchmark problems, and computed program running time based on the published computer specifications. The benchmark problems were:

1. A file processing problem, in which a sequential Master File is updated by input transactions pre-sorted in the same sequence, and a transaction report is printed. The Master File is on magnetic tape except for the small card-oriented systems, where it is on punched cards. Transaction inputs are entered on cards and outputs are printed on a line printer, off-line for the large systems (which have separate I/O processors) and on-line for the others. Generally three running times are given for each configuration, corresponding to the situations where 0, 10, and 100% of the Master File records are updated by transactions.

2. A random access problem in which a Master File is updated by input transactions arriving in a random sequence, and a transaction report is prepared. The Master File is on a suitable random-access device, usually a disk. A two-stage indexing procedure is assumed necessary to locate a record in the file. Transaction inputs are assumed to arrive at a rate which insures that at least one is always waiting to be processed, and the transaction report is stored for printing at a later time.

3. A sorting problem in which 10,000 eighty-character magnetic tape records are arranged sequentially according to an eight-digit key.

4. A matrix inversion problem where a numerical matrix having at least eight-decimal-digit precision and expressed in floating-point form is inverted by the computer. The matrix elements are assumed to be located in internal memory, so no I/O operations are involved. Generally two running times are given for each system, one for a 10 x 10 and the other for a 40 x 40 matrix.

5. A mathematical problem where an input record containing ten eight-digit numbers is read, a series of floating-point arithmetic operations are carried out, and an eighty-digit output record is printed for every ten input records. Generally three processing times are given for each configuration, depending on whether the arithmetic operations are carried out 1, 10, or 100 times for each input record.

(More detail about configurations and performance is given in connection with Tables II.2.23.1 and II.2.23.2.)

In Figure 2.23.1 the benchmark performance of three of the most widely used systems—IBM's second-generation 1401 and third-generation 360/20 and /30—are plotted. In these curves and the ones that follow, the IBM 360/30 is arbitarily chosen to be the "standard" system against which others are compared. And the six-tape Business System, renting (in 1969) for $6960 per month and including six 30-kc magnetic tapes, a 500 line-per-minute printer, a 500 card-per-minute card reader, and internal storage for 2000 instructions and 8000 data bytes, is the reference configuration having relative performance and rental of 1.0. The rental of all other configurations is then expressed as a ratio to $6960 and the speed of other configurations in solving a benchmark problem is expressed as a ratio to the speed of the 360/30 six-tape Business System in solving that same problem. Each point plotted on the figure corresponds to the performance of a particular system configuration on one of the Auerbach jobs, relative to the 360/30. Comments:

1. For a given configuration (a horizontal line on the figure) a particular system generally displays a range of performance characteristics relative to the 360/30. The price-performance plot of a system thus typically occupies an area on the graph, and I have drawn outlines which encompass all points for each system. The odd shapes which result have no particular significance (to a large extent they arise simply because performance data is not available for every configuration—Auerbach computed only one processing time, for example, for the cheapest 360/20 configuration), but

presumably the relative positions of the various areas fairly reflect differences in price/performance relationships.

2. Knight's commercial performance measure is also plotted in Figure 2.23.1, identified by the letter K followed by the CPU number. The measure for the 360/30 itself is of course located at the point where performance and rental both equal one. Note that point K20 lies outside its Auerbach outline, apparently because Knight examined a very small 360/20 configuration.

3. The extraordinarily successful 1401 and 360/30 systems—numerically the most popular systems of their respective generations—encompassed almost precisely the same price range (though the 360/30's six-tape Business System cost only 70% of the cost of a corresponding 1401 configuration). But the newer machine was from five to 50 times as powerful as its predecessor.

4. The first two members of the 360 family cover a range of roughly four to one in price and twelve to one in performance, measured in terms of the Auerbach benchmarks.

5. Grosch's Law (performance increases as the square of price) is plotted as a diagonal dotted line through the point (1,1). The benchmark figures cannot confirm but surely do not deny the appropriateness of Dr. Grosch's hypothesis. (See also the similar lines plotted in subsequent figures.)

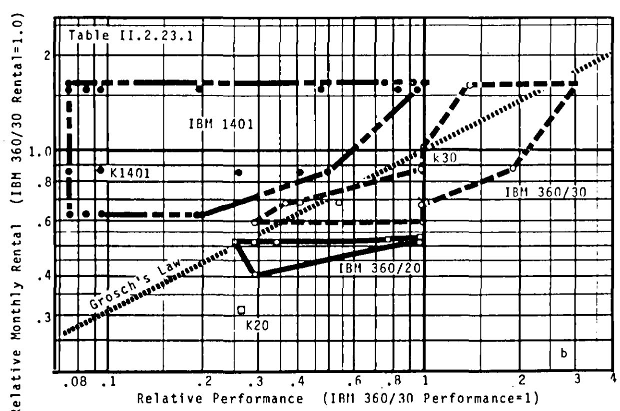


FIGURE 2.23.1 BENCHMARK MEASURES OF SYSTEM PERFORMANCE I.

6. For each system, there is a maximum coefficient of relative performance at a given cost. To simplify the presentation, we might plot only this "best" performance figure, corresponding to the right-hand boundary of the Auerbach outline. To show the performance range, we might add the range of the cheapest configuration—the bottom boundary of the outline. The resulting curve (which is plotted in Figure 2.23.2 for these same computers and some others) is generally concave upward, as one might expect: a small increase in the size of a modest configuration can lead to a large performance improvement; but each system basically has a maximum capacity limited by CPU speed and as this capacity is reached additions to memory capacity or to the peripheral complement have little or no effect in improving performance.

Four generations of IBM systems appear in Figure 2.23.2, and we can observe the performance improvements achieved from generation to generation. (Compare with Figure 2.11.8.) If we were to fit three different trend lines, one to the 1401- 1410- 2094, one to the 360/ family, and one to the 370/ family, they might quite reasonably be Grosch Law lines, having the slope shown at the bottom of the figure. Note, however, that the trend lines are apparently getting closer together, as if the second generation were a great improvement over the first, the third a lesser improvement over the second, and the 370's only a slight improvement over the 360's. This conclusion—that the *rate* of improvement in system performance per dollar has been falling off—is surely a reasonable one. We cannot expect that performance will improve at a constant rate indefinitely. But the rate of improvement shown here appears to be less than that indicated in Figure 2.11.7. And Knight's analysis, shown in Figure 2.11.8, seemed to indicate that, as of 1966, at any rate, performance improvements were accelerating.

The differences are a result of the different measures used. Figures 2.11.7 and 2.11.8 basically treat processor measures, while Figure 2.23.2 shows how rapidly systems solve simple benchmark problems. The former figures thus tell us something about theoretical best performance, and the latter something about actual practical performance. If most of a user's applications require that long magnetic-tape files be updated periodically, he might indeed have found a bigger performance improvement in trading from a 650 to a 1401 than he found in moving from a 360/30 to a 370/135.

But the Auerbach measures have a number of drawbacks. The benchmarks consist of only a limited number of applications, and the applications which are included are severely constrained so that the effect of changing critical parameters, like the magnetic tape blocking factor for example, cannot be observed. By far the most serious limitation is the fact that they do not evaluate the effects of system software—they measure system hardware performance only. With first- and second-generation systems little was done to improve throughput with software. But increasingly during the past ten years the effectiveness of an operating system has become a key factor in determining how well a user can apply the hardware's inherent power. Specifically, the operating system's ability to reduce hardware idle time by executing two or more jobs at once (multiprogramming) can substantially improve system throughput, so that one system having good multiprogramming software can outperform a system whose Auerbach benchmark performance is better but which uses unsophisticated software. The curves representing the 360/s and 370's of Figure 2.23.2 would thus slide further to the right if the benchmark measures properly demonstrated the effect of multiprogramming. And a user would observe performance improvements greater than those shown, in moving his applications from a second generation system to a multiprogramming 360 or 370, assuming his applications contained a mixture of jobs which balanced input-output and computation.

The Auerbach benchmarks give us some insight into the often-heard thesis that IBM systems give less performance per rental dollar than do its competitors. Figure 2.23.3 compares three important low-cost systems and five large systems. The IBM 1401, first shipped in 1960, was extraordinarily successful (see Figures 2.10.1 and 2.10.4). In 1964 Honeywell introduced the HIS 200 along with a program called "Liberator" which translated 1401 programs so they would run on the 200. Many IBM customers traded in their 1401's for 200's to handle bigger workloads at no additional expense, and some customers who would have used 1401's went to the HIS 200 instead. The very popular low-cost Univac 1004, introduced in 1963, is also shown in the figure. The 200 and 1004 are examples of widely-adopted systems with price-performance characteristics better than or equivalent to IBM systems which were introduced later—the IBM 360/20 and /30 weren't shipped until 1965, and were comparable in performance to the 1004 and 200 (see Figure 2.23.1).

We noted in Section 2.10 that the Burroughs 5500, the Univac 1108, and the CDC 6600 were each important systems in terms of installed computing power. The performance of all three of these systems is plotted in Figure 2.23.2, along with that of the 360/65 and 370/165. Comments:

1. The Auerbach measure of the BGH 5500 indicates that it is *not* competitive with the 360 family. However, Knight's performance index gives it a higher rating. And the success of the 5500 was due in part to its early use of multiprogramming (whose effect Auerbach doesn't measure), and in part to its unconventional design, which forced users to write programs in efficient high-level language.

2. The Univac 1108, introduced at about the same time as the 360/65, is two to four times as powerful for some applications, especially those requiring complex calculations, at a price 20% to 30% higher.

3. The CDC 6600, first delivered more than a year before the 360/65, is up to eight times faster for computer-bound calculations, yet cost only about 40% to 65% more for comparable configurations. Even IBM's 370/65, first shipped seven years after the 6600, cannot match its performance.

Let us now return to the effect of multiprogramming, attempting to see how it has evolved and to evaluate it quantitatively.

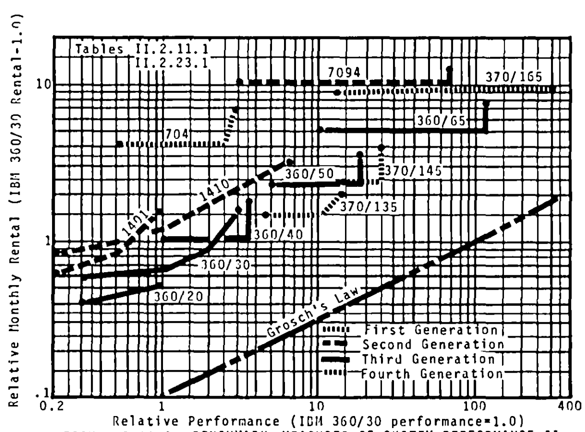



FIGURE 2.23.2 BENCHMARK MEASURES OF SYSTEM PERFORMANCE II FOUR GENERATIONS OF IBM EQUIPMENT

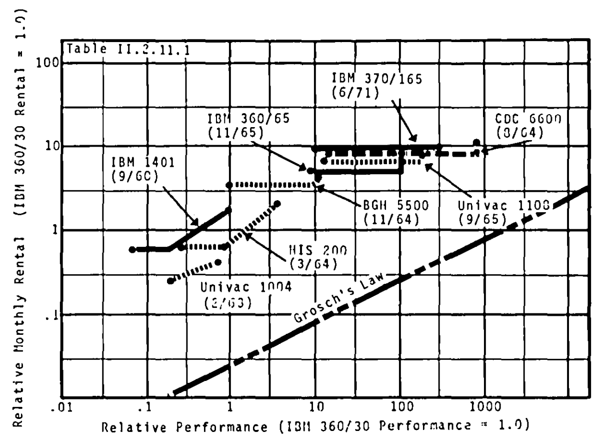



FIGURE 2.23.3 BENCHMARK MEASURES OF SYSTEM PERFORMANCE III. COMPARING IBM AND NON-IBM PRODUCTS

**A History of System Throughput.** In the beginning, back in the early fifties, operations were primitive and the world was amazed that computers worked at all. In their government and university environments they were often programmed, operated, and maintained by Ph.D.'s in Mathematics or Physics who delighted as much in inventing programming tricks as in solving numerical problems.

The first-generation business data processing installations were not, of course, able to call on such talented manpower resources to produce payrolls and keep accounts. Nevertheless, the operating procedures for first generation commercial systems were very similar to those of their primitive predecessors. At completion of one job, the computer stopped and the operator loaded cards or magnetic tape and set switches on the CPU and peripheral equipment consoles in preparation for a new job. Next the new program was loaded in the memory, and once again the computer stopped so that the operator could set up the system for the production run. The run would then take place, with data being read, computations performed, and results output in sequence—in the early systems only one of these functions could be performed at a time.

The just-described sequence of events is diagrammed in Figure 2.23.4a. In order better to perceive how early systems worked, and to trace the changes which have taken place in performance, we will establish a simple model which will enable us to examine individual systems and which can be expanded to treat more complicated system performance. The parameters of this model are given in Figure 2.23.5. Three sets of parameters are shown: workload parameters (input/output data characters, program size, and computer operations required per I/O character—the parameter shown in Figure 2.21.7 and Table 2.21.3); system characteristics (central processor and I/O rates, and operator time required to initialize the system); and characteristics which can be derived from the workload and system characteristics. Processor time per job is found by dividing the number of operations required per job by the processor's operating speed; I/O time is similarly found by dividing total I/O characters (including those required to read in the program) by the I/O rate. The value of computer operations per I/O character for which processor time equals I/O time is, as we shall see, a critical system parameter, and I have called it s(c). And throughput is defined as the rate at which data characters are processed.

With these quantities in hand, we can calculate throughput for the unbuffered operation of Figure 2.23.4a. The algebra is shown in Figure 2.23.4b. Processing time is the sum of operator times, the time required to read programs and data, and computing time. Throughput is the ratio of data characters processed to processing time; and in Figure 2.23.6 the dotted line shows how throughput varies with s. Comments:

1. Maximum throughput of D'/k, limited by the system I/O rate D' and the size of the processing program, can be approached if s is small—that is, if very little computation per character is required. As more and more operations are required per character, throughput falls off rapidly: for the critical value of s, throughput is only half the maximum.

2. The throughput shown by the dotted line is only achieved when operator time—the time required to set up a job, when both CPU and I/O are idle—is zero. In early systems, operator time was definitely not zero.

System designers were of course very aware that the early systems were inefficient, and the larger first-generation systems, along with an increasing proportion of second-generation systems, improved throughput by permitting simultaneous I/O and compute operations. Timing charts and equations describing the resulting "buffered" systems (so called because input and output functions took place through special "buffer" hardware independent of the CPU) are given in Figures 2.23.7 and 2.23.8. Two different situations exist depending on whether the CPU or the I/O equipment limits system performance. If, on the average, the time required to read programs and data and to output results is greater than the time required to perform necessary computations, the system is said to be I/O limited, and Figure 2.23.7 applies. As the timing diagram shows, the I/O channel is continuously in use, first to input the program and then alternately to input data and output results; and the processor operates intermittently, starting when input data is available and waiting while its results are printed or punched, and while new data is read in. In this situation, throughput is constant at its maximum value of D'/k.

On the other hand, if computation time is greater than I/O time, the compute-bound situation of Figure 2.23.8 results. In the timing diagram I assume that the I/O system is operated in such a way that programs and data are always available when required by the processor, so that processor capacity limits throughput to the maximum C'/s.

The resulting best throughput with buffered input/output is shown as a solid line in Figure 2.23.6. Note that for large or small values of s, unbuffered throughput approaches that of buffered systems. But where s/s(c) lies in the range $.2 < s/s(c) < 5$, a buffered system will provide *at least* a 20% improvement in throughput over an equivalent unbuffered system, with a maximum 100% improvement when s = s(c).

In practice, it is not easy to achieve the "best" throughput shown in Figure 2.23.6 for buffered systems. The practical difficulties which lead to reduced efficiency and less than maximum throughput include the following:

A. Operators may find it difficult to maintain a workload backlog necessary to keep the system busy. This problem stems in part from the fact that computer operating people may simply have too much to do (locating and loading cards and magnetic tapes, distributing printouts, operating the computer console, responding to error messages from the computer, loading special paper in the printer, etc.) and occasionally make errors or take coffee breaks. But in part it stems from the fact that a user may procure a system having extra capacity, either to allow for growth or to handle periodic peak loads, with the result that the system is necessarily idle at some periods.

B. Given perfect operators and a heavy workload, it is very difficult to design the system so that the processor (in a compute-bound system) or the I/O channels (in an I/O-limited system) are continuously in operation. The practical problems faced by the system designer may be described as follows:

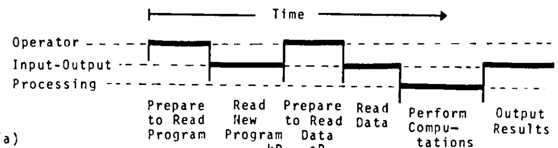
1. It is difficult to overlap input-output for a job with computations on that same job. If a job is started while its program is still being input, one runs the risk of trying to execute commands which have not yet been stored in memory. If it is started after the program has been read, but before all data is input, one runs the risk of trying to process data which has not yet been stored in memory. There are no corresponding risks associated with the practice of starting to output results of a job before the job is complete. But if such a partial output is completed before another output segment

is ready, the I/O channel's intermittent operation may be inefficient; and if the the output is going to a card punch, line printer, or magnetic tape unit, there is no practical way of using the output device for other output data in between partial outputs, so that the device is tied up during the entire output period.

2. Two or more jobs must be resident in internal memory simultaneously if the processor is to be kept busy continuously. If only one job is present at a time, the processor obviously has an idle period while the last results are output from the current job, and data and program for the succeeding job are input. If a system operates with two or more resident programs and is able to alternate their execution, it is called a *multiprogramming system.*

3. To keep the processor busy, it may also be necessary to provide two or three simultaneously-operating I/O devices. A single card reader/punch, for example, may not be able to keep a processor supplied with jobs, depending upon the relative processor/card equipment speed and the workload characteristics.

4. Even when a system can handle simultaneous resident jobs, and has sufficient I/O and processor capacity to handle the average workload, it may require additional capacity to keep the processor busy in the face of a stream of variable-length jobs.




(a) Processing Time = $T(op) + \frac{kD}{D'} + \frac{sD}{C'}$

$$\text{Throughput} = \frac{D}{\text{Processing Time}} = \frac{D}{T(op) + \frac{kD}{D'} + \frac{sD}{C'}} = \frac{D'/k}{\frac{T(op)D'}{kD} + 1 + \frac{sD'}{kC'}}$$

(b) $$= \frac{D'/k}{1 + s/s(c)} \text{ if } T(op) << \frac{kD}{D'} + \frac{sD}{C'}$$

FIGURE 2.23.4 OPERATION OF EARLY SYSTEMS I UNBUFFERED SYSTEMS

Workload Characteristics:

$D_I$ = Number of Characters of Input Data

$D_O$ = Number of Characters of Output Data

P = Number of Characters in Program

D = $D_I + D_O$ = Total I/O Data Characters

kD = D + P = Total I/O Characters

s = Computer Operations Required Per I/O Character

sD = Computer Operations Required Per Job

System Characteristics:

C' = Processor Speed, in Operations Per Second

D' = I/O Speed, in Characters Per Second

T(op) = Total Operator Time Required Per Job

Derived Characteristics:

$\frac{sD}{C'}$ = Processor Time Per Job

$\frac{kD}{D'}$ = I/O Time Per Job

$s(c) = \frac{kC'}{D'}$ = Value of s for which Processor Time Equals I/O Time

$r = \frac{s}{s(c)} = \frac{sD'}{kC'}$ = Ratio of Processor to I/O Time

System Throughput = $\frac{\text{Number of Data I/O Characters Processed}}{\text{Total System Time Required}}$

FIGURE 2.23.5 SYSTEM AND WORKLOAD PARAMETERS. DEFINITIONS FOR EARLY SYSTEMS

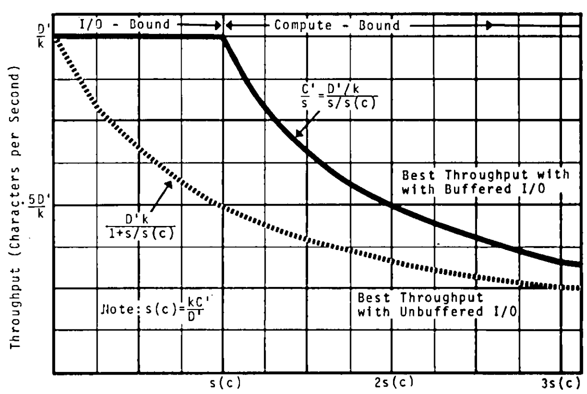
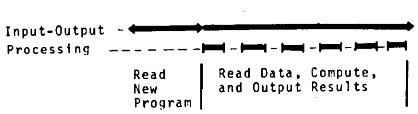



FIGURE 2.23.6 SYSTEM THROUGHPUT VS. WORKLOAD

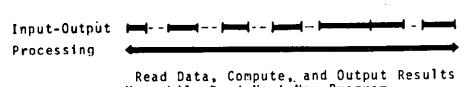



If $\frac{kD}{D'} > \frac{sD}{C'}$ $[s < s(c)]$ Then

Processing Time = $\frac{kD}{D'}$, and

Throughput = $\frac{D'}{k}$

Figure 2.23.7 OPERATION OF EARLY SYSTEMS II BUFFERED SYSTEMS, I/O BOUND




If $\frac{sD}{C'} > \frac{kD}{D'}$ $[s > s(c)]$ Then

Processing Time = $\frac{sD}{C'}$, and

Throughput = $\frac{C'}{s} = \frac{D'/k}{s/s(c)}$

FIGURE 2.23.8 OPERATION OF EARLY SYSTEMS III BUFFERED SYSTEMS, COMPUTE BOUND

These problems are illustrated in Figures 2.23.9 and 2.23.10. To begin with, an example which allows no overlap of I/O with computation is diagrammed in Figure 2.23.9a. The line labelled "input-output" represents time on a channel to the computer consisting of one input and one output device (they may in fact be two different devices, like a card reader and line printer, or one I/O device like a magnetic tape unit) with associated buffers, controls, and channels to memory. The segment labelled Ii represents the period of time during which programs and data are input to memory for job number i; that labelled Oi represents time when results of job i are output. Blank periods represent time when the I/O channel is waiting.

The line labelled "Job Segment" similarly represents processor/memory time. We assume the memory is divided into segments (only one segment in Figure 2.23.9a) and that at any moment a segment is assigned one and only one job. At any time it may be waiting for an I/O channel for a job, engaging in I/O activity, waiting for CPU processing, or engaged in CPU processing. The period during which the processor is operating on job i is represented by a solid line labelled Pi. Other activities related to job i are designated by dotted segments labelled i.

In the examples of Figure 2.23.9 we assume that a series of similar jobs must be processed, each having processing time equal to the time it takes to read input or transmit output on a single channel. In the one-segment system of Figure 2.23.9a, having a single input/output channel, we observe the properties of an unbuffered system—where I/O and computation cannot be performed simultaneously. We can infer that s = 0.5 s(c), since s(c) is the value of s for which I/O and computing times are equal, and in this instance computing time is half I/O time. In an unbuffered system, assuming no separate operator time is required, Figure 2.23.6 or the equations of Figure 2.23.4 show us that throughput will be two-thirds of maximum throughput. Noting that the time interval labelled "cycle" is repeated over and over again, we can also see that the CPU is busy one-third of the time, and the I/O system two-thirds of the time. We might then say that, for this workload on this system, CPU and I/O efficiency are .33 and .67, respectively. These various results are summarized on the first line of Table 2.23.1.

We can keep the I/O channel busy, and therefore improve throughput, by adding another job segment and thus providing a very rudimentary multiprogramming system, as shown in Figure 2.23.9b. Now the I/O channel can input program and data for the second job while the first is being processed, and can output the results of the first job while the second is processed. Throughput is now at its maximum value of D'/k and I/O efficiency is 1.0 (I/O efficiency is obviously closely related to throughput, for throughput by definition is the rate at which characters are processed by the system). But the CPU is still busy only half the time. Its efficiency has increased from .33 to .50, but the system is I/O limited.

We get a further improvement, then, by adding another I/O channel as shown in Figure 2.23.9c. We have now doubled the system I/O rate and, consequently, the potential throughput; and we have halved s(c), which is inversely proportional to the I/O rate. However, the CPU is now the bottleneck because two job segments are not enough to keep the I/O busy. Note that I/O and CPU efficiency are each only .67, and throughput is only two thirds of its maximum potential value of 2D'/k.

By adding a third job segment, as shown in Figure 2.23.9d, we can achieve CPU and I/O productivity of 1.0, and maximum throughput of 2D'/k. No additional I/O channels or job segments can further increase throughput for this value of s. Table 2.23.1 summarizes the characteristics of all four of these system configurations, and Figure 2.23.10 provides some further insight into their properties. In the top portion of the figure, we plot absolute throughput against an absolute value of s. Since the four systems operate under a constant s, they all lie on the same vertical line, and we see that configuration (b) provides maximum throughput with one I/O channel, and that that throughput is doubled with configuration (d). If a new workload appeared with a lower value for s, it would be possible to increase throughput by adding other I/O channels; if the new workload had a higher value for s, throughput would necessarily drop.

The lower graph in Figure 2.23.10 describes the same four systems in a different way, plotting them on a scale of relative values of throughput and s. For system (a) we are operating in an unbuffered mode—the dotted line is the same as that plotted in Figure 2.23.6. Adding a job segment we move to point (b). Then by doubling the potential I/O rate, we reduce s(c) and double s/s(c). And depending on whether we have two or three job segments, we operate at point (c) or (d).

All the examples in Figure 2.23.9 describe the unlikely world where the workload consists of an infinite series of uniform jobs. In fact, as we have seen in looking at real workloads, the job parameters D(in), D(out), k, and s all vary wildly around their average values. To get a first impression of the effect of workload variability, let us examine the example of Figure 2.23.11. We begin (2.23.11a) with a series of uniform jobs having the characterisitic that s=s(c); and we provide two jobs segments, and achieve a CPU efficiency of 1.0 as shown. Now let us assume that the workload changes, with alternating long and short jobs. Each short job has input, compute, and output times two-thirds of the corresponding times of the original fixed-length example, and each long job has times four-thirds of the original example—so the average job time has not changed. But, as Figure 2.23.11b illustrates, two job segments in memory can no longer keep the processor busy. The difficulty arises simply because while the processor is working on the long job, the I/O system runs out of work to do and must wait until the processor finishes. The problem is easily solved by adding another job segment to memory, so that the I/O system can input another job during the time it would otherwise be idle.

To summarize: Though a buffered system with sufficient I/O capacity can theoretically achieve maximum productivity (i.e. referring to Figure 2.23.6, though a buffered system with s greater than s(c) can theoretically achieve CPU productivity 1.0 and thus throughput C'/s), the practical problems of scheduling variable-length workloads make it difficult to achieve the maximum. How close can we come to the maximum? Gaver (GaveD67) has analyzed the system under the conditions described above, and has computed expected CPU productivity over a range of circumstances. Specifically, Gaver's analysis assumes:

1. There exists a backlog of jobs, so the system never has to wait for inputs.

2. Individual jobs have an average ratio r of compute time to total I/O time, assuming a single I/O channel. However, the ratio varies from job to job, the distribution being exponential with rate r. Since the ratio is given by

r = sD'/(kC'), the job-to-job variability presumably comes about mostly through variability in the workload parameters s and k.

3. A variable number of I/O channels, I, is permitted. As the number increases, the maximum system I/O rate increases proportionally. As we saw in the top graph of Figure 2.23.10, adding I/O channels potentially increases absolute throughput. It also reduces s(c), and thus increases s/s(c) for a given job, as we saw in the bottom graph of Figure 2.23.10.

4. A variable number of job segments, J, is also permitted, and it is assumed that J is constant for a given run.

5. Compute time has an average value of unity, but like the CPU/I/O time ratio, it varies from job to job. Gaver considered a number of different distributions for compute time, as we shall see in a moment.

6. Input-output and compute functions for a given job are not permitted to overlap. This is, of course, the assumption implicitly included in Figures 2.23.9 and 2.23.11.

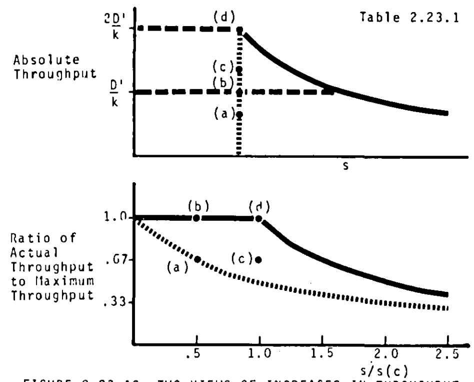



FIGURE 2.23.10 TWO VIEWS OF INCREASES IN THROUGHPUT

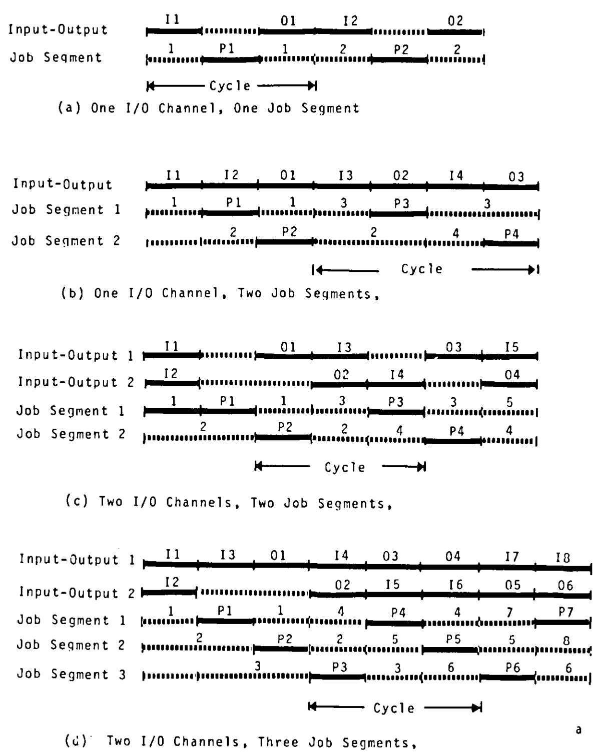



FIGURE 2.23.9 CPU PRODUCTIVITY WITH VARIOUS SYSTEM ARRANGEMENTS FIXED-LENGTH JOBS

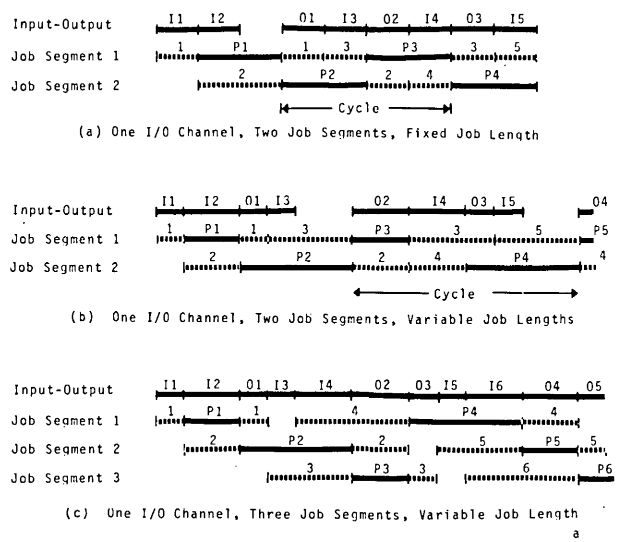



FIGURE 2.23.11 EFFECT OF VARIABLE JOB LENGTH ON CPU PRODUCTIVITY

## TABLE 2.23.1 SYSTEM THROUGHPUT AND EFFICIENCY

| Figure | Job Segments J | I/O Channels I | I/O Capacity | Efficiency I/O | Efficiency CPU | s/s(c) | Throughput |
|---|---|---|---|---|---|---|---|
| 2.23.9 a | 1 | 1 | D' | .67 | .33 | .50 | .67 D'/k |
| b | 2 | 1 | D' | 1.00 | .50 | .50 | 1.00 D'/k |
| c | 2 | 2 | 2D' | .67 | .67 | 1.00 | .67 2D'/k |
| d | 3 | 2 | 2D' | 1.00 | 1.00 | 1.00 | 1.00 2D'/k |
| 2.23.11 a | 2 | 1 | D' | 1.00 | 1.00 | 1.00 | 1.00 D'/k |
| b | 2 | 1 | D' | .75 | .75 | 1.00 | .75 D'/k |
| c | 3 | 1 | D' | 1.00 | 1.00 | 1.00 | 1.00 D'/k |

**Multiprogramming System Operation.** Gaver's results are indicated in Figures 2.23.12 through 2.23.14, where they are superimposed on the "best unbuffered" and "best buffered" curves of Figure 2.23.6. Figure 2.23.12 illustrates the effects of variations in r, I, and J. Look first at the dotted lines. They connect points for which r = 0.2— that is, for which average job I/O time is five times compute time. The dotted line labelled J = 10 connects four points for which the number of job segments in core is ten, but for which the number of I/O channels is 3, 5, 7, and 10 respectively so that s/s(c) is 0.6, 1.0, 1.4, and 2.0. The other dotted lines also connect points for which r = 0.2, and differ in the number of job segments present. Comments:

1. Note it is never worthwhile to add more I/O channels than there are job segments—when all J job segments are inputting or outputting data, J I/O channels are in use and any other channels would be idle.

2. The addition of job segments materially increases CPU effectiveness, as we expect. However, note that when s = s(c) (and a buffered system theoretically should be able to keep the CPU occupied 100% of the time) five jobs leave the CPU idle about 37% of the time, and even ten jobs only reduce idle time to 27%.

The dashed lines in Figure 2.23.12 connects points for which r = 0.5—for which the average job I/O time is *twice* compute time. Once again improvements in productivity come with increases in I/O channels and/or job segments. And once again improvements are harder and harder to come by as we approach maximum producitivity. Comparing dashed and dotted lines in this figure we note another effect: for a given s/s(c) and a given number of jobs J, productivity is higher for the situation where the average job ratio r is larger. In other words, as I/O time increases relative to CPU time for the average job, it becomes harder to schedule I/O operations in such a way as to keep the processor busy. The effect can be seen back in Figures 2.23.9c and 2.23.11a. In both figures, J = 2 and s = s(c). In the former figure, r = 0.5 and two I/O channels are present; in the latter, r = 1.0 and only one is necessary. With the relatively long I/O times of Figure 2.23.9c, two job segments are not enough to keep the CPU busy, and throughput is only 67% of maximum; but 100% throughput is possible with two job segments when I/O and computer times are balanced.

Figure 2.23.13 provides another look at the same data, from a different point of view. Taking the ten-segment system, we plot throughput (solid lines) as a function of the number of system I/O channels. We start with a single I/O channel, and make its data rate our unit of capacity. Our jobs have the characteristic that r = 0.2—that is, for the single-channel system, compute time is one-fifth of I/O time. The system is, of course, I/O limited, and the potential throughput is one unit of I/O capacity. If we add another I/O channel, doubling I/O capacity, the system is still I/O limited (compute time is now *two*-fifths of I/O time), and potential throughput is two units of I/O time. As we continue to add I/O channels, potential capacity continues to increase until, with five I/O channels, compute time and I/O time are equal and the system becomes compute bound. We can continue to add I/O channels with the object of keeping all job segments busy at all times, but the potential throughput cannot further increase: if the processor were *never* idle, the compute time:I/O time ratio r = 0.2 specifies that an I/O rate of 5 units exactly watches the computing speed.

The actual throughput for ten job segments and 3, 5, 7, and 10 I/O channels is also plotted in Figure 2.13.13. As we add channels, we increase absolute throughput, of course. But note that in increasing I/O channels from three to five, the actual throughput as a percentage of potential throughput (dotted line) decreases, from 91% to 73%. With ten I.O channels (the maximum number useful with ten job segments), throughput is 88% of the potential.

We can look at the situation from still another point of view if we start with a simple, unbufferred system and simultaneously add I/O channels and job segments. The result is plotted in Figure 2.23.14. In the curve marked by triangles, for example, we start with a single-channel, single-job segment system having the property that the average job processing time is one-tenth the I/O time. Throughput is then 91% of I/O capacity. If we now add another I/O channel, we double potential throughput and halve s(c). Adding a second job segment in core, we now have a system represented by the second triangle, whose throughput is 88.5% of (the doubled) I/O capacity. If we keep on adding I/O channels and job segments, we move along the line marked by triangles—the last point shown is a system with ten I/O channels, and a throughput 68.5% of the new I/O capacity, which is of course ten times the original I/O capacity.

The dotted curve connecting circles represents a similar family of systems where successive I/O channels were added to a system having an original s(c) of 0.2; and the systems described by the dashed curve had an original s(c) of 0.5.

It is instructive to look at this figure from another point of view. Consider the four points on the vertical line s/s(c) = 1. They represent four systems all operating with the same workload (described by s and k) on the same hardware (described by C' and D'). The unbuffered system, represented by the small square, has a single I/O channel and a throughput 50% of the maximum throughput, D'/k. The next system, represented by a black dot, has two I/O channels, each of capacity D'/2, and two job segments in core. Its throughput is 54.8% of the maximum. And the next two systems have five and ten I/O channels respectively, each of capacity D'/5 and D'/10, and provide throughput of 62.4% and 68.5% of maximum.

The degree of improvement provided by increases in I and J is naturally dependent on the statistical properties of the workload—on the variability in computer time, and in I/O time. As mentioned above, Gaver assumed an exponential distribution of the compute/I/O time ratio, and then examined the effect of a number of possible distributions for compute time. Figures 2.23.12 to 2.23.14 are based on the most violently fluctuating distribution—a hyperexponential distribution having a variance of 8.0 (assuming mean compute time of 1.0). To understand better the effect different distributions have on efficiency, look at Figure 2.23.15, where we plot productivity for ten job segments in core, with three different assumptions about compute-time distributions. The lower dotted curve with a variance of 8.0, is the same as the dotted J=10 curve in Figure 2.23.12. The second curve shows the effect of keeping the same type of distribution but reducing the variance to 2.0. And the upper curve represents performance with the less extreme exponential distribution. Comments:

1. Given the exponential distribution and ten job segments, the system achieves nearly maximum possible throughput as long as s is less than 0.5 s(c) or greater than 2.0 s(c).

2. As indicated in Section 2.21, we have very little data about typical or, average values of compute times or of s. We know even less about their detailed statistical properties.

Gaver states, "The large $\sigma^2$ cases tend to represent situations where business jobs, characterized by relatively short compute times, are mixed in core with 'scientific' applications requiring much longer times." He cites no source in establishing this characterization. But the data we have on typical CPU idle time (see Tables 2.23.5-6, to be discussed later) seems to imply a large variability in workload parameters.

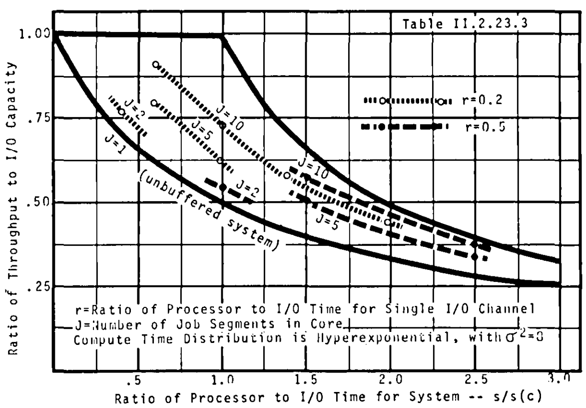



FIGURE 2.23.12 SYSTEM THROUGHPUT WITH MULTIPROGRAMMING I

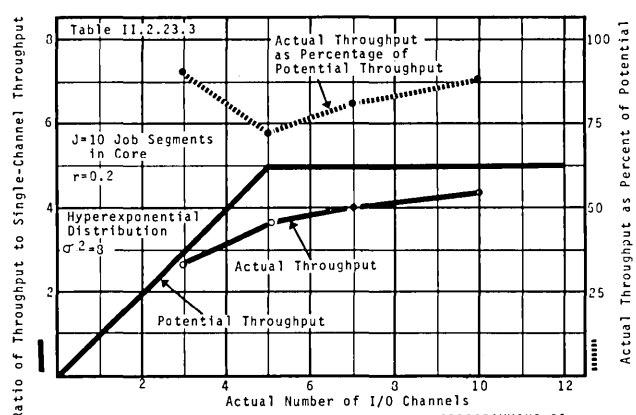



FIGURE 2.23.13 SYSTEM THROUGHPUT WITH MULTIPROGRAMMING II

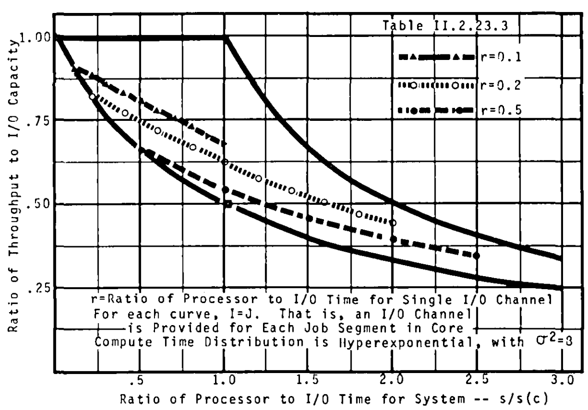



FIGURE 2.23.14 SYSTEM THROUGHPUT WITH MULTIPROGRAMMING III

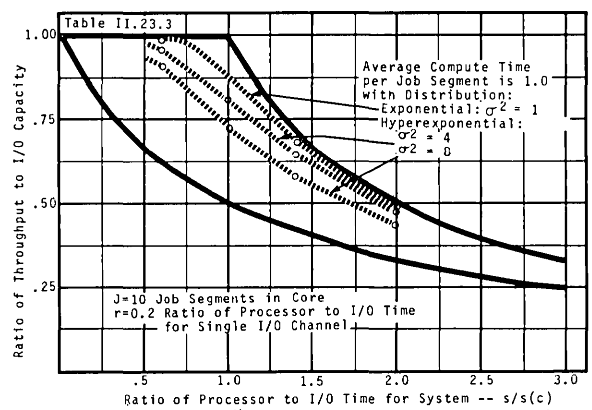



FIGURE 2.23.15 SYSTEM THROUGHPUT WITH MULTIPROGRAMMING IV

Let us now attempt to apply these results to some of the important computer systems which have proven to be so useful during the past few years. In Table 2.23.2 we summarize their important features. Processor rate C' is a weighted rate for raw CPU operations—computed by assuming the instruction mix consists of 95% additions and 5% multiplications, using the timing from lines 5 and 6 of Table II.2.11.1. Input/output rates are shown for four types of peripherals—card readers, line printers, magnetic tape units, and moving-head files. The rates given are intended to be practical, not maximum, data rates, as is indicated in the notes to the table. Finally, the table shows the critical value of s for k = 1 (i.e. program length very small compared to data I/O) and for three values of D'.

Throughput for the IBM 370/135, based on the data in this table, is plotted in Figure 2.23.16 as a function of the workload s in processor operations per I/O character. Comments:

1. We are plotting the same variables that appeared in Figure 2.23.6 and subsequent figures. However, we are here using a log-log scale, so that compute-bound throughput, which is inversely proportional to s, appears as a straight line instead of a hyperbola.

2. The critical value for s—s(c) in Table 2.23.2—is represented by the intersection of the horizontal I/O-bound curves and the diagonal compute-bound curve. A 370/135 with unit record equipment as the *only* I/O would have an s(c) of 287 as shown; while with a single disk I/O channel the value would be 1.66.

3. The throughput curve of an unbuffered, single-channel magnetic tape system is shown as a dashed line in the figure. (Similar curves could be plotted for unbuffered unit record or disk systems.) We have seen that multiprogramming is effective in improving throughput when s/s(c) lies in the range between 0.1 and 10. For the magnetic tape system, this means multiprogramming would not be effective if the average value of s were greater than 30 or less than 0.3.

4. As shown, the curves assume k = 1. As k increases, throughput (D'/k) decreases and s(c) increases accordingly—the I/O-bound horizontal line moves downward on the figure, and its intersection with the compute-bound line moves to the right.

5. The figure is based on single-channel systems. If a particular 370/135 has two I/O channels permitting simultaneous I/O on a disk and tape, the I/O-bound curve moves up appropriately and s(c) decreases. A tape channel added to a disk channel would reduce s(c) from 1.66 to 1.05, approximately.

The next three figures give us a way of comparing various systems using this throughput vs. workload graph. In Figure 2.23.17 and 2.23.18 we show the improvements which have taken place over four generations of IBM equipment, and in Figure 2.23.19 we look at three third-generation non-IBM systems. Comments:

1. Generally speaking, single-channel s(c) has increased with time as a natural consequence of the fact that processor speed as measured by C' has increased more rapidly than has the I/O rate of the various peripherals. However, modern systems can be assembled with multiple I/O channels which of course makes it possible to increase D' and reduce s(c). I have seen no statistics on the average number of I/O channels in use, and don't know how this has changed in practice over the years.

2. The input-output ratios shown are based on assumptions detailed at the bottom of Table 2.23.2. The various units chosen are intended to be representative of those in use with the depicted systems. But in general higher- and lower-performance peripherals have been available with each generation, and a different choice would of course affect s(c) and the I/O-bound throughput for each system. Note also the assumptions made about block lengths and recording densities. The use of longer blocks would increase I/O rates; shorter blocks (or lower magnetic-tape recording densities) would reduce I/O rates. Once again, I have found no statistics available on actual I/O rates through the generations.

3. Based on the assumptions made, magnetic tapes have generally provided higher average I/O rates than have moving-head-files. However, tape is of course not usable in applications which require random access to data; and MHF I/O rates can be higher if the system is able to queue up requests or otherwise reduce average access time.

4. Despite the above qualifications, and the fact that some differences in performance are ascribable to price differences, Figures 2.23.17 and 2.23.18 describe a steady improvement in system performance from generation to generation. Similarly, Figure 2.23.19 shows the performance range of three non-IBM systems, all very successful, marketed at about the same time. They were first shipped between June, 1963 (the CDC 6600), and September, 1965 (the Univac 1108). The least powerful—the Burroughs 5500—is also the least expensive, and the most powerful, the most costly. The contemporary IBM 360-65 (first shipped November, 1965) lies between the BGH 5500 and Univac 1108 both in performance and price.

So far, all of our analysis and discussion has assumed that a computer installation handles its workload by loading a program, reading input data, performing necessary computations, and transmitting output on a job-by-job basis. The timing charts of Figure 2.23.4, 2.23.9, and 2.23.11 explicitly describe that form of operation—where a job basically requires only one input, only one compute, and one output interval of time. Early systems did in fact operate that way. But some second generation systems and many third and fourth generation systems permit a given job to be broken down into many input, compute, and output intervals, with a resulting profound effect on system operation. The factors which encouraged system designers to provide the capability for so subdividing jobs were as follows:

1. An increasing proportion of jobs consisted of relatively simple manipulations carried out on large files—files much too large to reside in internal memory. The processing therefore had to be performed in parts, with the delay between parts at least long enough to read in (from cards, magnetic tape, disk, or drum) the next data segment to be processed.

2. The average job has increased in size over the years, requiring increased internal memory capacity for programs and data. By making it possible to break big jobs into parts, system designers have made it possible for systems with small memories to handle the increasingly complex jobs.

3. To achieve maximum throughput for a mixture of jobs, we have seen that it is necessary to process several jobs simultaneously in internal memory. For a given internal memory capacity, this may greatly reduce the memory available per job, even if the average job size has not been increasing.

4. System operators must respond to job priority requirements from their customers—a high priority job which

arrives just after a long low-priority job has started must somehow be accomodated.

5. In many situations, it is useful to permit an individual user to input jobs directly from a keyboard-driven terminal. The resulting workload obviously compounds the priority problem referred to above: the system must give highest priority (responding in no more than two or three seconds) to trivial requests from terminals. In addition, it is convenient to give each terminal user the impression that he has available a relatively constant share of computer power, rather than letting him operate on a "first-come, first-served" basis. This "shared capacity" strategy can be implemented by delaying longer jobs at the expense of shorter ones.

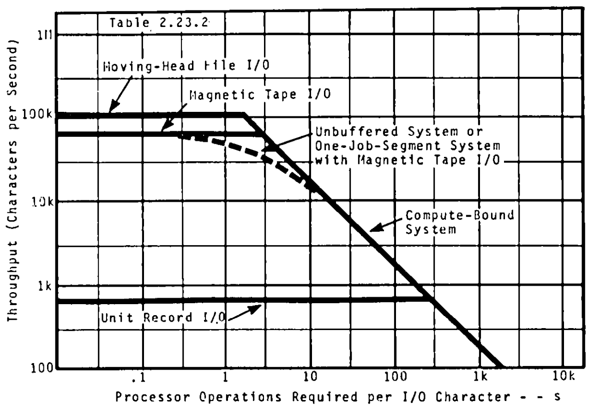



FIGURE 2.23.16 THROUGHPUT OF THE IBM 370/135

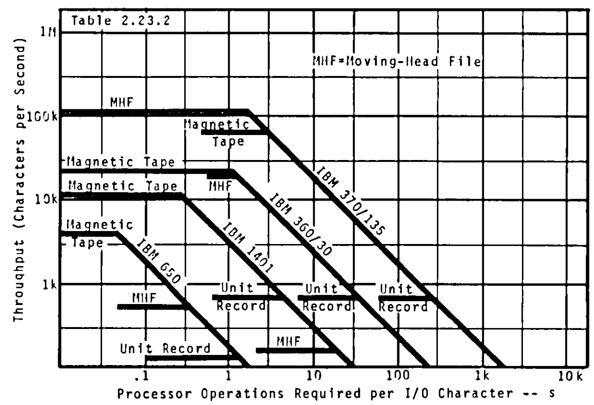



FIGURE 2.23.17 THROUGHPUT IMPROVEMENTS IN IBM SYSTEMS I SMALL-SCALE SYSTEMS

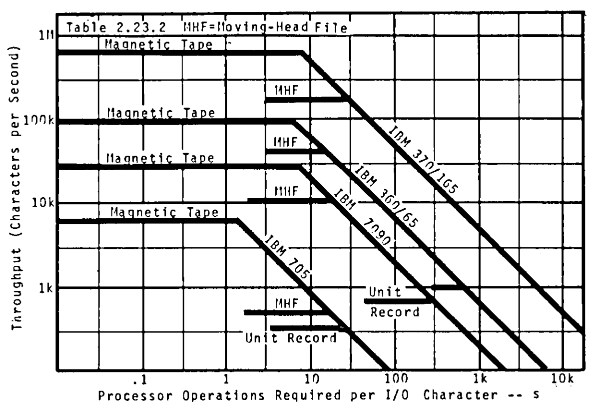



FIGURE 2.23.18 THROUGHPUT IMPROVEMENTS IN IBM SYSTEMS II MEDIUM-SCALE SYSTEMS

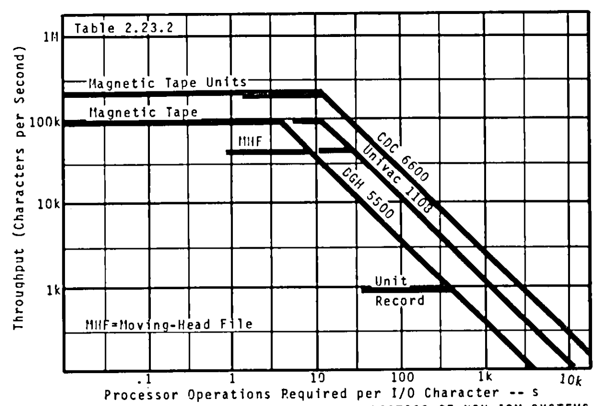



FIGURE 2.23.19 THROUGHPUT CHARACTERISTICS OF NON-IBM SYSTEMS THREE IMPORTANT THIRD-GENERATION SYSTEMS

## TABLE 2.23.2 THROUGHPUT PARAMETERS FOR IMPORTANT SYSTEMS

| | Processor Rate C' (kops) | Input/Output Rate D' Card Reader (kcps) | Line Printer (kcps) | Magnetic Tape Unit | Magnetic Tape Rate (kcps) | MHF Unit | MHF Rate (kcps) | s(c) for k=1 Unit Record (op/ch) | Mag. Tape (op/ch) | MHF (op/ch) |
|---|---|---|---|---|---|---|---|---|---|---|
| IBM 650 | .181 | .10 | .15 | 727 | 3.75 | 355 | .50 | 1.45 | .05 | .36 |
| IBM 1401 | 3.10 | .55 | .66 | 729-2 | 11.5 | 1405 | .16 | 5.12 | .27 | 19.4 |
| IBM 360/30 | 24.8 | .66 | .66 | 2401-1 | 20.7 | 2311 | 18.5 | 37.6 | 1.20 | 1.34 |
| IBM 370/135 | 189.5 | .66 | .66 | 3420-3 | 66.6 | 3340 | 114. | 287. | 2.85 | 1.66 |
| IBM 705 | 8.46 | .17 | .50 | 727 | 6.00 | 355 | .50 | 25.3 | 1.41 | 16.9 |
| IBM 7090 | 199.5 | .66 | .66 | 729-4 | 26.5 | 1301 | 10.6 | 302. | 7.53 | 18.8 |
| IBM 360/65 | 637. | .66 | 1.21 | 2401-6 | 94.7 | 2314 | 41.1 | 681. | 6.73 | 15.5 |
| IBM 370/165 | 5236. | - | - | 3420-9 | 612. | 3330 | 170. | - | 8.56 | 30.8 |
| BGH 5500 | 392.2 | .66 | 1.21 | - | 94.7 | - | 41.1 | 419. | 4.14 | 9.54 |
| CDC 6600 | 2632. | - | - | - | 207. | - | 185. | - | 12.7 | 14.2 |
| Univac 1108 | 1203. | - | - | - | 94.7 | - | 41.1 | - | 12.7 | 29.3 |

Card reader and line printer rates are half the maximum. Magnetic tape rates are computed by dividing an assumed block length by the sum of start-stop time and block read time. Read time is computed assuming maximum recording density for each unit. Block lengths used for the first four units were 100, 200, 800, and 1200 characters. Block lengths double those sizes were used for the next four units. Moving-Head-File rates were computed by dividing half the maximum record size by the average access time. For the Univac and Burroughs units I assumed rates comparable to the IBM 360/65. For the CDC 6600 I assumed rates ten times that of the 360/30. The unit record I/O rate is taken as the average of card reader and line printer rates.

There seems to be no quantitative analysis available of the relative or absolute importance of these five factors to users in general or to various classes or users. However, system designers could indeed solve all five problems with the strategy referred to above: they designed systems (and for the most part this means they designed the software) which broke each job down into pieces, and intermixed input, compute, and output elements of one job with similar elements from other jobs. In many ways, the resulting system operation is similar to the simple situation described earlier and pictured in Figures 2.23.9-11. When a job becomes active, it alternates between four different states: waiting for an I/O channel; using an I/O channel; waiting for the processor; and processing data. But where our previous discussion envisioned a straightforward progression of a job from input through computation to output, complex systems which have evolved to satisfy the above five requirements obey comparably complex rules.

In simplified form, these rules appear in Table 2.23.3. The first two columns define the state change, and the last two the events which trigger the change. The "complex system" whose rules are described by the last column differs from the simpler system primarily by virtue of the events which force a job to leave "using processor" states; and those events are directly related to the factors discussed earlier—the requirements of processing large files, handling long jobs, and meeting priority requirements. (In practice, the state change from "using processor" to "waiting for processor" often requires I/O operations before the job can be processed again. Intermediate results may be transferred to external storage and the user program may be overwritten to accomodate the interrupting task. Results and program must then be read in again when the system returns to work on the interrupted program.)

How does this fragmentation affect CPU productivity? What is its effect on our view of system operation, as provided by Figures 2.23.16-19? There are several effects:

1. Fragmentation may greatly increase the number of I/O bytes required per job. The minimum number of I/O bytes per job is obviously one copy each of program, input data, and output data. When a job is segmented, each job interruption may result in a re-reading of input data or program; or it may result in the temporary storage and later re-reading of output data. One way of taking this into account is to say that the workload has changed. If the program and input-output data (or some fraction thereof) must be transferred to and from memory several times, we can say that, in effect, parameter k has increased—k being the ratio of total I/O characters to data characters. An increase in k, as we mentioned in connection with Figure 2.23.16, leads to an increase in s(c) and a corresponding decrease in throughput.

2. The increasing input-output load has forced the user to procure fast access storage (moving-head and head-per-track files) to hold the programs and data, so the system can quickly switch from one job to another.

3. The software necessary to supervise and control the fragmentation has a variety of indirect costs. The most obvious might be called an overhead cost. We have so far assumed that every operation carried out in one second by the processor is used to help process a data character for a job—is one of the s operations required per data character in the user's workload. But "pure" s would include only those operations required to read the program and data once, process it, and output the results. The auxiliary processing steps required each second to read and store data and programs the second, third, and other times, to determine when to switch from job to job, to apply priority criteria, to manage storage in internal memory, etc., all subtract from processor capacity and effectively reduce processor speed C'. Furthermore, the enormous complexity of these multiprogramming systems has forced designers to add other overhead features to the operating system. These include such things as: error detection, recovery, and diagnostic features to help operators deal with software failures; accounting facilities to assign resource costs to different user programs; and access control elements to safeguard user privacy. These features likewise reduce effective processor speed.

In addition to this processor overhead, there are other costs. The operation system software itself occupies space in internal memory, which reduces the memory capacity available for jobs and therefore effectively causes another increase in k for each job. And the complexity of operating systems has made them difficult and costly to design, and has led to software reliability problems.

As usual, it is difficult to find data with which to quantify the above effects. Software "overhead" is variously estimated at 5% to 15% with no general agreement on a definition of the term. Software reliability is also hard to measure, though we will touch on this subject later in this section. There has been a great deal of work done on system performance measurement in the past two years, and occasionally the results of a study are published or otherwise made available. Tables 2.23.4 and 2.23.5 provide a representative sample of available information. In the former, the first three columns show the percentage of time the CPU is active, broken down into time when the CPU overlaps input-output operations, and when CPU alone is active. The next column shows CPU idle time (the difference between CPU active time and 100%); and the following five columns break that "input-output only" time down into various categories. The next column shows the percentage of time the whole system is idle. And the last column shows the computed value of r, the ratio of total CPU time to total I/O time. Comments:

1. "CPU Active" is the percentage equivalent of the CPU efficiency we discussed in connection with Table 2.23.1; and the sum of "CPU Idle" and "CPU-I/O Overlap" is equivalent to I/O efficiency. The sample is, of course, very small, and it is correspondingly dangerous to draw conclusions from such little data. Nevertheless, it is clear that many systems operated in the past, and still operate today, well below their maximum capacity—which would occur, as we have seen, when both CPU and I/O efficiency are 1.0.

2. The data provides no indication that the enormous sums spent on third-generation software have contributed much to system efficiency.

3. There is a great deal of variability in the operation of a given system from hour to hour or day to day, in the operation of a given manufacturer's system from one site to another, and in the operation of a system depending on how well its operating parameters have been "tuned" to an installation workload. The variability at a given installation is apparent from the standard deviations (SD) given for the XDS system and for the IBM 360/65. The variability from site to site is apparent in the XDS Sigma 7 data—installations number 1 and 2 are industrial, the second having a heavy FORTRAN load; installation number 3 is at a university. (It seems likely that the large differences in operating parameters are due to differences in workloads and in the way the

systems are tuned, and are not due to differences in hardware complement.) The variability in "tuning" is shown in the data on the IBM TSS system, in which the CPU active percentage nearly doubled as a result of changes which were made in scheduling strategies.

### TABLE 2.23.3 RULES GOVERNING PROGRAM STATE CHANGES

| Job State Changes From: | Job State Changes To: | Events Causing State Change: Simple System | Events Causing State Change: Complex System |
|---|---|---|---|
| Waiting for I/O channel | Using I/O channel | I/O channel becomes available | I/O channel becomes available |
| Using I/O channel | Waiting for processor | Input or output is complete | Current fraction of input or output is complete |
| Waiting for processor | Using processor | Processor becomes available | Processor becomes available |
| Using processor | Waiting for I/O channel | Processing is complete for this job | 1. Processing is complete for this job.<br>2. Processing of current input data is complete.<br>3. Program required to perform next processing is not in internal memory. |
| Using processor | Waiting for processor | (Not required) | 1. Job has used its allocated share of processor time.<br>2. Higher-priority job requires processor time. |
| Using I/O channel | Terminating job | Last output completed for job. | Last output completed for job. |

### TABLE 2.23.4 CPU AND I/O ACTIVITY OF VARIOUS SYSTEMS

| | | | | Percent of Total Elapsed Time | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | I/O Only | | | | | | |
| | CPU Active | CPU-I/O Overlap Only | CPU Only | Total (CPU Idle) | Disk Only | Tape Only | Unit Record Only | Non-Disk Only | Two or More | Idle | Ratio of CPU to I/O Time |
| Units: | % | % | % | % | % | % | % | % | % | % | r |
| **IBM 7094 (1966)** | | | | | | | | | | | |
| FORTRAN—Short | 48 | 3 | 45 | 52 | | 46 | 6 | | | | .87 |
| Long | 94 | 6 | 88 | 6 | | 4 | 2 | | | | 7.83 |
| Misc. Jobs | 32 | 10 | 22 | 68 | | 59 | 9 | | | | .41 |
| Total | 58 | 5 | 53 | 41 | | 36 | 5 | | | | 1.26 |
| **IBM 7074 (1966)** | | | | | | | | | | | |
| One Run | 28 | 27 | 1 | 72 | | 16 | 56 | | | | .28 |
| **ATLAS (1967)** | | | | | | | | | | | |
| Summer Vacation | 74.7 | | | 25.3 | | | | | | | |
| Excluding Weekends | 88.0 | | | 12.0 | | | | | | | |
| Michaelmas Term | 72.9 | | | 27.1 | | | | | | | |
| Excluding Weekends | 69.9 | | | 30.1 | | | | | | | |
| **IBM 360/67 (1970)** | | | | | | | | | | | |
| TSS/360 Before | 45 | | | 55 | | | | | | | |
| After | 80 | | | 20 | | | | | | | |
| **XDS Sigma 7 (1972)** | | | | | | | | | | | |
| Installn. No. 1—Mean | 39.4 | | | 58.2 | 14.8 | | | 27.3 | 16.1 | 1.8 | |
| S.D. | 14.6 | | | 16.0 | 9.0 | | | 9.9 | 8.9 | 6.0 | |
| Installn. No.2—Mean | 81.1 | | | 18.1 | 4.3 | | | 7.1 | 6.7 | 0.3 | |
| S.D. | 20.6 | | | 8.4 | 2.9 | | | 7.0 | 3.6 | 1.1 | |
| Installn. No. 3—Mean | 54.3 | | | 41.3 | 8.3 | | | 16.2 | 16.8 | 0.7 | |
| S.D. | 21.4 | | | 15.6 | 4.8 | | | 12.4 | 8.3 | 1.9 | |
| **IBM 360/65 (1973)** | | | | | | | | | | | |
| First Week—Mean | 61.65 | | | 38.35 | | | | | | | |
| S.D. | 12.91 | | | | | | | | | | |
| Second Week—Mean | 68.11 | | | 31.89 | | | | | | | |
| S.D. | 8.40 | | | | | | | | | | |
| Third Week—Mean | 64.81 | | | 35.19 | | | | | | | |
| S.D. | 11.00 | | | | | | | | | | |

See Notes in Part II.

All this, of course, provides some insight into system operation only from a very gross point of view. If we want to know, not only what proportion of the time the CPU is operating, but also what proportion is spent on overhead functions compared with that spent doing useful work, we find data very hard to locate and to interpret. As mentioned above, one problem seems to be that we have no good and universally-adopted definition of "overhead". Table 2.23.5 summarizes the little data I could find bearing on this subject, though it should be viewed with some suspicion because of the lack of common definitions (see the notes in Part II). The first column shows CPU idle time as a percentage of total elapsed time, and the next three columns break CPU active time into three parts (two parts for the IBM and ATLAS systems). Supervisory time is time spent in the monitor, not attributable to user's functions. "User's service" time, in XDS nomenclature, is time spent in the monitor for "user services", though I could find no more detailed definition. User execution is presumably the proportion of time spent doing useful work—though it is clear that Operating Systems often charge users with time which basically has nothing to do with the work they are trying to complete. (See, for example, BellT74.)

**A Paradox.** If we compare the results of our analysis of throughput with the data we collected on workloads in Section 2.21, we find a paradox. Figure 2.21.7 and Table 2.21.3 indicated that, in typical second- and third-generation installations, at any rate, s, the average number of computer operations required per I/O character, lay in the range between 25 and 6000, with a median value in the hundreds. Furthermore, we found in Table 2.23.4 that it is common to observe systems operating with their CPU's idle 30% to 50% of the time. CPU idle time implies, as we have seen, that a system is operating with a workload such that $s < 10s(c)$. However, if we return to Table 2.23.2 and Figures 2.23.17 to 2.23.19, we observe that s(c) for single-channel magnetic tape systems has ranged from 0.5 to 12.7. If these figures truly are typical, and if workloads really do have values of s in the hundreds, then the systems we've been describing should be compute-bound, and CPU idle time should be very small indeed. (Operating system overhead, described above, in effect reduces C' and thus s(c), and makes the discrepancy even worse.)

Several explanations might be advanced to account for this apparent paradox:

1. The values of s shown and discussed in Section 2.21 are undoubtedly too high. For the most part, they were computed by multiplying the Adams' addition rate (in operations per second) by system time, and dividing the result by the number of I/O characters processed in that time. The addition rate of course does not allow for CPU idle time; and if we assumed that idle time were 30% to 50%, our value of s would be halved. Furthermore, the figures provided are generally averages, and it is possible that median times, on a per-job basis, could be much lower. (The median shown in Figure 2.21.7 is the median of the *systems* studied, not a job median.)

2. The values of s(c) shown in Figures 2.23.17-19 are based on the assumption that k = 1—that is, that I/O data is read and written once only, and that program length is very small compared with the number of data characters which must be handled. If in practice program length is *large* compared with data characters, or if (as seems more likely) the fragmenting of jobs into small time or memory segments makes it necessary to transfer data and programs repeatedly between internal memory and peripheral devices, then k and s(c) will be increased accordingly. I have no data regarding the effect on k of job fragmentation caused by forcing jobs into small time segments. However, Figure 2.23.20 shows the result of an experiment which demonstrated the effect of program fragmentation. The figure shows how the number of input-output transmissions increases as the amount of real internal memory allocated to a program is reduced. Three different programs each displayed very much the same result. A 129 kword sorting program, for example, required nearly 1000 I/O transmissions when it was run in 104 kwords of memory, and 13,653 when run in 80 kwords. Even small reductions in memory size may increase I/O transmissions markedly. Thus a multiprogramming operating system which partitions its memory in order to run several jobs simultaneously may as a result have to fragment some programs and inadvertently greatly increase I/O actions and therefore k.

3. The values of processor speed C' used in computing s(c) in Figures 2.23.17-19 were derived by assuming computer operations were 95% additions and 5% multiplications. In fact, logic and branch commands often comprise 20% to 40% of total executed instructions (see Table 2.21.8), and are usually a good deal faster than addition. Increased values of C' would give increased values of s(c). For example, if we assume a typical instruction mix consisted of 65% additions, 30% branches, and 5% multiplications, C' for the IBM 370/135 would increase from 189.5 to 225.6 kops, and s(c) for a tape system would increase from 2.85 to 3.39.

4. The values of I/O rate D' used in capacity s(c) are based on certain assumptions about the length of blocks stored on disks and tapes (see the footnote to Table 2.23.2). If typical blocks are shorter than those assumed, data rates will be lower and values of s(c) will increase. For example, if typical block lengths used in the IBM 370/135 were 300 instead of 1200 bytes, D' would drop to 16.7 kbps, and s(c) for a one-channel tape system would increase from 2.85 to 11.4. I have no data on typical values of block length.

5. It is possible, though it seems unlikely, that systems are operated very inefficiently. If, for example, most system input and output were handled by unit record equipment with tape and disks used only occasionally, D' would be greatly reduced and many of the newer, faster systems would clearly be I/O-bound handling jobs with s in the low hundreds.

6. The values of CPU idle time shown in Table 2.23.4 may not be typical. The systems shown are large ones, and several were operating in the University environment, which is surely not typical of average U.S. system operations. It is possible that in fact the majority of commercial systems are and have been operating in a compute-bound mode with little CPU idle time.

Some combination of the above factors must account for the difference between our analysis of system throughput and the mode in which systems apparently operate in practice. It is, however, not at all clear just where the real explanation lies, and we will need more data about typical workloads and operating conditions, to better understand system throughput.

**Maintainability.**

Maintainability refers to the frequency with which a system manager finds that his system has failed, and the time that he loses due to those failures. Failures should be interpreted in the broadest sense, and should include hardware problems, software problems, and human errors made by the computer operators. Both solid failures, whose cause is identified and corrected, and intermittent problems which interrupt service and then disappear should be included.

The problem of collecting and interpreting data on reliability is a formidable one. To begin with, there is the practical and administrative task of collecting data. When the system fails, everyone is too busy trying to fix it to record what is happening. When the system is working, there is no data to collect, and system managers are often unwilling to expend resources investigating and analyzing a problem which has gone away.

Then there is the difficulty of categorizing failures. Intermittents are particularly troublesome in this regard. When an application program aborts in the middle of the run, but other programs and all diagnostics work, should one record a system intermittent, or assume that the application program is at fault? If the application program runs when tried a second time, one can presume that there was a system failure during the first run—though an intermittent application program bug may turn up later. But there are other classification problems. Suppose a line printer fails on two successive days and is each day repaired in an hour. Suppose that the system is well designed, so that the printer can be removed and repaired without affecting the operation of the rest of the system. And suppose that on the first day there is a long job which can be run for an hour without a printout, but that on the second day all current jobs make frequent use of a printer. The printer itself is of course down on both days. But what do we say about the availability or about the failure history of the system? Did it fail on the second day but not on the first?

Another categorization problem has to do with the introduction of new system components. We know that it is fairly common to change hardware, either to improve system performance or to reduce system costs. It is also common to change software—to make use of the manufacturer's newest version of an operating system or a compiler. When such changes lead to system failures—and they commonly do, for the act of change often causes trouble, and new system components (especially software components) are rarely error-free—how should we classify them? Should they be ignored, on the grounds that they are in effect operator-induced? Or should they be included with "normal" system failures?

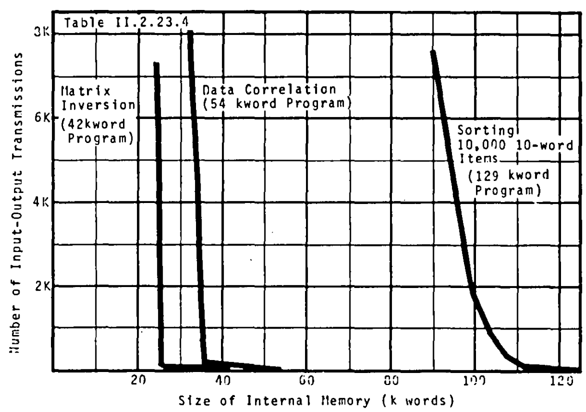



FIGURE 2.23.20 THE EFFECTS OF PROGRAM FRAGMENTATION
NUMBER OF I/O TRANSFERS VS. INTERNAL MEMORY SIZE

### TABLE 2.23.5 CPU OVERHEAD OF VARIOUS SYSTEMS ●

| | Percent of Total Elapsed Time | | | | |
|---|---|---|---|---|---|
| | CPU Idle | CPU Active Supervisory | User Service | User Exec. | User Total |
| **ATLAS (1967)** | | | | | |
| Summer Vacation | 25.3 | 12.7 | | 62.0 | 62.0 |
| Excluding Weekends | 12.0 | 6.2 | | 81.8 | 81.8 |
| Michaelmas Term | 27.1 | 13.7 | | 59.2 | 59.2 |
| Excluding Weekends | 30.1 | 15.2 | | 54.7 | 54.7 |
| **IBM 360/67 (1970)** | | | | | |
| TSS/360 Before | 55. | 36. | | 9. | 9. |
| After | 20. | 40. | | 40. | 40. |
| **XDS Sigma 7 (1972)** | | | | | |
| UTS Installn. No. 1 | 58.2 | 5.7 | 11.6 | 22.1 | 33.7 |
| No.2 | 18.1 | 8.2 | 9.4 | 63.5 | 72.9 |
| No.3 | 41.3 | 7.0 | 18.7 | 28.6 | 47.3 |

See Notes in Part II

**System Problems.** Despite the importance of Maintainability as a performance measure, there have been embarrassingly few efforts made systematically to report on the subject. In order to establish that there has been a problem, let us examine Figure 2.23.21. Here are shown availability data for a total of 166 systems, taken roughly at three different times: seven systems in the early fifties, 119 in the late fifties, and 39 in the mid-sixties. (I have been unable to find comparable data for third or fourth generation systems, though a few such systems are included in the latter 39.) Availability is defined as the ratio of the time a system was on and available to do useful work to the total time it was on. Note that this definition is somewhat ambiguous, for it depends on the definition of "time available to do useful work". Scheduled, preventive maintenance is *not* to be included as "useful work" time. But how do we categorize the period of time after a maintenance activity when the system is operating, but loading and initializing the operating system? How about the time it spends rerunning jobs which were interrupted by a system failure? The system manufacturer or manager might take the point of view that the system is doing useful work during these periods. But the system user might very reasonably argue that such time should not be counted as "available". For the data given on these pages, I have had to use the figures reported in various papers–see the Notes in Part II for details.

Looking at the data, we see there was a substantial improvement from early systems to their first-generation, commercial successors. The seven early systems were seven different machines (see Part II for further data) and five of the seven were available only 50 to 75% of the time. The 119 first-generation systems include only five model numbers (IBM 650, 704, 705, BGH 205, and Bendix G-15), and not one of the 119 had an availability as low as 75%, while 25 (21% of the total) were available more than 98% of the time.

The data in Figure 2.23.21 gives us some idea of the improvements users have seen in availability–at least up until the mid-sixties. But availability, while it is obviously of considerable importance to the users, is not a completely fair measure of the improvements which have taken place because it ignores the relative size of the systems. If we have a $100,000 and $1,000,000 system each available 95% of the time, surely we would agree that the latter has a better maintainability record. In fact, since each is out of service 5% of the time, we could say that the first has a "lost" time of 5% per $100k sales price, and the second of only 0.5% per $100k.

This approach to the measurement of maintainability is used in Figures 2.23.22 and 2.23.23. The former includes the commercial systems which were described Figure 2.23.21, and is based on average system prices for each computer model. The curve shown is my estimate of the trend of average lost time for all installed computer equipment, taking into account the population of the different models.

IBM systems are differentiated from all others in both Figures 2.23.21 and 2.23.22; and in Figure 2.23.23 the 39 U.S. government systems in use in the mid-sixties are sorted by manufacturer. (Though these are the same systems as those shown at 1965 in Figure 2.23.22, the lost time calculations are slightly different. In the former figure they were based on average system prices so as to be comparable to the earlier data. In this figure they are based on actual system prices.) The sample is, of course, small. And the non-IBM systems, from a total of eight different manufacturers, are from a most heterogeneous population. But the data clearly suggests first that IBM works hard to achieve superior maintainability in practice; and second that IBM's competitors *in general* are much less successful than IBM in providing reliable service. Note that more than half of the non-IBM systems have a lost time percentage per $100k worse than *any single* IBM system in the sample.

**Causes of System Failures.** If it is difficult to locate representative statistics about computer system lost time, it is virtually impossible to get a clear picture of the reasons for the lost time. The results of one analysis by Yourdon (YourE72) of several Burroughs 5500 systems are plotted in Figure 2.23.24. The solid line in that figure shows how the number of system failures varies from month to month, and the dotted lines plot two classes of failure as a percentage of the total. A *system failure* is defined as a problem serious enough that the whole system must be restarted, presumably interrupting any and all jobs in progress. Comments:

1. The average of two or three system failures per day is not at all unusual for medium-size business data processing systems. In fact, Yourdon reports that larger systems like the IBM 360/91 and 360/95 usually suffer four or five system failures per day, and he mentions that CDC established a goal of reducing failures on their 7600 systems to an acceptable level of fifty per month. Table II.2.23.11, in Part II, gives data on a dual IBM 370/165 system which had a mean time between failures of only nine hours over a two-and-one-half year period.

2. More than half of the system failures are unexplained, which means that operating personnel either neglected to classify them or else were unable to identify the cause of the failure and had neither the time or motivation to investigate further. As mentioned earlier, one critically important but little discussed class of failure is the *intermittent*, a failure which is difficult or impossible to reproduce because the conditions under which it occurred have disappeared. Software intermittents occur when flaws in the software design are exposed by unusual combinations of events or circumstances. (I remember one in a real-time stock quotation system which caused a system crash only when a broker in a particular area of the Southwest was a subscriber to the Commodity service and requested a quote on an American Stock Exchange stock which was traded in sixteenths.) Hardware intermittents can similarly be caused by flaws in the design. But in addition they can be caused by electronic or mechanical parts whose characteristics have drifted to the border of the range over which the system was designed to operate, or whose characteristics exhibit a sudden but reversible discontinuity–as when a bad solder joint momentarily opens due to vibration, or a dirt particle interferes with current in a relay contact.

It is usually difficult and often impossible to isolate intermittent failures unless special provisions are made for that purpose in system design. IBM explicitly recognized the seriousness of the problem in designing the 360 System, and made provisions in hardware and software to collect and preserve data on intermittent failures as they occur in real-time (CartW64). I have not seen a report evaluating the effectiveness of the measures taken.

3. Operating system failures accounted for about 10% of the total Burroughs 5500 system failures–not counting the software errors in the "unexplained" category. Yourdon comments that the 10% "seems abnormally low", and refers to "unsubstantiated reports" that each new release of IBM's OS/360 contains 1,000 bugs.

Other analyses of system failures provide similar results. For example, during 1974 a Univac 1108 system experienced an average of 2.2 software failures and 1.8 other failures per week (LyncW75–see Table II.2.23.10). And the operators of the dual IBM 370/165 system mentioned earlier attributed 44% of system failures to hardware, and 22% to IBM software (Table II.2.23.11). Obviously software problems are an important, and probably a growing factor in system reliability.

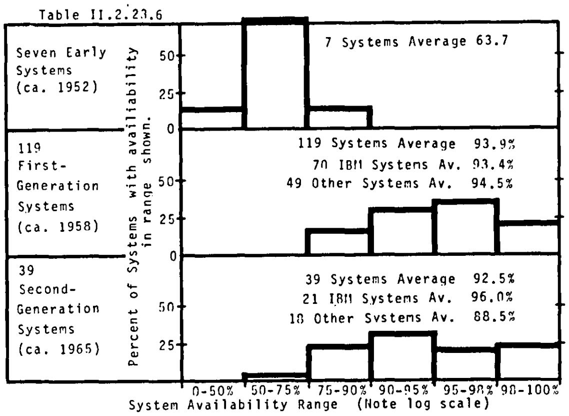



FIGURE 2.23.21 MAINTAINABILITY RECORDS OF THREE GENERATIONS OF COMPUTER EQUIPMENT

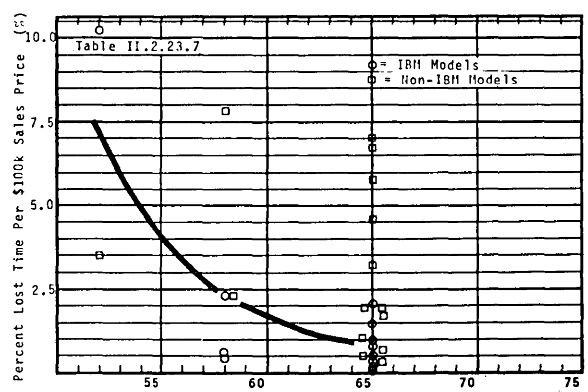



FIGURE 2.23.22 MAINTAINABILITY OF VARIOUS COMPUTER MODELS PERCENT LOST TIME PER $100,000 SALES PRICE

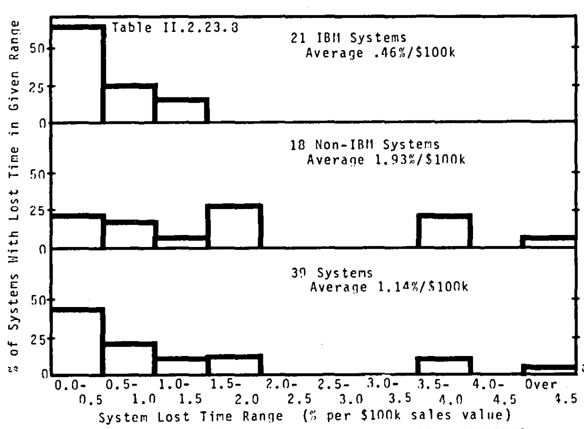



FIGURE 2.23.23 LOST TIME FOR IBM AND OTHER SYSTEMS SECOND AND THIRD GENERATION SYSTEMS, ABOUT 1965

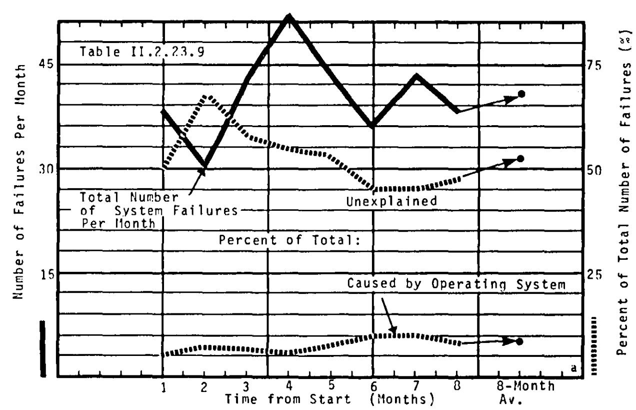



FIGURE 2.23.24 ANALYSIS OF SYSTEM FAILURES FAILURES PER MONTH ON BURROUGHS 5500 SYSTEMS

## 2.3 Physical Characteristics

Hardware products obviously have physical as well as performance features, and we will close this chapter with a brief look at three such attributes: density, heat dissipation, and (for memory technologies) storage density.

**Density.** We can compute the "density" of a product by dividing its weight by the volume occupied by its cabinet. Density is evidently determined by the materials used in manufacturing a product, and by the way they are arranged in the package. Figures 2.3.1 and 2.3.2 show the range of densities observed over a sampling of (mostly IBM) products. Comments:

1. The average density over the variety of product types shown was remarkably close to 25 pounds per cubic foot—remarkable because the technologies involved are so different. One factor contributing to uniformity is the designers' need to consider installation problems: units must be assembled in cabinets of a size which can readily be manhandled into office buildings, and must not be so dense that they would exceed load-bearing limits of the floors in those buildings.

2. The 46 processors in the sample have the widest range of densities of any of the units. Probably the principal cause of this spread is the fact that core memories and processors are mixed in the sample, which includes ten memories averaging 20.4 pounds per cubic foot, ten processors averaging 29.3, and twenty-six processors-with-memory averaging 22.9.

3. I have not shown density plotted against time because there seems to be no notable tendency for density either to increase or decrease from one generation of equipment to another.

4. The calculations discussed in this section are all based on volumes, computed from the outside dimensions of cabinets as given in manufacturers' installation manuals. For most peripherals there is no ambiguity in the dimensions given; for processors, however, the cabinets often include consoles, or work tables containing control panels and some electronics. I have tried to take such things into account in estimating total volume, but errors in my estimates obviously lead to incorrect densities.

**Heat Dissipation.** Data processing equipment uses electrical power, and the resulting heat must be carried away lest the components be damaged by overheating. Hardware engineers design cabinet interiors so that the heat can be quickly and efficiently removed. The cheapest way to dispose of it is simply to draw outside air into the cabinet and force it over the components and then out into the room, where the system user must remove it, usually by supplying an air conditioning system. However, very-high-performance systems require so much power that forced air cooling may not be practical, and liquid cooling systems become necessary.

One measure of the way designers have coped with heat removal is found by dividing the heat dissipated in a cabinet, in BTU's per hour, by the cabinet volume. This "heat density" will evidently be a function of the power requirements of the components used in the technology, and the way the components are arranged in the cabinet. Figures 2.3.3 and 2.3.4 show the range of densities observed over the same sampling of products as were covered in the previous two figures. Comments:

1. The IBM peripherals had a relatively uniform average dissipation factor—around 115 BTU's per hour per cubic foot. The seven non-IBM peripherals (all from Univac, as it happens) had a significantly higher factor, as if some different technology were in use which required more power than that employed by IBM.

2. The average dissipation of processors and memories is almost twice that of the peripherals. Memories-only had lower factors than processors-alone (145 BTU/hr. per cubic foot compared with 387 for ten IBM systems), and IBM units had lower factors than non-IBM units (sixteen IBM processors-with-memory averaged 169 BTU/hr. per cubic foot, ten non-IBM units averaged 209.) The IBM 370 processors generally have power dissipation factors well above the average—the 370/135, /145, /155, and /165 each dissipate more than 300 BTU/hr. per cubic foot. The 360 family *averaged* only about 130. Presumably the relatively high power density arises from the use of higher-density integrated circuits in the 370 family than were used in the IBM 360's.

3. When the heat dissipation per cubic foot exceeds about 500 BTU/hr., it is difficult to carry it away with a forced-air system and liquid cooling must be considered. The IBM 370/165 processor generates over 750 BTU/hr. per cubic foot and requires customer-supplied cooling water. (The first-generation, vacuum-tube IBM 704 and 709 dissipated over 1000 BTU/hr. per cubic foot, but were air-cooled machines. I don't know whether my source data and therefore my density calculations are wrong, or whether air cooling is more effective for vacuum-tube than for solid-state machines.)

**Storage Density.** Finally, we can look at the physical characteristics of memory technologies. In Figures 2.3.5 and 2.3.6 we plot storage density, computed by dividing storage capacity by cabinet volume, for magnetic core internal memory and for moving-head files. Storage density, unlike weight density, has increased substantially and is therefore plotted against time. The density of various specific units is plotted against their first shipment date. The dotted line in Figure 2.3.5 traces the density improvements of the five "typical" memories described in Section 4.13 below.

The dotted line in Figure 2.3.6 suggests that moving-head file gross density has improved by roughly a factor of ten every ten years. Note (Figure 2.12.1) that the disk-*surface* recording density has increased faster than capacity per unit volume—implying that designers have relaxed other factors contributing to volume density, over the years.

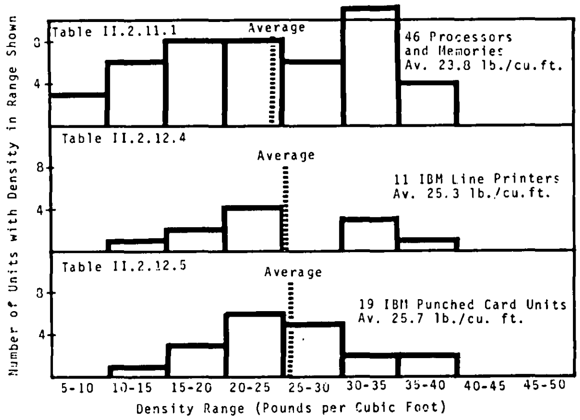



FIGURE 2.3.1 PHYSICAL CHARACTERISTICS
DENSITY OF PROCESSORS AND UNIT RECORD EQUIPMENT

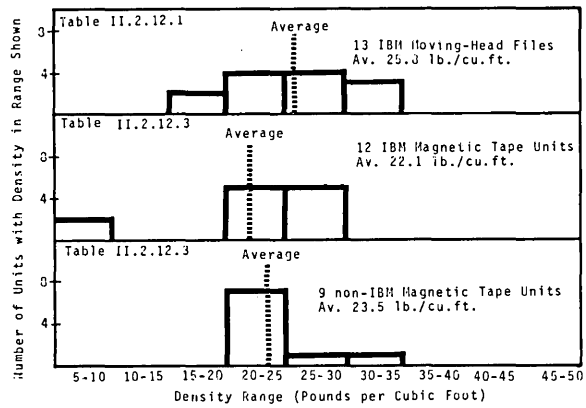



FIGURE 2.3.2 PHYSICAL CHARACTERISTICS
DENSITY OF VARIOUS MEMORY PERIPHERALS

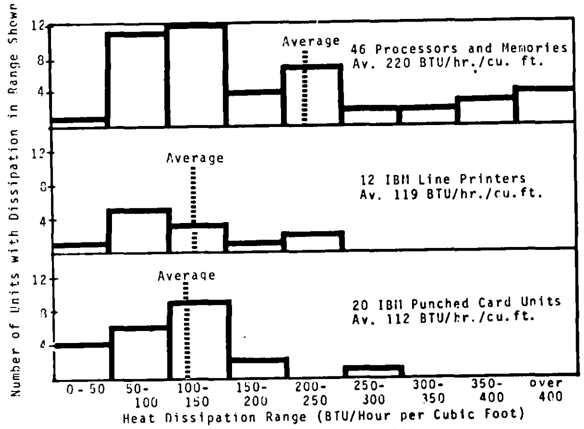



FIGURE 2.3.3 PHYSICAL CHARACTERISTICS
HEAT DISSIPATION OF PROCESSORS AND UNIT RECORD EQUIPMENT

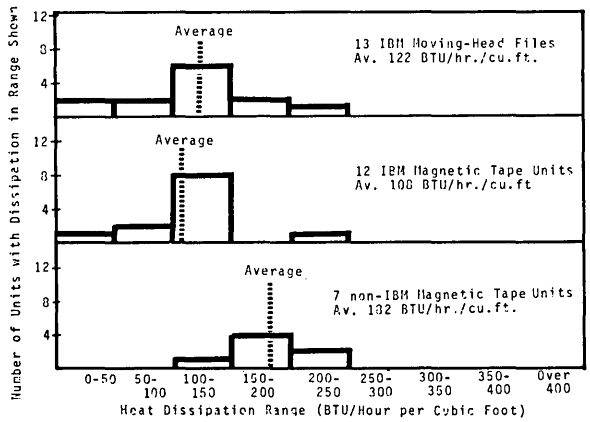



FIGURE 2.3.4 PHYSICAL CHARACTERISTICS
HEAT DISSIPATION OF VARIOUS MEMORY PERIPHERALS

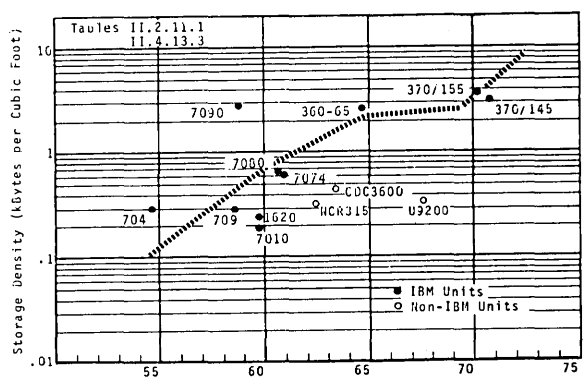



FIGURE 2.3.5 PHYSICAL CHARACTERISTICS
STORAGE DENSITY OF MAGNETIC CORE MEMORIES

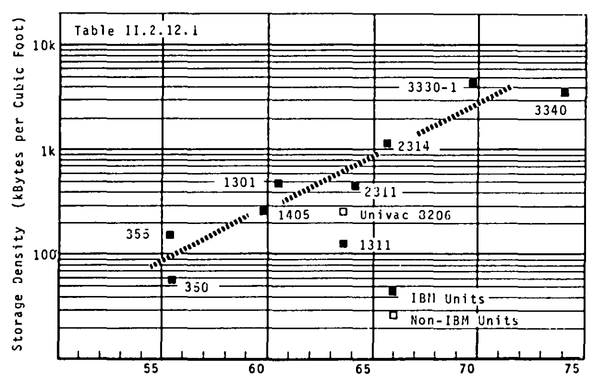



FIGURE 2.3.6 PHYSICAL CHARACTERISTICS
STORAGE DENSITY OF MOVING-HEAD FILES

## 3.0 Applications—Introduction •

In the first chapter we observed that the computer industry has grown rapidly, and in the second we traced the improvements which have taken place in the price and performance of digital products. The rapid growth has of course come about because an increasing number of users of data processing equipment and services have been able to use the improving products. In this section we will examine the users.

Every organization, from the smallest Boy Scout Troop to the largest corporation, must process data. Records must be established and maintained on people (employees, customers, members), receipts (deposits, revenues, dues, contributions), disbursements (purchases, salaries, interest payments, investments), procedures (manufacturing methods, parts procurements, regulations, policies), other organizations (competitors, suppliers, unions, customer companies, agencies), and operations (costs, budgets, plans, designs, moneys owed and owing, inventories). In a small organization, records are maintained and calculations performed manually, and there is a tendency to minimize formal data processing functions and to encourage key individuals to handle many functions informally—for example, by remembering names, or by developing and executing special procedures to solve problems as they arise. In larger organizations, the volume of records involved, the frequency with which they change, and the operating problems which arise because of the size and complexity of the organization itself, all combine to make necessary a formal data processing function which tends to grow in size and cost faster than the organization itself grows.

Computer systems are purchased or leased by organizations to help perform part of this data processing function. When a user acquires a computer, he has in mind certain functions or applications for the equipment, and he justifies its cost on the basis that, one way or another, it will make or save him money. The user organizations, their data processing applications, and the economic justification for those applications thus have been, and will continue to be, key factors determining the market for computer equipment—determining how much equipment of what kind can be sold.

Our examination of users must cover these subjects, and will be developed as follows. First we will define and analyze the data processing function in an attempt to understand the extent of potential applications. Then we'll look at existing users and computer applications statistically. Who are the users? What jobs are they doing? How have they justified their use of computer equipment and services? And finally, we'll examine data processing economics. What does it cost to operate a computer? How do these costs compare with the costs of alternative ways of processing data? How readily can computer installations be justified, where the justification is based solely on direct cost comparisons? What other justifications exist, and how are they quantified?

We have, in this chapter and throughout the book, been using some important terms without bothering to define them precisely. As we think about computer applications and potential applications, we begin to perceive how data and data handling problems pervade our lives and activities. The definitions which follow are intended to stimulate and broaden our view of the marketplace.

An *organization* is an association of persons for some common purpose. Generally, each of us belongs to many organizations: our jobs may involve several (e.g. company, division, department, section); our families, churches, political parties, unions, and clubs involve others. The purpose of an organization is to supply *goods* (tangible material items) and/or services to its members or to others. A *service* may be defined negatively, as "any result of useful labor which does not produce a tangible commodity" (Webster's Collegiate Dictionary); or positively, as the furnishing or transporting or processing of goods or people or skills or data.

*Data* is a representation of facts, concepts, or instructions in a formalized manner suitable for communication, storage, or processing, by humans or by automatic means. *Communication* is the transmission of data between two points with resulting mutual understanding between sender and receiver. *Storage* is the operation of accepting data, retaining it, and permitting it to be retrieved at a later time. *Processing* is the act of forming processed data by applying a set of rules (i.e. procedures, or algorithms) to input data. These concepts—data, communications, storage, and processing—are fundamental to our discussion. We will begin by interpreting them in the broadest possible way, so that for example a painting may be regarded as a collection of data. The data may be communicated to a viewer or camera through the medium of light, or by putting it on an airplane and shipping it from Paris to New York. It is stored in paint on canvas, or (once a photograph is taken) in emulsion on film, or in ink in a book which reproduces it. It is processed by a camera or by an X-ray machine or by an art critic.

The fundamental means by which data is communicated and stored are obviously very important, and the principal communications channels are set down in Table 3.0.1, with examples. Note that the first three include means normally used to communicate with humans through the senses of sight, hearing, and touch.

Most practical devices or systems involve the use of more than one form of communication channel. In a TV set, for example, the input signal is electromagnetic radiation, processing is done electrically, and the outputs are sound and light. The TV receiver system obviously includes devices which convert data from one form to another. Such devices are called *transducers*, and a sampling of the more important transducers is given in Table 3.0.2. The usefulness of electricity in complex systems is indicated by the existence of common transducers between electrical and all other signals. A TV transmitting system uses an iconoscope, microphone, and transmitting antenna. A TV receiver system uses a receiving antenna, loudspeaker, and cathode ray tube. Both, of course, use transformers and amplifiers.

**TABLE 3.0.1 COMMUNICATION CHANNELS**

| Means of Communication | Examples |
|---|---|
| Electromagnetic Waves | Light reflected from painting to eye. |
| | Light transmitted through hole in punched card to photocell. |
| | Radio wave from TV transmitting antenna to home antenna. |
| | Infrared radiation from earth to satellite camera. |
| | Laser beam transmitted along optical filament. |
| Sound Waves | Sound from radio loudspeaker to ear. |
| | Sound from one end of magnetostrictive delay line to the other. |
| Mechanical Action | Report mailed from New York to Los Angeles. |
| | Motion of finger on manual typewriter key, transmitted to print ribbon and paper. |
| Electric Signal | Telephone conversation transmitted from one office to another. |
| | Program received by antenna carried on lead-in wire to TV set. |
| | Signal from photocell in punched card reader passed through wires and cables to storage. |

**TABLE 3.0.2 TRANSDUCERS**

| Input Signal | Output Signal Electromagnetic | Sound | Mechanical | Electrical |
|---|---|---|---|---|
| **Electromagnetic Waves** | Lens<br>Mirror | Radio Receiver | Radio Controlled robot | Receiving antenna<br>Photocell<br><br>Iconoscope<br>Selenium drum in Xerographic system |
| **Sound Waves** | – | Megaphone | – | Microphone<br>Piezoelectric crystal |
| **Mechanical Action** | | Percussion musical instrument | Lever<br>Linkage<br>Wheel | Manual switch<br>Microswitch<br>Magnetic pick-up |
| **Electrical Signal** | Transmitting antenna<br>Light emitting diode<br>Incandescent bulb<br>Gas discharge tube<br>Cathode ray tube | Loudspeaker<br>Piezoelectric crystal | Solenoid | Transformer<br>Amplifier |

Next, let us examine methods of storing data. The principal storage means are shown in Table 3.0.3 with examples. The first three methods have been used since ancient times; the latter two are basically twentieth century applications of older science. Each storage method must of course include provisions for at least one way of writing and reading data, and the principal transducers used with each storage scheme are shown in Table 3.0.4. The inputs to writing transducers, and the outputs from reading transducers are, of course, compatible with the previously-described communication channels.

One additional family of storage methods should be mentioned: it is possible to store data by making use of the delay inherent in communication channels. Professor D.R. Hartree used to tell the story of a Cambridge Don who stored important dates by mailing them to a non-existent address in America. When his letter was "returned to sender" by the Post Office, he would open it, use the data if he needed it, and simply mail the letter once again to the same address if he still wanted it "stored". Computer memories have been made using this principle by transmitting sound at one end of a length of mercury, wire, or glass, waiting until the signal reaches the other end, and immediately retransmitting the data if it is to be retained.

Whatever the means used to transmit and store it, we find that data can be represented in one of two forms. It is handled in *analog* form if its meaning or value is made to correspond to a measure of a continuously variable physical quantity—intensity of light, loudness of sound, magnitude of mechanical force or electrical voltage, for example. It is handled in *digital* form if its meaning or value is made to correspond to a discrete interpretation of such a measure. Table 3.0.5 gives examples of various common analog and digital representations of data in each of the communication channels.

**TABLE 3.0.3. BASIC STORAGE METHODS**

| Means of Storage | Examples |
|---|---|
| Multiple materials (One material is selectively placed on another.) | Ink on paper (typewritten, printed, or handwritten page.)<br>Chemicals on paper (photograph).<br>Oil on canvas (painting).<br>Cloth on cloth (tapestry, embroidery). |
| Deformed material. (Material is selectively displaced.) | Holes punched—in card, tape.<br>Embossed material (Braille characters on paper; cunieform writing on clay tablets; grooves in phonograph records.)<br>Sculpture. |
| Mechanical position. (One object is selectively located with respect to another.) | Lever position (light switch; automobile gear shift; semaphore arm position).<br>Rotary position (clock hands; rotary switch; stove burner control). |
| Magnetized material. (Material is selectively magnetized.) | Magnetic film on another material (magnetic tape; magnetic drum or disk; plated wire memory).<br>Discrete magnet (magnetic core memory). |
| Electrically charged material (Material is selectively charged with electricity.) | Charge on semiconductor (integrated circuit flip-flop; selenium drum in Xerox copier, storing image as electric charge).<br>Charge on non-conductor (electrostatic memory). |

**TABLE 3.0.4. TRANSDUCERS FOR STORAGE METHODS**

| Means of Storage | Writing Transducers | Reading Transducers |
|---|---|---|
| Multiple Materials | **Mechanical:**<br>1. Motion of stylus forms image and deposits material on paper (pen, pencil, ink jet printer, paint brush.)<br>2. Embossed type moves to deposit ink on paper. (Typewriter, line printer, printing press.) | **Electric:**<br>Coil of wire moved relative to material has voltage induced as it passes over magnetic ink characters. |
| | **Electromagnetic:**<br>Light triggers chemical reaction on special paper. (photography, blueprinting.). | **Electromagnetic:**<br>Light directed at materials is selectively reflected or transmitted. (Optical character reader.) |

### TABLE 3.0.4 TRANSDUCERS FOR STORAGE METHODS

| Means of Storage | Writing Transducers | Reading Transducers |
|---|---|---|
| Deformed Material | **Mechanical:**<br>Motion of stylus, embosser, or cutter displaces material. | **Mechanical:**<br>Lever arm (or finger) moving over surface detects displacement.<br>**Electromagnetic:**<br>Light directed at material is selectively reflected or transmitted. |
| Mechanical Position | **Mechanical:**<br>Force supplied by external device (lever, motor, finger) displaces the object. | **Mechanical:**<br>Lever arm or linkage detects position.<br>**Electromagnetic;**<br>Light directed on object is selectively reflected or transmitted.<br>**Electric:**<br>Electric circuit contacts open and close depending on position of object. |
| Magnetized Material | **Electric:**<br>Current in coil creates magnetic field. | **Electric:**<br>1. Coil of wire moved relative to material has voltage induced as it passes over magnetized surface.<br>2. Coil of wire linking magnetic element has voltage induced when magnetic flux changes. (Magnetic core.) |
| Electrically Charged Material | **Electric:**<br>1. Current through diode, capacitor, or transistor switches charge on flip-flop circuit.<br>2. Electric field modulates and deflects beam of electrons in a vacuum.<br>**Electromagnetic:**<br>Light striking charged selenium drum selectively discharges it. | **Electric:**<br>1. Charge is detected as an output voltage.<br>2. Electron beam incident on charged non-conductor causes secondary electron current.<br>**Mechanical:**<br>Charge on selenium drum is transferred to paper moved close to it. (Xerography.) |

### TABLE 3.0.5. EXAMPLES OF ANALOG AND DIGITAL REPRESENTATIONS OF DATA

| Means of Communication | Analog Examples | Digital Examples |
|---|---|---|
| Electromagnetic Waves | Optical image of a photograph or drawing.<br>Signal broadcast by a radio or TV station. | Optical image of a printed character or a printed page.<br>Telemetry signal from a rocket circling Mars.<br>Light striking photocell in paper tape reader. |
| Sound Waves | Human conversation<br>Music from hi-fi speaker. | Morse code as heard by radio "Ham".<br>Signal in magnetostrictive delay line. |
| Mechanical Action | Motion of stylus following groove in phonograph record. | Motion of spring contact in electromechanical punched card reader. |
| Electric Signal | Current in radio antenna, hi-fi speaker coil, or record-player amplifier.<br>Voltage in analog computer circuit. | Current in paper tape reader photocell, magnetostrictive delay line crystal, or card reader circuit.<br>Voltage in digital computer circuit. |

Just as we need transducers to convert data from one channel type to another, so also we need analog-to-digital and digital-to-analog converters to change the mode of representation. Most such converters are electrical, operating on electrical digital input signals to produce electrical analog signals, or vice versa. But there are other types. A 'shaft encoder" has as input a (mechanical) shaft rotation. A disk fastened to the shaft has digital codes marked out on the disk radii. An external, fixed line parallel to and close to a radius of the disk provides a read-out position. To each angular position of the disk (a mechanical analog quantity) there corresponds a digital code, mechanically laid out along the read-out radius. The digital signal is usually read into a communication channel by shining light through the code wheel (mechanical to light transducer) onto a series of photocells (light to electric transducers).

We have spoken of transducers for changing data channel types and converters for changing between analog and digital modes. One more transformation is possible: in the digital mode, and in a given channel type, data can be *encoded* in a number of ways. We are said to encode data when we apply a set of rules to it which specify how the data may be converted unambiguously from one representation to another. We use these different representations for a variety of reasons, and in a variety of situations. Some codes (RZ, NRZ, Manchester) are used in writing on magnetic media, to enhance readout reliability. Other codes are used to detect and even to correct errors in the transmission of data. Sometimes data is encoded to make it easier to process. For example, we may convert a Gray Code, convenient for unambigious conversion from the analog mode, to a binary code, convenient for arithmetic operations. And in order to encode the optical image of a digital character—letter or number—we usually begin with an operation called *scanning* which encodes the image as a long sequence of binary digits. Subsequent processing of that sequence then converts it into a byte of information.

**Basic Data Processing Functions**

We noted that organizations invariably keep files. (For some organizations, like government bureaus, libraries, software houses, investment counsellors, etc., some files are the organization's *product*. We are, however, here interested in *control files* not product files). The organizations record pertinent data of many kinds in the files, and then operate on the files to perform the following functions:

1. Compare plans with performance and determine on a course of action when the two do not agree.
2. Instruct individuals or organizations by providing orders, directives, or procedures.
3. Control the flow of money, within and out of the organization.
4. Answer questions about the organization or its operations, posed by outsiders (customers, vendors, banks, government, stockholders, etc.) or by insiders.

The Data Processing Organization described by Figure 2.20 is responsible for constructing, conserving, and combining the files. The organization presides over four types of data processing operations, and it is these four functions which we will analyze and discuss in this chapter. The functions are *collecting data, storing data, manipulating data, and distributing data.*

**Collecting Data.** Some data originates within the organization, some is generated outside. In its original form it can appear on any of the communication channel types of Table 3.0.1: an operator may observe that a machine has broken down (electromagnetic waves); a salesman may receive a verbal order from a customer (sound waves); the personnel office may recieve a letter of acceptance from a prospective employee (mechanical action); the purchasing department may receive telephone notification of a price increase in some purchased part (electrical signal). In each situation where the data is of importance to the organization, the Data Processing Group must insure that the data is put in some specified form ready for additonal processing, and that it is transmitted to the proper location where it is to be stored. The data collection operation may proceed in a series of steps: for example, the salesman who receives the verbal order may be required to fill out a form and mail it to a regional center; and at the regional center a clerk may read the order and enter it, with others, into a terminal connected to a central computer. The best collection procedure will be a function of clerical, equipment, and communications cost, of the timeliness of the data, and of the motivation and abilities of the pertinent employees, among other things.

**Storing Data.** The data collecting function ends when data has reached the location where it is to be stored. The storing function includes facilities both for filing the data and for retrieving it when required. For small organizations the file may be an employee's memory, or a drawer full of handwritten forms. For a large one, it may reside on rooms full of magnetic tape or in microfilm reels.

The storage medium and read/write mechanisms or methods chosen by an organization for its files depend on a number of factors including: the size of the file; its growth rate; the expected frequency with which references will be made to data in the file; the type of data to be filed (e.g. reference only, or as inputs to other calculations and analyses); the form in which data originally appears within the organization; other storage systems used by the organization; and of course the cost of alternative storage systems.

**Manipulating Data.** Once data is stored in an organization's files, it is available for use in manipulations or analyses. One form of manipulation is rearrangement, in which no new data is formed, though some data may be copied and filed in several places, and the new arrangement may provide new *information* despite the fact there are no new numbers. Sorting files in alphabetical order, merging one file with another, interchanging columns in a table or paragraphs in text are all examples of rearrangement. The other form of manipulation creates new data by means of some process. The processes most often used apply to numbers and are therefore arithmetic, creating sums, differences, products, quotients, roots, powers, means, integrals, etc. Some however apply to alphanumeric data—examples are the machine translation of languages, and the reduction, expansion, or simplification of algebraic equations.

**Distributing Data.** The whole purpose of collecting, storing, and manipulating data is to provide some user or activity with data when needed. Distribution is the function of delivering data to a specified location in a form appropriate to its subsequent use. It therefore may involve two kinds of action: the conversion of data from one form to another (as when a clerk copies figures from his payroll calculation sheets onto a paycheck, or a computer system prints a report or plots a graph from data in a magnetic-tape file); and the movement of data from one place to another (as when a clerk copies figures from his payroll calculation sheets onto a paycheck, or a computer system prints a report or plots a graph from data in a magnetic-tape file); and the movement of data from one place to another (as when the paycheck is mailed to an employee, or the computer system transmits a report over telephone lines to a remotely-located printer or plotter.)

Whether the above four functions are carried out by people, by equipment, or by some combination of the two, they must be controlled by procedures. As was indicated in Figure 2.20 and discussed in Section 2.21, the preparation of these procedures is an exceedingly important, difficult, and costly data processing function—a fifth function, perhaps, to be added to the above four.

**User Files**

The creation, updating, and analysis of files are thus the functions of primary and critical interest to organizations, and the study of these files is of paramount interest to students of data processing. Figure 3.0.1 is intended to be a general representation of the structure of an organization, established to identify the files which exist in the organization. Examining the figure starting at the left, we see that purchasing and personnel departments procure materials and labor for use by the organization. Received materials go to inventory and new people become employees. Development creates new products (goods and services) which are in turn provided to customers by manufacturing and operations. A marketing organization finds customers and distributes products to them, and a quality control (QC) function assures product quality. A financial and legal department handles the collection and disbursement of monies and interfaces the organization to sources of money and to the government. A general management function (not explicitly shown) establishes the organization's goals and insures that the other functions work smoothly together to achieve the goals. Some of the functions shown may not exist in every organization. Pure service organizations (like banks or government agencies) do not have manufacturing or production control functions, and usually do not perform development. Pure manufacturing organizations do not need operations or operations control functions, inasmuch as they do not provide a service product. Organizations may use names for their functions different from the names shown in the figure. The Federal Government, for example, has nothing known as a marketing department. But millions of pamphlets, brochures, press releases, and advertisements are distributed every year by the government to let us all know what services are available, and the individuals who prepare and distribute that material are some of the government's sales and marketing people.

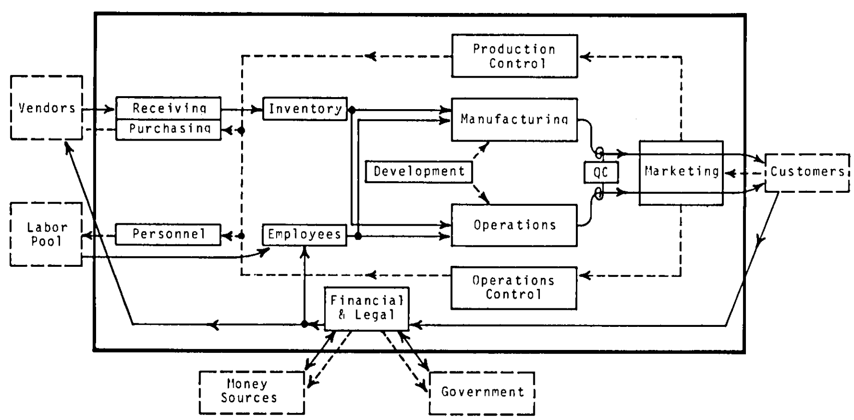



FIGURE 3.0.1 THE STRUCTURE OF AN ORGANIZATION

The organizations's principal files are described in Table 3.0.6, keyed to the functions in Figure 3.0.1. For each file I describe the contents, list the major users, estimate the file size (in measures related to the organization's size), and the frequency of references and updates to a typical record in the file. Inasmuch as the table attempts to describe the files of any and all types of organization, its entries must be very general and the estimated ratios shown must span a wide range. However, it can serve as a model for studies of particular industries and specific companies and is thus useful as a guide. Comments:

1. The product file for a manufacturing company is based on parts lists and assembly drawings. For a service company, the product file of course describes the services offered by the organization. For an insurance company, for example, the product file would contain copies of each type of policy and endorsement, procedures for combining policies and endorsements, rules for determining premiums and claims, and a listing of the number of policies issued of each type. For a time-sharing service bureau, the product file would include a list and description of services provided, rules for combining services and determining their prices, lists of equipment, facilities, and people required to provide the services, operator procedures and computer programs necessary to provide the services, and an accounting of the number of subscribers to each facet of the service.

2. In practice, duplicate files or duplicate portions of files are maintained in many organizations. Only in the smallest (and most numerous) organizations does one file serve all purposes. As soon as an organization contains 20 to 100 people, it begins for many reasons to create and maintain redundant files in various parts of the organization. Though the master personnel file may reside in the personnel department, portions of it are likely to be duplicated in the payroll department, in finance, and in the particular department where the employee works. The master parts file may be maintained and controlled by development, but working copies exist in purchasing, manufacturing, and quality control. This duplication occasionally leads to serious troubles (as when an employee is paid at his old salary rate because payroll has not received notice of the new one from personnel, or when purchasing procures parts, or manufacturing tests subassemblies, to an obsolete specification.) But these occasional troubles are judged to be less serious than those associated with making the satellite functions frequently refer to the master file.

3. One class of redundant file I have not included is the report. Management requires a variety of periodical (daily, weekly, monthly, quarterly, annual) reports to insure that the organization is meeting its planned goals, and to help determine corrective action when the plan is not met. These reports are redundant in the sense that they are created from the master files—given a copy of those files and of the programs or rules which were used to prepare the report, one could of course duplicate the report at any time. However, it is generally considered today to be cheaper and more convenient to store copies of the reports themselves for possible later reference, rather than to rely on the theoretically possible recreation process. The reports file is thus a redundant file which perhaps should be included.

4. For different types of organizations, different files will be important, in terms of size and of frequency of use. The study of file characteristics and of the economics of file usage—the value of files to the organization, and the trends that we see in file cost—would seem to be critical to any study of the future of data processing.

**TABLE 3.0.6 DESCRIPTION OF AN ORGANIZATION'S MAJOR FILES**

| File Name | File Contains Data on: | User Organizations | Typical File Size | Frequency of Use of a "Typical" Record: Reference | Modification |
|---|---|---|---|---|---|
| Personnel | Individuals who are current or past employees, or current or past job applicants. Includes name, address, vital statistics, education and employment history, performance appraisals, salary and expense records. | All | 200 to 2000 bytes per individual<br>1.1 to 3 individuals per employee | Weekly (pay rate) | Weekly (payments) |
| Job Descriptions | Different job functions or classifications within the organization. Includes statement of responsibilities, qualifications, pay range | All | 500 to 1500 bytes per description<br>.001 to .1 descriptions per employee | Monthly | Annually |
| Vendors | Companies which are current or past suppliers of parts, or potential suppliers of parts. Includes name, address, part number(s) supplied, outstanding and past orders and deliveries, price history, financial and QC appraisal of vendor, correspondence | Purchasing, Finance | 300 bytes per vendor plus 100 to 500 bytes per part number plus correspondence | Monthly (inquiry) | Monthly (delivery) |

## TABLE 3.0.6 DESCRIPTIONS OF AN ORGANIZATION'S MAJOR FILES

| File Name | File Contains Data On: | User Organizations | Typical File Size | Frequency of Use of a "Typical" Record: Reference | Frequency of Use of a "Typical" Record: Modification |
|---|---|---|---|---|---|
| Parts | Parts, materials, or assemblies purchased from vendors and fabricated or assembled by the organization. Includes purchase and test specifications, list of approved vendors, quantities on hand or on order | Purchasing, QC, Development | 1000 to 10,000 bytes per part number | Monthly (QC inspection) | Annually (spec or Vendor change) |
| Products | Procedures to be used by manufacturing or operations to provide products. Includes parts lists, assembly drawings, process procedures, test specifications, programs, operating instructions, labor requirements, order status, shipment history, prices | Development, Manufacturing, Operations | ? | Daily | Weekly (change in order status) |
| Customers | Individuals or organizations which are current, past, or prospective customers. Includes names, addresses, financial appraisal, purchase order, account, and payment records. | Marketing, Finance | 200 to 2000 bytes per individual or organization<br>1.1 to 5 individuals per customer | Monthly | Monthly |
| Markets | Competitive products, services, and companies, customer classes, and the total sales history and sales potential (forecast), domestic and foreign, for products of the kind produced by the organization. | Marketing, Finance | ? | Semi-Annually | Semi-Annually |
| General Ledger | The organizations's financial transactions. Includes an account for each major category of transaction, and records all receipts, payments, and accruals in each account. | Finance | ? | Weekly | Weekly |
| Assets | The organization's non-cash assets. Includes description of the assets for purposes of insurance, replacement, identification, valuation, or resale. | Finance | ? | Annually | Annually |
| Budgets | Plans on Income and Expenditure for the coming 12 to 24 months. Includes detailed budget itemizing all significant income and expenses for every organizational subdivision. | All | 500 to 3000 bytes per $1M sales | Monthly | Annually |
| Procedures | Methods and Policies to be used by organization members in carrying out their various functions. Includes rules, prohibitions, explanations, policies, and guidelines. | All | ? | Daily | Annually |
| Finance/ Legal | Government Agencies and money sources with which reports have to be filed or payments have to be made. Includes reports, payment records, correspondence | Finance | ? | Quarterly | Quarterly |

## 3.1 Computer Applications—History and Status ●

The foregoing discussion has, I hope, provided some insight into the questions of where computers *might* be applied. Let us now review the little data that is available on how and where they actually *have been* applied. We'll begin by surveying the relative use of computers by different kinds of organizations, will then look at the uses to which these machines reportedly have been put, and finally will present the results of a variety of studies which have been carried out over the years on computer applications.

### 3.11 COMPUTER USE IN ORGANIZATIONS—GENERAL ●

Four independent studies, summarized in articles published in 1968 and 1970 (see the notes to Table II.3.11.1 for details) estimated the number of computers in use in each of the major SIC Code Groups in 1953, 1959, 1966, and 1969. The results are plotted in Figure 3.11.1, which shows the percentage of GP computers in use in the principal industrial classifications in each of those years—with reasonable-seeming interpolations for the years between. The Federal Government was of course the biggest user initially, followed by the service industry, which includes the large number of university installations. Though the government (including state and local government) continues to be a major user, its share of total installations has continuously decreased. In the 1950's, manufacturing installations grew most rapidly and by 1960 about half of all computers were operated by manufacturing companies. Meanwhile financial organizations had begun to use computers, and in the early 1960's installations in banks, insurance companies, stock broker offices, etc., grew to represent nearly one fifth of all installations. In 1970 manufacturing accounted for about one third of the installations in the United States, finance and service industries between them shared another third, and the remaining third was divided between all other industries. A recent study (BurnE75) suggests that probably the distribution has not changed much since 1970.

Figure 3.11.2 provides comparable data for Great Britain in 1963 and 1968, and for Japan in 1969, superimposed on the U.S. data. The results are strikingly similar, though the differences raise questions impossible to answer from the available data. Did Britain's usage ratios really change so little between 1963 and 1968? Why haven't British "Service" applications grown bigger? What uses are Japanese wholesale and retail trade organizations making of computers?

This view of installations fails to take into account the relative size and importance of the various segments of industry. In the next three figures, we take the data on U.S. computer installations and show installation per thousand organizations (proprietorships, partnerships, corporations, or farms), per million employees, and per billion dollars of national income. Comments:

1. The early years are naturally characterized by very large changes in ratios and in the relationships between the industry groups. Obviously the initial growth rate could not be maintained indefinitely, and it appears that the ratios are approaching an equilibrium. In fact, the dashed line in Figure 3.11.3 shows that the total number of GP computers per billion dollars of national income has remained almost constant for the past eight years. However, we must keep in mind that these figures are based on GP installations only, and thus ignore two extremely important factors: the growing use of minicomputers and of time-sharing services.

2. Manufacturing, mining (including crude petroleum and natural gas), and finance generally are ranked among the top three in installations, whichever measure is used; and agriculture, construction, and trade are at the bottom. The latter three are of course characterized by having very small national incomes per employee, on the average.

3 There is an enormous range in ratios from one industry to another. Note the graphs are plotted on a semi-log scale, and that (for example) the manufacturing, mining, and finance industries have a computer installation for about every ten million dollars of national income, where agriculture and construction use only one per $250 million.

4. Wholesale and retail trade organizations conspicuously lag behind all groups except agriculture and construction, in all three ratios.

We can get additional insight into some of the reasons for the differences between industry groups by examining the absolute size of organizations in each group. In Figure 3.11.6 the total number of U.S. plants or establishments existing in 1967 are shown, along with the per cent of those plants having computers, both as a function of the number of employees per plant. Thus we see, for example, that there were about 3,000,000 plants with less than 20 employees, and that only about .03% of them had computer installations. We also find that nearly all sites with over 1,000 employees had a computer installation (i.e. one *or more* computers), and that there were about 3,500 such sites. Figure 3.11.7 shows the same kind of data for eight industries, together with the summary for all of them. Note, as pointed out in the notes in Part II, that the data plotted here probably understates the number of installations by some 7,000 sites, most of which must be in plants with from 20 to 1,000 employees. As presented, the figures show 3.2% of the sites in that size range have computers. If another 7,000 installations were added, the saturation would increase to 5.0%.

The most interesting aspect of these two figures, which describe installations in 1967, is the potential market in the smaller establishments. Looking at the graph for "all" industry we see there are 3,000,000, 300,000, and 45,000 plants with less than 20, twenty to 99, and 100 to 250 employees respectively. And that only about 0.03%, 1%, and 7% of these plants had computer installations. Looking at the distribution of computers and plants in various industries, we see striking differences. Almost two thirds of 1% of the 300,000 "finance" establishments (banks, insurance and real estate offices, stock brokers, credit agencies, investment companies, etc.) with less than 20 employees had computers; but none of the more numerous construction, trade, or service establishments did. It is easy, and thought-provoking, to speculate on this difference and on the others which show up in the figure.

Figures 3.11.6 and 3.11.7 indicate the status of GP installations in 1967. Inasmuch as the number of computers installed has continued to grow since then, and IBM's small System/3 (and more recently the System/32) has been introduced and has proven to be very successful, we would expect that more recent figures would indicate a greater penetration in smaller establishments. Figure 3.11.8 shows how the total distribution had changed by the end of 1971. Note that the proportion of installations in very small plants has not changed much, and that the large plants continue to be saturated with computers. But there have been very substantial increases in the penetration of computers into

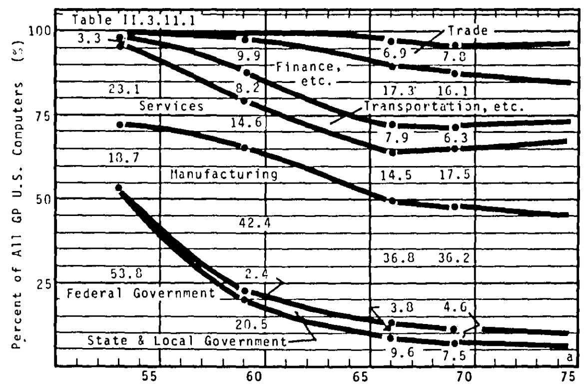



FIGURE 3.11.1 COMPUTER USAGE BY ORGANIZATIONS I
PERCENT OF ALL GP COMPUTERS IN USE IN THE U.S.

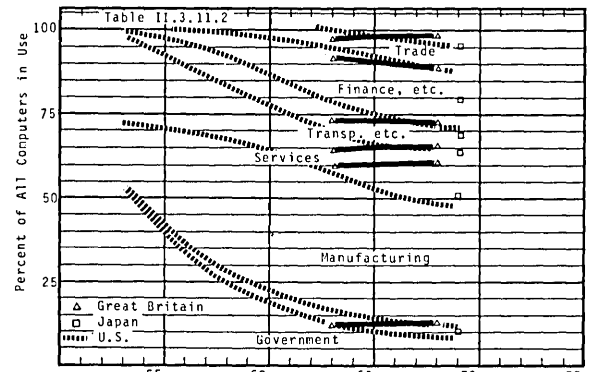



FIGURE 3.11.2 COMPUTER USAGE BY ORGANIZATIONS II
PERCENT OF ALL COMPUTERS IN USE IN BRITAIN & JAPAN

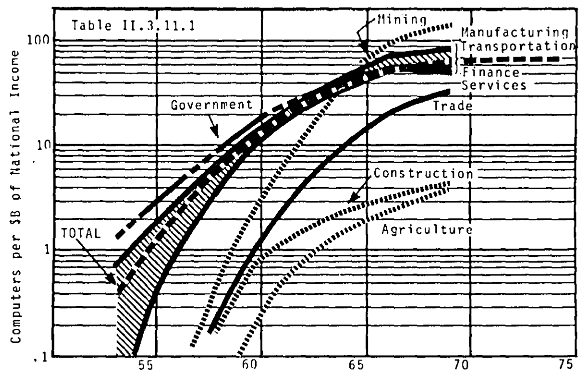



FIGURE 3.11.3 COMPUTER CONCENTRATION I
GP COMPUTERS IN USE PER BILLION DOLLARS U.S. NATIONAL INCOME

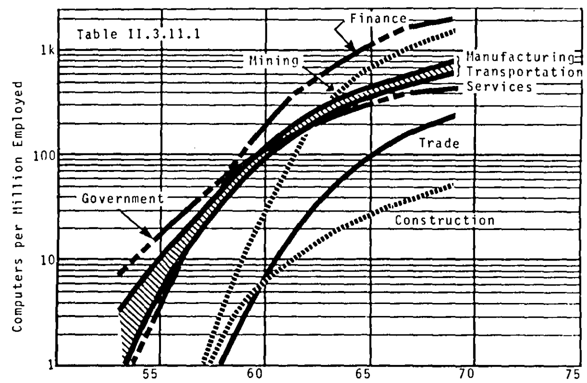



FIGURE 3.11.4 COMPUTER CONCENTRATION II
GP COMPUTERS IN USE PER MILLION EMPLOYED

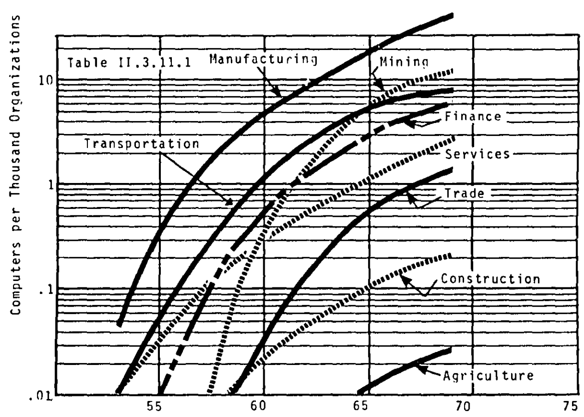



FIGURE 3.11.5 COMPUTER CONCENTRATION III
GP COMPUTERS IN USE PER THOUSAND ORGANIZATIONS

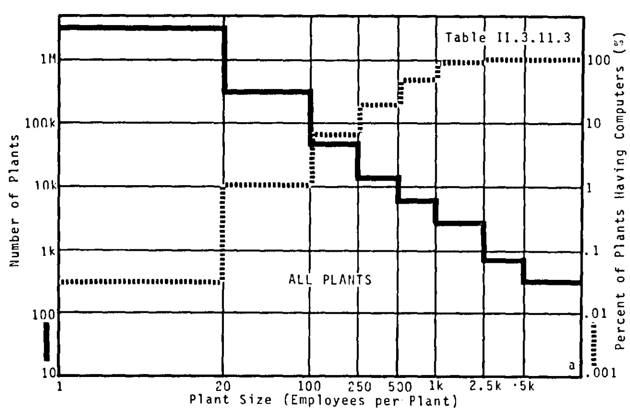



FIGURE 3.11.6 PLANT SIZE AND COMPUTER SATURATION (1967) I
NUMBER OF PLANTS AND PERCENT HAVING COMPUTERS VS. PLANT SIZE

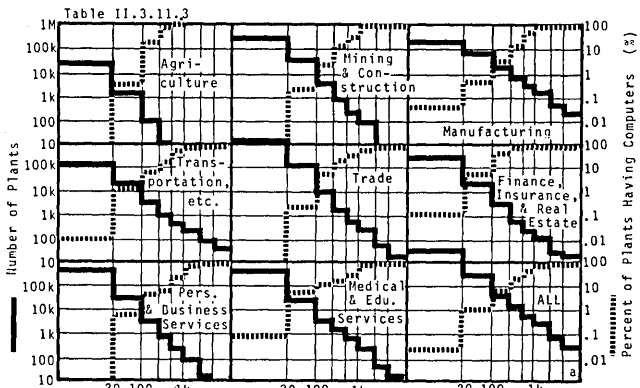



FIGURE 3.11.7 PLANT SIZE AND COMPUTER SATURATION (1967) II
NUMBER OF PLANTS AND PERCENT HAVING COMPUTERS VS. PLANT SIZE

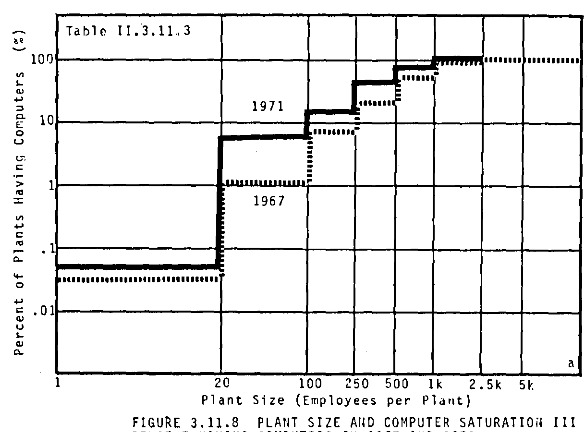



FIGURE 3.11.8 PLANT SIZE AND COMPUTER SATURATION III
PERCENT HAVING COMPUTERS IN 1967 AND 1971

establishments with 20 to 1,000 employees. (The change implied by these figures is substantially overstated, because of the already mentioned fact that the 1968 distribution clearly is incomplete. But, once again, remember that these figures are for GP computers only. As we shall see below, minis are finding increasing use in business applications; and some time-sharing services are catering to the needs of small organizations. These trends weren't so significant in 1968, but had begun to have some impact by 1972.)

A study published in 1969 by the Research Institute of America (RIASurv69) of over 2,400 firms in the manufacturing, financing, trade, and service industries, generally confirms the above data and gives some additional insight into the use of computer services and of large versus small systems. For 1500 manufacturing firms of various sizes, we show in Figure 3.11.9 the proportion of firms classified as nonusers, users of outside services, and users with small, or with medium and large computers. ("Small" is defined in the RIA study as "an IBM 1400 series machine, a 360/20 or 360/30, a Honeywell H110, an NCR Century 100, or an equivalent machine from other manufacturers." A medium computer has "the power and performance of an IBM system 360/40 or 360/50", and a large computer the power and performance of a 360/65.) About 20% of manufacturing firms use outside services exclusively, and such services are used by companies of all sizes. One might speculate that a "typical" company would gain some experience with computers using an outside service, and then get a computer of its own, either when it had grown large enough or experienced enough to make such a move. However, the RIA study showed that three out of four firms with small computers did *not* start by using an outside service.

A study published in EDP/IR provides some interesting data on computer usage by the largest firms in the U.S. The survey includes only companies receiving more than half their revenue from manufacturing or mining, and excludes the major computer companies. In 1969 the top 100 companies in this category operated 3.3 billion dollars worth of computer equipment, which was 43% of the computer value of all such companies, and 18% of all computers installed in the U.S. Table 3.11.1 gives data on the ten companies with the largest installed computer value, and provides, on the bottom line, a summary: the 100 firms average $33 million installed value of equipment, which is 1.4% of sales revenue, 1.5% of assets, and represents over $400 worth of equipment for each employee. Note the large concentration of computers in the high technology aerospace companies, where equipment acquisition was directly or indirectly financed under government contracts.

**Computer Usage in Some Specific Organizations**

Figure 3.11.9 describes the results of a study of some 1500 manufacturing organizations. There have been other studies published on various classes of organization, and in the next few paragraphs we will examine some of the results. The organization types described were chosen solely because the data is available, though of course the subject industries are themselves interesting and important. All four are in the Services sector.

**Banks and Hospitals.** We observed, in connections with Figure 3.11.7, that in every industrial classification the number of organizations in a given size range is invariably less than the number in the next smaller size range; and we saw that the more numerous smaller organizations are, in general, the less active computer users. In Figures 3.11.10 through 3.11.13 we look at the distribution of computer use from a different, but related point of view: instead of observing differences as a function of organization size, we observe them as related to the size of the computer installation—to the price of computer equipment at the site. For each of six price ranges, the figures show the proportion of sites, CPU's, and equipment value in each price range, along with average number of CPU's. For example, looking at the four figures we see that, for Banking computers, 8% of all computer sites are in the $2M to $4M price range, and these sites contain 14% of the CPU's and 19% of all Banking computer equipment value. There are an average of 2.9 CPU's per site at these installations.

I am unable to report the distribution of sizes of banks and hospitals which goes with this distribution of computers. And of course these figures give us no insight as to how banks are able to justify so much more, and so much more costly equipment than hospitals can. Undoubtedly the explanation is to be found in Ogden Nash's poem, "Bankers are Just Like Everyone Else, Only Richer"—or to put it less elegantly, the average bank's revenue is higher than that of the average hospital.

A series of studies carried out by *Banking* magazine in 1963, 1966, and 1969 help give us some background behind the growing use of computers in that industry. The studies were based on surveys conducted by the American Bankers Association, and in Figure 3.11.14 some of the results appear. The solid line provides an estimate of the number of computers used in banks, consistent with the total number in 1973 which formed the basis of Figures 3.11.10 to 3.11.13. (The squares on the chart at 1966 and 1969 represent total "Banking" computers including Savings and Loan Associations, while the solid line, and the ABA study, includes banks only). The dotted lines show the proportion of banks in various states of automation in 1963, 1966, 1969, 1972, and 1974. Note the proportion of banks having their own computers seemed to be levelling off by 1972, then jumped surprisingly by 1974. Meanwhile the proportion using computer services continues to rise. I have not been able to find comparable studies on hospital applications.

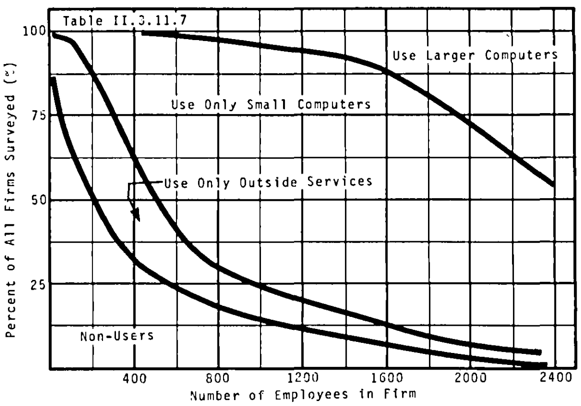



FIGURE 3.11.9 MANUFACTURING FIRMS AND COMPUTERS USAGE OF 1500 COMPANIES IN 1968, BY FIRM SIZE

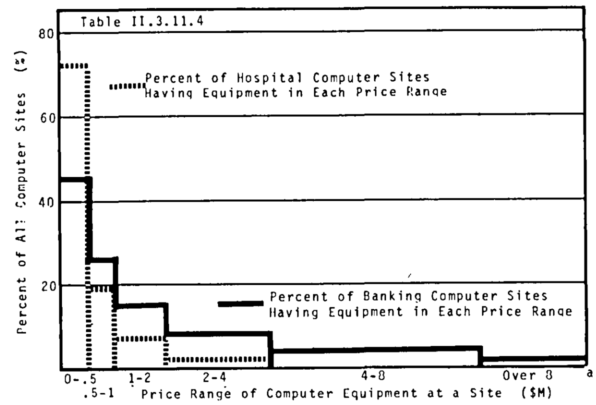



FIGURE 3.11.10 BANKING AND HOSPITAL APPLICATIONS (1973) I PROPORTION OF SITES HAVING EQUIPMENT IN EACH PRICE RANGE

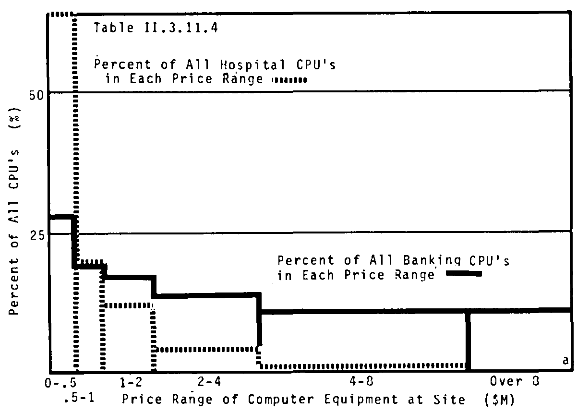



FIGURE 3.11.11 BANKING AND HOSPITAL APPLICATIONS (1973) II PROPORTION OF CPU'S IN EACH PRICE RANGE

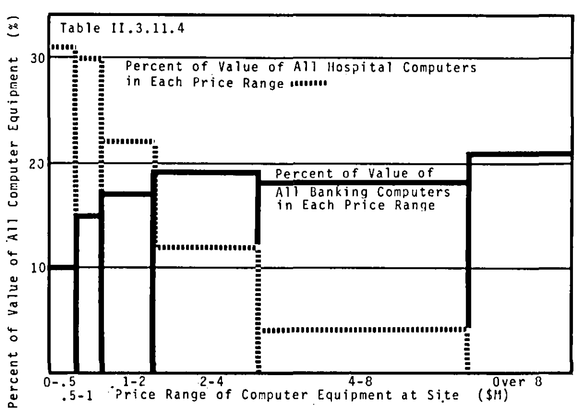



FIGURE 3.11.12 BANKING AND HOSPITAL APPLICATIONS (1973) III PROPORTION OF TOTAL COMPUTER VALUE IN EACH PRICE RANGE

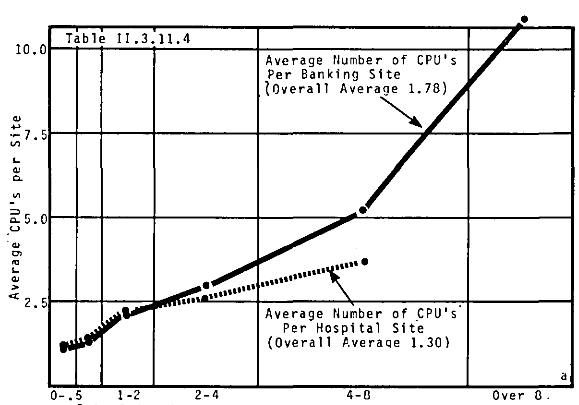



FIGURE 3.11.13 BANKING AND HOSPITAL APPLICATIONS (1973) IV AVERAGE NUMBER OF CPU'S PER SITE IN EACH PRICE RANGE

## TABLE 3.11.1 COMPUTER CONCENTRATION IN THE UNITED STATES IN 1969 ●

| Company | Computer Value Total ($M) | Per $1k Sales ($) | Per Employee ($) | Per $1k Assets ($) |
|---|---|---|---|---|
| **The Top Ten** | | | | |
| General Motors | 228.9 | 10.06 | 302 | 16.3 |
| General Electric | 220 | 26.3 | 550 | 38.3 |
| Boeing Aircraft | 140 | 42.8 | 986 | 64.0 |
| Ford Motor Co. | 139 | 9.8 | 334 | 15.5 |
| McDonald-Douglas | 98.5 | 27.3 | 788 | 74.1 |
| Lockheed Aircraft | 93.9 | 42.4 | 988 | *101.0 |
| Westinghous Elec. | 89.2 | 27.1 | 646 | 39.3 |
| Sperry-Rand | 85 | *54.4 | 841 | 77.6 |
| Shell Oil | 84 | 25.3 | *2153 | 19.9 |
| North American Rockwell | 82.6 | 31.3 | 724 | 60.2 |
| **Other Companies** | | | | |
| Standard Oil, NJ | 58.24 | 4.13 | 385 | *3.47 |
| McGraw Hill | 13.78 | 37.45 | 1060 | 44.89 |
| Gulf & Western Ind. | 10.32 | 7.86 | *138 | 5.02 |
| Natl. Dairy Prod. | 9.36 | *3.86 | 199 | 9.87 |
| Top 100 Firms | 3306.5 | 13.95 | 408 | 15.05 |

Source: *EDP/IR* Oct. 9, 1969. Includes non-computer companies receiving more than 50% of their revenue from manufacturing or mining. Firms are ranked in order of installed computer value.

* These items are either the maximum or minimum values for all of the 100 companies.

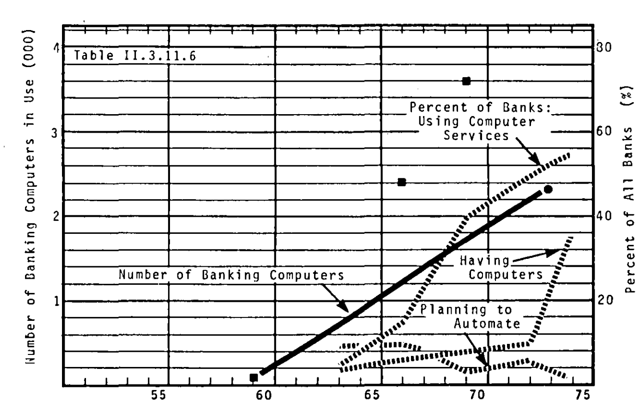



FIGURE 3.11.14 COMPUTERS AND BANKING NUMBER OF COMPUTERS, AND BANK STATUS

**Insurance Companies.** The insurance industry is another which has been analyzed in substantial detail, and some of the results are shown in Figures 3.11.15 through 3.11.19. The first of these figures shows how the number of systems in use by insurance companies has grown since the mid-fifties, and estimates the number of CPU's in use per company. As is indicated by the solid line, the insurance industry was an early buyer of data processing equipment, and by the early sixties had enough experience that it was able to make excellent use of second-generation systems. And the dotted line suggests that the growth in installations within large companies dominated the history of the early sixties, while the spreading use by smaller companies led to a drop in computers per company since about 1965. (As is indicated by the dashed line and the small circles, three sources of data are represented here and are not consistent. The solid line represents one source, the point at 1500 computers in 1973 a second, and the three small diamonds at 1959, 1966, and 1969, a third. I have concluded that the diamonds at 1966 and 1969 are not likely to be correct, and have drawn the dashed line to indicate the probable trend during the late 1960's.)

The next four figures represent the situation in 1973, and give us a glimpse of computer policy as a function of company size, as measured by the value of corporate assets. (Note the log scale, with each decade range in assets broken into two parts, one 1 to 5, the other 5 to 10). In Figure 3.11.16 the solid-line bar chart describes a reasonable-looking distribution of firms having computers. Since we suspect that the *total* number of firms in each size range increases as the size gets smaller, we suspect that virtually all companies with assets over $50M have computers, and that the proportion of firms with computers decreases rapidly as the firms get smaller. (Compare with the "Finance" data in Figure 3.11.7 and Table II.3.11.3.)

Having concluded that the bigger insurance companies are represented by the data, we observe with some surprise that there is a substantial lack of uniformity in the way these firms reportedly use and distribute their data processing equipment. The dashed line in Figure 3.11.17 shows that the value of computer equipment in use falls off fairly uniformly as a percent of total assets as the companies get larger. But a careful study of the variations in the other curves leads one to a perplexing conclusion: companies in the $500M to $1B size range and in the $5B to $10B size range employ more computer sites per company (Figure 3.11.16), and have fewer and smaller CPU's per site (Figures 3.11.17 and 3.11.18), than companies in the size categories just larger and just smaller. The 34 corporations in the $500M to $1B asset range, for example, average 2.38 sites and (coincidentally) 2.38 computers per site. The $100M to $500M companies have only one site per corporation, but average 2.81 computer on each site; and similarly the seventeen $1B to $5B companies average only 1.18 sites but have 4.2 computers per site.

There are various possible explanations for this phenomenon. The data may be incorrect. Or, if it does accurately represent the actual situation, it may express the fact that insurance companies are a far from homogenous group, and that centralized power is economically better suited to one class of company, and scattered computer capabilities better suited to another class.

Another explanation is that the averages shown are the result of very wide disparities between companies (with most companies having one large central system, and a few others having five or more sites, each relatively small), and represent very significant differences in approach to data processing.

The existence of multiple sites in an industry whose operations depend completely on the timely and accurate maintenance of a large data base raises a number of interesting questions. In multiple-site systems is the insurance policy data base centrally located, or distributed among the various sites, or duplicated at various sites? What form of inter-site communications is provided, and what use is made of those communications links? Should we be designing Data Management Systems so that they permit various combinations of central, distributed, and duplicated data bases, with various combinations of remote and local update and query actions?

**U.S. Government Installations.** We have seen that the Federal Government was the earliest big user of computers (Figure 3.11.1). Though its proportion of the total number of systems in use has steadily dropped, it is still by far the biggest single purchaser of data processing equipment, and the next six figures give us some insight into the character of this enormous market, as it has been described in a series of annual reports on Federal computer operations.

The solid line in Figure 3.11.20 shows how the total number of Government computers has grown since the early fifties. The Government census distinguishes General Management computers from Special Management systems, the latter class including control system components (but not fire-control systems), mobile systems, and classified systems. The former category has been dropping as a proportion of total installations, as shown by the dotted line of Figure 3.11.20.

There have been some marked changes in the Government's buying practices during the brief history of the industry, and two of them are brought out in the next two figures. With the introduction of the first commercial machines in the mid-fifties, IBM came to dominate the Federal marketplace both by installing a large number of machines, and by persuading Government users that their best policy was to rent rather than purchase equipment. By 1960 55% of all Government systems were IBM-manufactured, and only 19% of the total number were government-owned. At about this time Congress, the General Services Administration, and many government users questioned the desirability of domination by a single manufacturer, and pointed out the savings which could be achieved through purchase, rather than rental, of equipment. As a result, the proportion of IBM systems dropped to 21% by 1972, and the proportion owned increased to 78%. (IBM's share of the total installed *value* has dropped also, though not so markedly—the data on market share by value is not so readily available). Incidentally, the average value of a General Management government system was about $660K in 1972, and was thus 43% higher than that of the average US GP system at $461K. (See tables II.1.21 and II.3.11.6). And the comparison is even more striking when we remember that the General Management category includes many mini-computers.

The Government's estimate of its operating costs is shown in Figure 3.11.23, along with the two biggest components of cost: salaries and equipment rentals. Other components include equipment purchase and site preparation (in an amount comparable to what ten-year depreciation might be if depreciation of owned equipment were included), outside

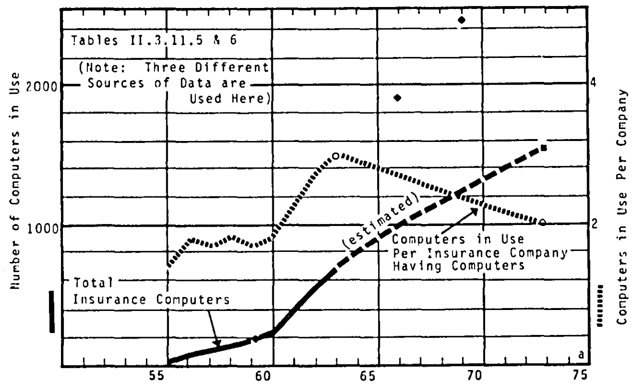



FIGURE 3.11.15 INSURANCE COMPANY APPLICATIONS I
NUMBER OF COMPUTERS, TOTAL AND PER COMPANY

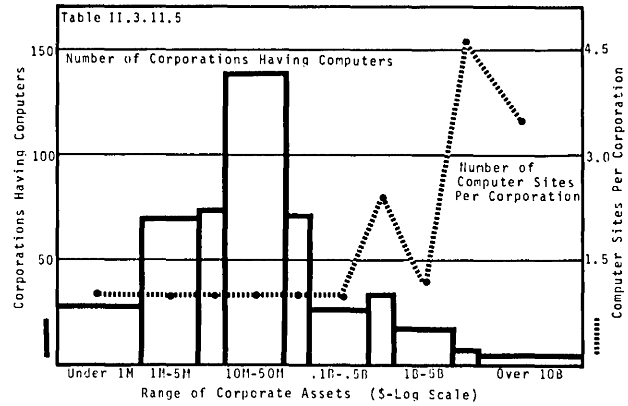



FIGURE 3.11.16 INSURANCE COMPANY APPLICATIONS (1973) II
CORPORATIONS AND SITES PER CORPORATION, BY CORPORATE SIZE

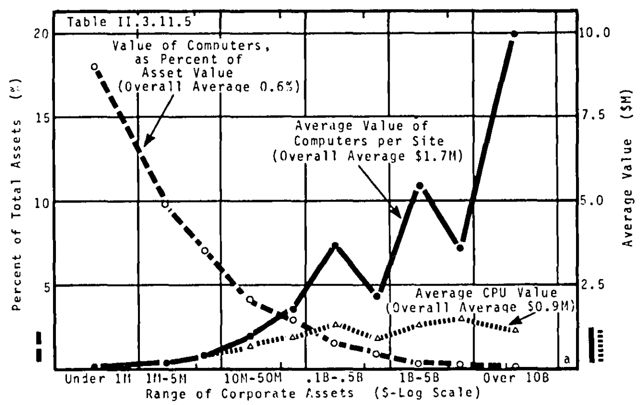



FIGURE 3.11.17 INSURANCE COMPANY APPLICATIONS (1973) III
COMPUTER VALUE PER ASSET DOLLAR, PER SITE, AND PER CPU

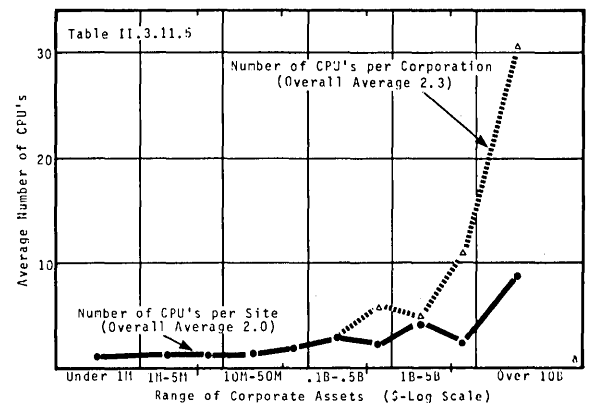



FIGURE 3.11.18 INSURANCE COMPANY APPLICATIONS (1973) IV
AVERAGE NUMBER OF CPU'S PER CORPORATION & PER SITE

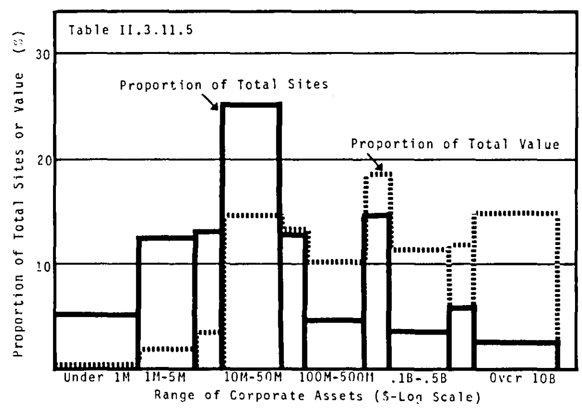



FIGURE 3.11.19 INSURANCE COMPANY APPLICATIONS (1973) V
PROPORTION OF SITES AND VALUE, BY CORPORATE SIZE

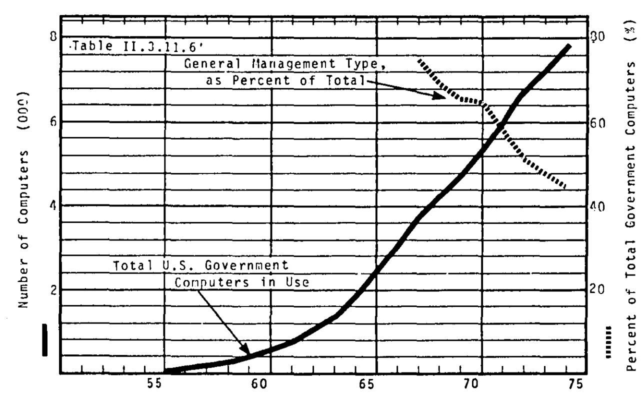



FIGURE 3.11.20 U.S. GOVERNMENT COMPUTERS I
TOTAL COMPUTERS IN USE, AND PERCENT "GENERAL MANAGEMENT"

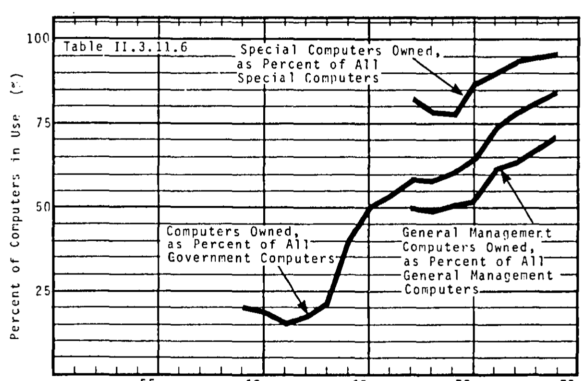



FIGURE 3.11.21 U.S. GOVERNMENT COMPUTERS II
PERCENT OF COMPUTERS IN USE OWNED BY THE GOVERNMENT

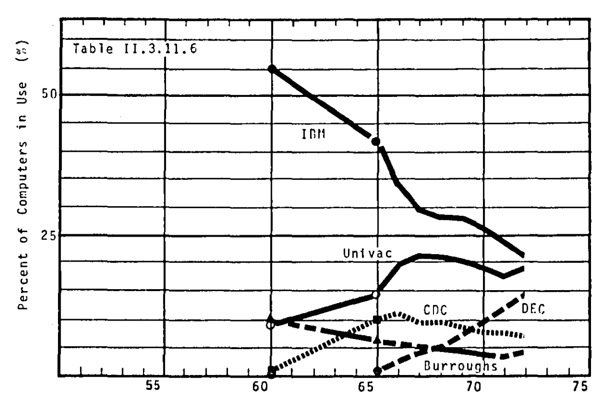



FIGURE 3.11.22 U.S. GOVERNMENT COMPUTERS III
PRINCIPAL MANUFACTURERS' SHARES, BASED ON NUMBER IN USE

services, and supplies. As usual, one cannot help but be impressed by the enormous cost of people necessary to keep the equipment in operation.

The Government marketplace is of course fär from homogeneous, and the last two figures show the principal using agencies, as measured by percent of number of systems in use, and percent of total operating costs. The four most important agencies in the years for which data is available are shown in each graph. The enormous impact of the Department of Defense is of course striking. So also are the increases which have recently taken place in the relative *number* of AEC systems and the relative *operating costs* of Treasury systems. (Note the percent breakdown by *numbers* is based on the total of general management and special computers, while the breakdown by *operating cost* refers only to the general management systems.)

**Process Control.** In the mid-fifties, digital computers had been developed for use in real-time military fire-control and navigation applications, and hardware was available for converting analog signals from measuring instruments into digital numbers which could be manipulated by computer programs. It was evident that this technology could be applied to a variety of production processes in industry, and in 1958 the first systems were installed, in a petroleum refinery and in a power plant.

The systems have been employed for two principal purposes: to exert control over the production or distribution processes, with the object of making those processes more efficient; and to collect and analyze data about processes, enabling human operators to exert improved control. The use of such systems has grown spectacularly, as shown in Figure 3.11.26—by 1964 there were over 300 installations in the United States, and ten years later there were over 2000 worldwide, *in the petrochemical industry only.* (I have not been able to find recent data on total process control installations.) In addition to their application in the power and petrochemical industries, such computers are used in manufacturing steel, cement, and paper. For the most part minicomputers rather than GP systems are used in control—see Figure 3.12.2.

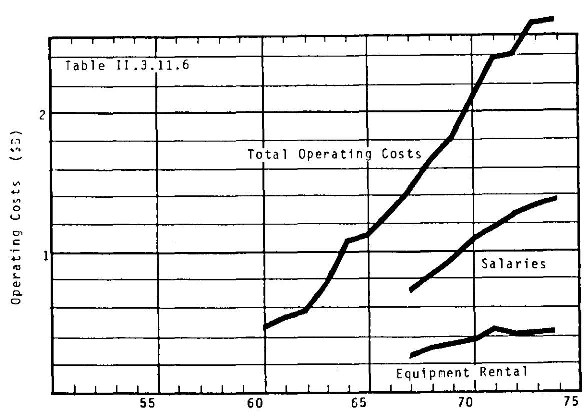



FIGURE 3.11.23 U.S. GOVERNMENT COMPUTERS IV
OPERATING COSTS OF GENERAL MANAGEMENT COMPUTERS

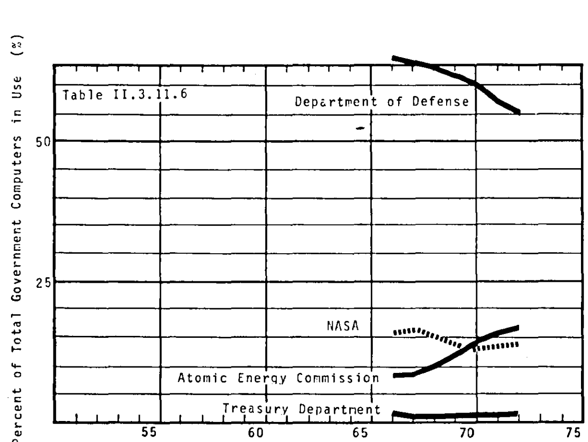



FIGURE 3.11.24 U.S. GOVERNMENT COMPUTERS V
PRINCIPAL USING AGENCIES, BASED ON NUMBER

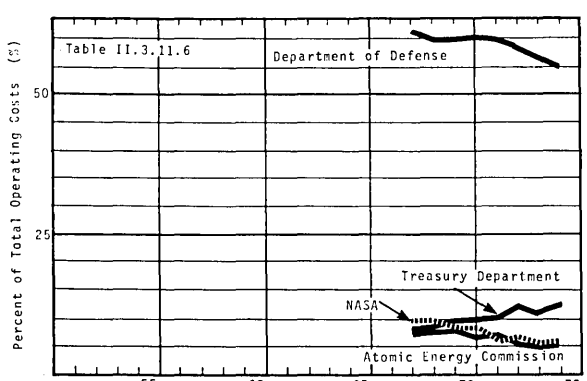



FIGURE 3.11.25 U.S. GOVERNMENT COMPUTERS VI
PRINCIPAL USING AGENCIES, BY OPERATING COSTS

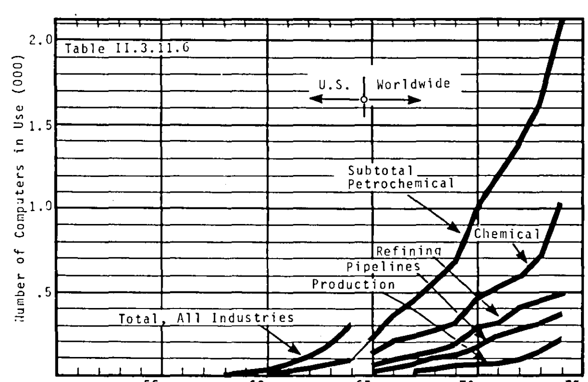



FIGURE 3.11.26 COMPUTERS IN PROCESS CONTROL

## 3.12 COMPUTER USE BY FUNCTION

Let us now turn from a preoccupation with the question of where computers are, to the study of what they are accomplishing. In one sense, we looked in detail at what they are doing in Section 2.2, when we studied system performance and learned something about computer workloads. But we were then looking at computer functions in the microscopic sense, microsecond by microsecond. Let us now look at their functions in a macroscopic sense, hour by hour.

In a panel discussion at a computer conference in 1972, Dr. Richard Hamming of Bell Telephone Laboratories described a macroscopic point of view which should illustrate the point we will investigate in this section. He said that, when he visits University Computer Centers and talks to their managers he asks them the following question: "What are you doing to increase the probability that a faculty member at this university will win the Nobel Prize?" In one sense the question is most unfair, and an appropriate reply might be, "Nothing. It is not the University's goal that faculty members win Nobel Prizes." But the question is provocative because it makes us think about the computer's function as related to the organization's objectives—about what the computer is accomplishing rather than what it is doing, about the functions it is carrying out rather than the proportion of time it is not idle.

Just as, at the microscopic level there are several layers which are of interest (what gates and flip-flops are employed, what instructions are most often used, what proportion of the time the CPU and other system components are active, what FORTRAN features are most often invoked), so also are there several layers at the macroscopic level. The first is the one inspired by Dr. Hamming's inquiry. What are the objectives of the organization which uses the computer system, and how do the system's functions further those objectives? There are as many answers to the first part of that question as there are organizations. But there is one fair answer to the second part, an answer independent of the nature or purpose of the organization: The system furthers the organization's objectives if it performs specified data processing functions at the lowest possible cost. We will analyze data processing costs in Section 3.2, and will examine the particular functions which organizations have regarded as important in the remainder of this section. But before we do that, let us spend a moment discussing the relationship between organization objectives and "specified data processing functions."

It is management's responsibility to define the organization's goals and then to assign tasks, consistent with those goals, to various members of the organization. In assigning tasks to the data processing organization, management should begin by listing the essential or necessary data processing functions, and then should establish criteria by which other functions should be added. The essential functions are those required by law and those without which the organization fails. Employees, vendors, and the government must be paid, and so (referring to Table 3.0.6) there must be personnel, vendor, finance, and general ledger files, and payroll, vendor, and government checks written. Products must be delivered, so there must be parts and product files and they must be kept up-to-date. Deliveries must be made to, and money collected from customers, so there must be customer files.

Once the "essential" list is drawn up, management can create a second list of "desirable" functions, listed in order of their value to the organization. Useful but non-essential files like job descriptions, markets, and procedures can be added. Desirable but non-essential features can be added to the essential files—performance appraisals to the personnel files, and credit ratings to the vendor files, for example. Helpful but non-essential reports and analyses can be provided, like monthly reports of inventories sorted by total value, or daily reports of production status. To each useful, desirable, or helpful (non-essential) feature, management can assign a value, based on the increased revenue or reduced costs that feature will provide.

Finally, management takes the two lists and assigns responsibilities. It delegates the essential processing tasks to the organizations best able to handle them economically, and determines which of the non-essentials will be done, based on their value and on the incremental cost of doing each one. The result, finally, is a list of specified data processing functions to be carried out by various parts of the organization, including the data processing group.

The process as described is obviously complex and difficult. To some extent, the difference between essential and non-essential functions is arbitrary. It is often very difficult to assign values to some "desirable" features. (How much is it worth to maintain a file on the products and operations of a competitor, for example?) And the determination of the incremental costs of processing is far from simple.

In practice, decisions about data processing are usually not made as described above. In a new organization, management is too preoccupied with other matters to give any but the barest attention to data processing; and in existing organizations there is so much momentum ("this is the way it has always been done") that changes are very difficult to make.

For many organizations, it is probable that the *ad hoc* methods used to assign data processing functions are quite effective, and that few or no savings could be achieved even if some perfect set of assignments were made. But for many other organizations, there is clearly a great deal of waste. Too much is spent for data processing, either because functions are performed whose cost exceeds their value, or because expensive methods are used where cheaper ones would be adequate. These unfortunate situations usually occur because functions are added without a proper appraisal of their value, or because once-valuable functions are continued after their value has disappeared, or because (all too often) the approach is "how can I use a computer to do this" rather than "why should I do this, and if I must do it, what is the cheapest way". (See Section 3.27 for further discussion of user justification of data processing.)

**Important Functions.** The net result of management's deliberations and actions is a set of data processing functions carried out in a given organization, including the subset implemented on a computer. Table 3.12.1 presents the results of four surveys conducted between 1956 and 1969 on the number of applications carried on each respondent's computer. In the table, the data is normalized to show how many mentions occurred per 100 users. Note that the 1956 study only mentioned six applications; the British and RIA studies were somewhat biased in that they identified only seven and eighteen applications, respectively, on the questionnaires and asked the respondents to check those they had implemented; and the IDC study, which covered the largest number of respondents, identified a total of 30 applications.

If we compare the various studies, we can note various conclusions. Payroll was originally and still is the most common application, on systems of all sizes. Bookkeeping and accounting functions have grown rapidly—more rapidly than payroll, which often was the first application implemented. Non-essential functions like Sales Forecasts and Labor Distribution have been justified in many installations.

In some ways, however, the most interesting figures are those at the bottom of the table, which list the total applications named per 100 installations. They uniformly show the average number of applications per computer has been increasing with the passage of time. According to the British survey, for example, the average number increased from 2.88 applications in 1964 to 5.01 five years later.

It is of course gratifying to learn that computers are becoming more useful. But it is most distressing to discover how slowly things have changed and how little today's fantastic machines seem really to be accomplishing. According to the table, a typical IBM 650 was handling about 2.5 jobs. In 1969, when the average GP computer was over 150 times faster than the 650, and was probably operating at least 50 more hours per month, a typical machine was handling less than twice as many jobs—4.4 compared with 2.5.

In evaluating this evidence, one can take one of two points of view.

1. The data is misleading and is being misinterpreted; and in fact computers are today *more than* one hundred times useful than they were in 1956. One problem with the data is that there are no good definitions for each of the different applications, so users do not respond uniformally to a questionaire. Some of the named applications, like "general bookkeeping/accounting" or "engineering and scientific calculations" obviously could be broken down into several applications. In addition, even simple sounding applications like "payroll" require many different programs and have grown and increased in complexity during the past ten years to accomodate government and management reporting requirements.

Alternatively one might conclude:

2. The evidence points to the correct conclusion—that computers are today used very inefficiently. There are host of reasons. Operating systems are great wasters of computer time. Many old programs are still being run (very wastefully) in the emulation mode because users have found it costly to reprogram them. Higher-level languages, invented because programming is so difficult, are substantially less efficient than the machine language programs written in the mid-1950's. A typical user's application programs, developed over a period of years, are a patchwork of uncoordinated increments, operating on redundant files which themselves must be compared and checked with special programs. Finally, the complexity of the whole system is such that computer operations people find it very difficult to choose the most efficient combination of operating parameters and procedures.

While acknowledging that the data of Table 3.12.1 probably understates the number of 1968-1969 functions performed, I submit there is nevertheless a substantial body of qualitative and quantitative evidence in support of the thesis that present day systems are inefficient. For example:

1. It is commonplace to hear corporate managers complain about their data processing operations: about the delay between the end of a reporting period and completion of computer reports on that period; about the difficulty of adding new applications; about the failure of "management information systems". The RIA study found that "scheduling and priorities" was the most serious computer operations problem for both large and small computers, and was increasing in severity.

2. As we saw in Chapter 2 when we discussed system performance, there are a great many published reports on improvements which have been effected during the past few years through the use of various techniques of performance analysis. The relative ease with which improvements can be made, and the widespread interest in the subject of performance analysis, indicate that current operations are inefficient.

3. The British and IDC studies determined the average computer hours per month for each application, as well as the average number of applications per system. Figure 3.12.1 provides a composite look at the results. On the horizontal axis is plotted the percentage of installations implementing the function, and on the vertical axis the average computer hours per month for the function. The results of the US study are plotted as black dots, those of the British survey as circles. We note for example that Payroll was implemented at 52% of the US sites, where it required an average of 39 hours per month. Sixty-nine percent of the British computers handled payroll, on the other hand, requiring an average of 50 hours per month. (Note that, for the four British tasks comparable to American ones, computer time per month was roughly the same, but British percent implementation was substantially higher.) As shown in the upper corner of the table, US and British operating time was about the same, at 320 hours per month. If we imagine a specific US installation which implemented the four most popular applications (Accounting, Payroll, Inventory Control, and Sales Analysis), we would find they used up 247 of its 320 hours—leaving 73 hours for another 0.4 applications to bring the installation to an average of 4.4. The hours spent are thus compatible with the small number of functions performed.

This is really the crux of the matter. The average 1969 machine required 39 hours per month to perform the application loosely defined as "Payroll". The IBM 650, since it handled fewer appliacations (2.5 compared with 4.4), probably took more time to calculate a payroll—say, 70 hours per month. But the IBM 650 carried out 291 operations per second (Knight's Commercial measure), while the average 1969 machine did approximately 46,500 o.p.s. and the IBM 360/30, roughly comparable in price to the 650, carried out 17,000 operations per second. A 1969 machine could therefore do 70 hours of IBM 650 work in 25 to 71 minutes. Why then did it require 39 *hours* ? What are we getting today in 39 hours of 360/30 time that we didn't get in 1956 with 70 hours of IBM 650 time?

**TABLE 3.12.1 COMPUTER APPLICATIONS PER HUNDRED INSTALLATIONS**

| Sample: | 81 IBM 650 Sites | British Survey | 1,589 Sites | Research Institute of America Survey Small Comp. in Mfg. Cos. | | Medium Computers | | Large Computers | | IDC Report 720 Cos. | 2000 Cos. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date:** | **1956** | **1964** | **1969** | **1965** | **1968** | **1962** | **1968** | **1960** | **1968** | **1969** | **1969** |
| Payroll | 65 | 59 | 69 | 70 | 85 | 56 | 73 | 59 | 82 | 67 | 56 |
| General Bookkeeping | | | | 31 | 57 | 39 | 58 | 37 | 64 | | |
| General Ledger | | | | | | | | | | 15 | 14 |
| Accounting | 25 | | | | | | | | | 65 | 52 |
| Financial Accounting | | 40 | 82 | | | | | | | | |
| Accounts Receivable | | | | 43 | 64 | 39 | 58 | 41 | 64 | | |
| Accounts Payable | | | | 35 | 57 | 25 | 51 | 33 | 55 | | |
| Order Processing and Billing | | | | 43 | 64 | 53 | 58 | 41 | 64 | | |
| Order Analysis | | | | | | | | | | 30 | 12 |
| Billing | | 36 | 67 | | | | | | | 31 | 21 |
| Sales Analysis and Control | | | | 55 | 85 | 42 | 66 | 41 | 73 | 56 | 31 |
| Sales Forecasts | | | | | | 0 | 37 | 0 | 36 | | |
| Inventory Control | | 40 | 64 | 39 | 71 | 28 | 58 | 22 | 64 | 74 | 41 |
| Production Sched. or Control | 33 | 19 | 32 | | | | | 0 | 55 | 33 | 14 |
| Cost Accounting | 35 | | | | | | | | | 23 | 13 |
| Labor Distribution | | | | | | | | | | 13 | 6 |
| Mailing Lists | | | | 16 | 50 | | 44 | | 64 | 2 | 4 |
| Engineering/Sci. Calcs. | 53 | 28 | 61 | | | 0 | 37 | 22 | 36 | 10 | 8 |
| Information Storage/Retrieval | | | | | | 0 | 37 | 0 | 46 | | |
| Savings & Demand Deposit | | | | | | | | | | 0 | 15 |
| Student Records | | | | | | | | | | 0 | 5 |
| Other Identified Appl. | 34 | 54 | 81 | 58 | 177 | 68 | 153 | 74 | 207 | 58 | 143 |
| "Other" or "Miscellaneous" | | 12 | 45 | | | | | | | 5 | 5 |
| **Grand Total** | 245 | 288 | 501 | 390 | 710 | 350 | 730 | 370 | 910 | 482 | 440 |

Source: See Notes in Part II.

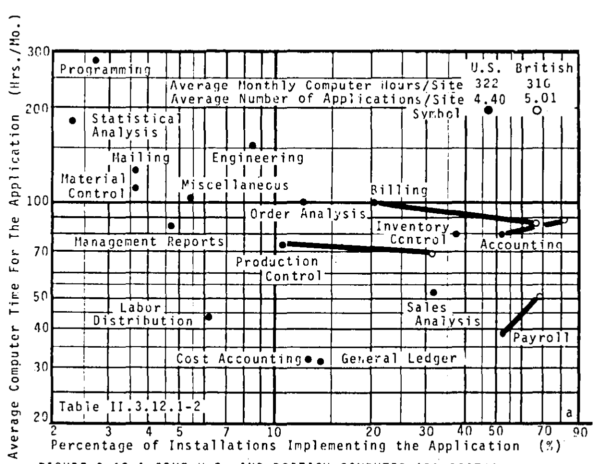



FIGURE 3.12.1 SOME U.S. AND BRITISH COMPUTER APPLICATIONS IN 1969 MONTHLY COMPUTER TIME AND FREQUENCY OF OCCURENCE

4. Let us define a *transaction* as a data processing function which records or analyzes an event. The definition (and the concept) is not precise, but perhaps most of us could agree that the following might be regarded as examples of transactions: compiling a FORTRAN statement; modifying an insurance policy file as a result of a policyholder's address change; preparing a paycheck for an individual; answering a query regarding availability of space on an airline flight; analyzing an electrocardioagram input from a patient; or inverting a matrix whose elements are submitted. A transaction is initiated by the introduction of a request, usually including input data; it requires that certain data processing operations be carried out; and it usually results in the generation of output data.

While reviewing workloads in Section 2.21 we got a quantitative feeling for what a transaction might require: there are 2.3 output characters per input character, and 300 computer operations are required per I/O character. (The figures are medians from the Army/Air Force Management Information Systems Catalog—Table II.2.21.1.) If we assume a median transaction processes 100 input characters, we find that it requires (100 x 3.3 x 300) 99,000 computer operations. If a payroll transaction is somewhere near the median, then a 360/30 processed 24,000 transactions in 39 hours, and the average 1969 machine processed almost 66,000 transactions. And those numbers certainly sound reasonable as numbers of payroll transactions per month, if we contemplate weekly payrolls and several thousand employees. But the IBM 650, in its 70 hours for monthly payroll, would only be able to handle 740 transactions, assuming a transaction required 99,000 computer operations back in 1956. And that is not a reasonable number at all. So one reaches the tentative conclusion that the number of computer operations per transaction has increased remarkably since the mid-fifties. Why?

Amaya has remarked, "Through several generations of computers the average job execution time is independent of the speed of the computer" (HalfM73). The evidence presented here strongly supports that conclusion without explaining it. An explanation requires detailed analysis. If a payroll transaction today requires 99,000 computer operations, we need to do a "value analysis" on those operations, breaking them down into functional sub-categories and comparing the complexity of each sub-function with the complexity, and therefore time and cost, of the operations which implement it—just as an engineer does a value analysis of a sub-assembly, comparing the functions of its various component parts with their costs.

A preliminary look at applications from a macroscopic point of view, making use of the little published evidence available, certainly raises more questions than it answers. But it also suggests that continuing, more detailed analysis will greatly enhance our understanding of the data processing function, and may lead to substantial improvements in system efficiency at the same time.

**Minicomputer Applications.** Though, or perhaps because, the market for minicomputers grew like a weed in the late 60's, there have been no well-documented studies on their use. One important early application area was process control, already discussed in connection with Figure 3.11.26. But what have been the other principal applications? Figure 3.12.2 presents a personal guess, based on Figure 3.11.26 and a number of fragmentary pieces of data. The small machines were originally used primarily for engineering and scientific calculations. Process control was the first non-military application of digital equipment to control applications, and its primary attributes—a system dedicated to one application, acting in real time, and receiving and transmitting data directly from and to a process via special transducers and digital/analog converters—led directly to data acqusition and test equipment applications. In the former, a system periodically samples and records attributes of an activity taking place in the field or in a laboratory, disgorging raw data, analyses, and statistical summaries, at regular intervals as appropriate. In the latter, a computer is used, often in association with a human operator, to control and process the results of tests on complex components, mechanisms, or systems.

More recently the mini has been adapted to perform specialized business data processing functions, often as a component in another system. In some such applications—data entry, communications control, character recognition—it may be invisible to the system user, who uses the system without being aware that it contains a stored-program computer. In other applications, it may be sold as a "small business computer", usually in some specialized application area, or as an "intelligent terminal". And once again it is important to emphasize that the definitions of GP and mini systems used here *exclude* many small business and accounting machines which increasingly contain small stored-program computers. These systems, manufactured by Burroughs, NCR, and Nixdorf, among others, represent one of the fastest-growing segments of the data processing marketplace.

## 3.2 Data Processing Costs •

Rational decisions about data processing are based on processing costs of various alternatives. In this section we will identify and catalog costs, and attempt to show how they have changed over the last twenty years. We will of course make use of the data from Chapters 1 and 2 on product and operating costs for data processing equipment and services, but will also introduce new information, especially about costs of non-computer processing. In Sections 3.21 to 3.24, we will discuss cost factors for the four basic functions: Collection, Storage, Manipulation, and Distribution. We will then examine system operating costs, attempting to take into account *all* the costs, direct and indirect, required to support a computer system. Finally, in Sections 3.26 and 3.27, we will apply the system cost data to various specific applications and will draw some conclusions. *It is important to remember, in examining the data in sections 3.21 to 3.24, that we are only looking at components of a total system cost, and that we must be very careful about drawing conclusions until we take all costs into consideration.*

### 3.21 DATA COLLECTION COSTS

As we discussed in Section 3.0, Data Collection covers the functions performed from the time and place data enters (or originates within) an organization until it is filed. Collection thus may require that data be transcribed from one form to another (e.g., by copying it from an original document to a standard file card, or by writing it on magnetic tape via a key-to-tape device) and communicated from one place to another. Communications costs were discussed in Section 2.14. We will concentrate here on transcription costs.

Some data is filed in the form in which it reaches the organization. This may happen for legal reasons (e.g., contracts are so filed), because the data is of little importance (e.g., correspondence with customers, vendors, or prospective employees), or because the system was designed to capture data in a form in which it can be used directly (e.g., credit card invoices, where the amount of the invoice can be read directly by OCR equipment; or employees' time cards in a small organization where a payroll clerk will calculate and write the paychecks directly from the time card). But a great bulk of data must be transcribed from its original form—written or typed on some source document—to some different form, with the transcribing being done by a human operator.

An efficient transcription takes place as follows: the operator takes a stack of source materials, and records selected data from them, in a standard, pre-determined format, on a sequence of standard documents. Each resulting "standard document" may be a sheet of paper with the data typed or handwritten on it, or it may be a machine-readable document—a punched card, magnetic tape, or disc record.

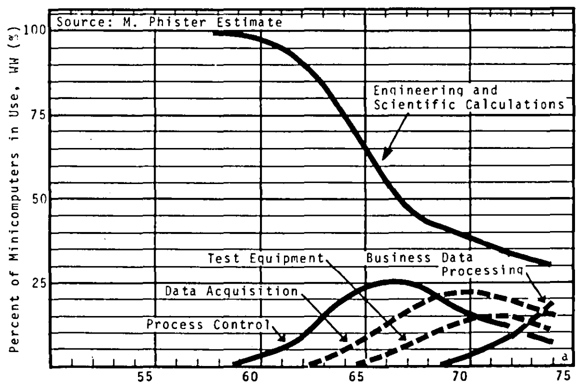



FIGURE 3.12.2 MINICOMPUTER APPLICATIONS
AN ESTIMATE OF THE PROPORTION IN USE IN VARIOUS APPLICATIONS

Since an operator is required, the cost of data collection is critically dependent on the time required to transcribe data onto a document. Comparative times for several different transcribing systems are shown in Figure 3.21.1 as a function of the number of characters recorded on each document. For most of the systems there is a "loading" time of one to four seconds every time a new document is started—the time required to get the completed document out of the way or out of a machine, and to get the new one in place. From then on, time is proportional to the number of characters entered. Hand copying of data is slowest and the various forms of keyboard input appreciably faster. "Normal text" typing is at the rate of 65 words per minute. Typing for OCR (with its implied commentary on the inability of optical character recognition equipment to read real-world source documents) is somewhat faster than keypunching and is said to have the advantage that it can be done by typists after a small amount of training, thus giving a saving both in time and in hourly wages.

The figure assumes certain fixed data entry rates for each system. However, the operations are being performed by people, with their rich variety of irrational idiosyncrasies. It is therefore not at all uncommon to find differences of 2:1 and 3:1 between the slowest and fastest operator at a given installation (with the faster operator usually being the more accurate one). The distinction between the various systems is much blurred if we take these differences into account, and it is easy to see that a well-run keypunch operation might have an average time per document substantially less than an inefficent key-to-tape or OCR typing operation.

Operator cost per thousand characters, computed from the times shown in Figure 3.21.1 and from salary data presented in Section 1.4, is shown in Figure 3.21.2. We assume that hand printing operations are performed by file clerks, that typing is done by clerk typists, and that the other systems employ keypunch operators —each of these occupations having a successively higher salary. Note the heavy penalty one pays if the prepared document contains only a few characters—a result of the fact that the operator requires a little extra time to "set up" each new document. As shown, one advantage of the key-to-tape or -disc systems is that a buffer isolates the operator from the recorded "document" and thus makes operator costs independent of characters per document. However, the figure serves as another reminder of the penalties paid by system design using short records. (Recall the magnetic tape storage capacity loss due to short records—Figure 2.12.14.)

We have noted that data entry rates vary considerably from operator to operator. They also vary depending upon the condition and character of the source documents, as shown in Figure 3.21.3. The previous two figures have assumed "Fair" source quality, and this figure shows the variation from "Poor" to "Good"; "Fair" lies between the two. A good document is physically clean and neat, contains easily-read data, presented in the same format and sequence in which it is to be recorded. A poor document is dirty and dog-eared, contains carelessly-written data mixed in with other data in a sequence different from that into which it is to be transcribed. If ones source data is classified as "poor" and one is keypunching 40 characters per document, would it be worthwhile to copy the data manually onto large sheets containing (say) 280 characters per sheet, and then to keypunch the data from this "good" source, creating seven records per sheet? With the rates and wages implicit in the figure, the answer is No: it still costs more per thousand characters to copy the original data than it would have to keypunch it originally. However, there certainly are situations where such a copying operation would make sense, depending on document characteristics.

The cost data in the previous figures was based on wages for the year 1970. In Figure 3.21.4 we see how data collection costs (for 100-character output documents) have changed over the years. Note how the introduction of new equipment tends to keep costs down by improving productivity: in 1955 it cost $0.20 per thousand characters to Keypunch data; by 1965 salary costs had increased by 35% to $0.27, but the introduction of Key-to-tape equipment at that time reduced the costs back to $0.23. The introduction of improved OCR equipment has since permitted a further relative reduction in operator costs. And meanwhile the costs of hand print operations continue to rise.

## 3.22 DATA STORAGE COSTS

Data is stored on some form of media, which in turn is stored on equipment which makes the data accessible, with or without the intervention of an operator. In this section we will look at media and equipment costs and at the access time and storage capacities of various simple sub-systems. Once again it must be emphasized that we are not looking at total system costs, and must be wary of drawing conclusions until all costs are visible.

We discussed trends in media costs in connection with Figure 2.16.1, and the 1970 costs from that table are repeated and expanded in Figure 3.22.1, along with some data on human-readable media. The range in cost and capacity of the 8.5-inch by 11-inch page as a function of whether data is typewritten or printed, and whether it appears on one side of the paper or both sides, is comparable to the range in magnetic tape characteristics as a function of recording density; but at the same cost per MByte, a full tape reel of course has over 1000 times the capacity of a single page. Three-by-five inch "index" cards, convenient for filing and referencing many kinds of data, lie between punched cards and letter-sized sheets, in cost and capacity. Microfilm is the cheapest media, though 1600 bpi magnetic tape is comparable, and even denser tape is available. The "diskette" or "floppy disk" is comparable in price per megabyte to the disk pack, but of course has much less capacity.

Next let us look at the cost per megabyte of units used to store the media and to facilitate or permit access to the data. For each equipment, the capacity shown in Figure 3.22.2 assumes it is loaded with the appropriate media, and that the media themselves are full of data. Equipment costs per megabyte are then simply the purchase price of each type of equipment, divided by its maximum, loaded capacity.

As one might expect, all the automatic read/write devices—tape units and files—have high equipment costs, of the order of $300 per megabyte. Unexpectedly the microfiche viewer has a comparably high cost, more than ten times that of the microfilm viewer. The microfilm viewer is comparable in cost per megabyte and capacity to a large (four feet wide, five feet high) 70-drawer cabinet for filing 3"x5" cards. The Kardveyer (Trademark, Sperry-Rand Corp.) is a mechanized filing cabinet which brings a desired drawer within reach of an operator in response to the operator's pressing certain control buttons. These devices have capacities moderately higher than the non-mechanized cabinets, and of course cost more. The common four-drawer filing cabinet filled with typewritten letter-sized sheets has very nearly the same capacity as the card file cabinet but is one twenty-fifth as costly per megabyte. A library bookcase section (three linear feet of single-faced shelves, 7.5 feet high) provides the lowest equipment cost per megabyte of all those considered.

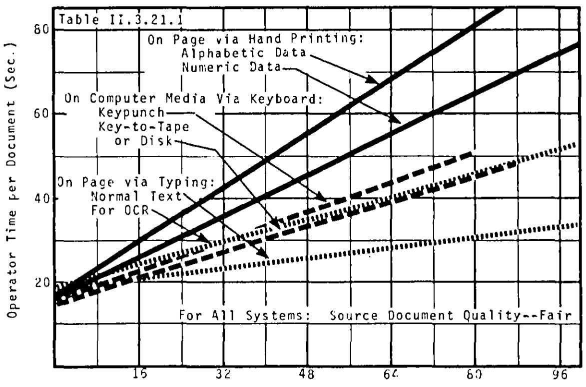



FIGURE 3.21.1 DATA COLLECTION I. OPERATOR TIME RECORDING DATA ON VARIOUS DOCUMENTS WITH VARIOUS SYSTEMS

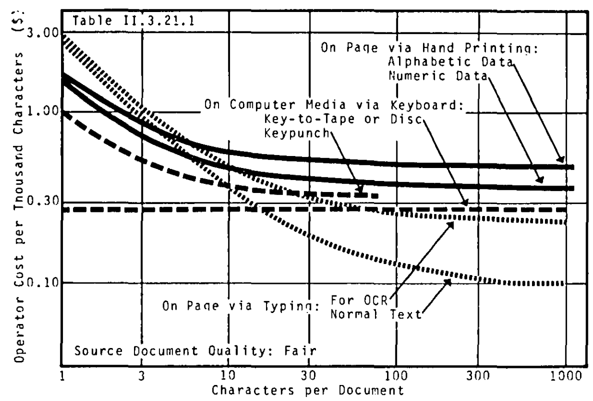



FIGURE 3.21.2 DATA COLLECTION II OPERATOR COSTS (1970) COST PER THOUSAND CHARACTERS WITH VARIOUS SYSTEMS

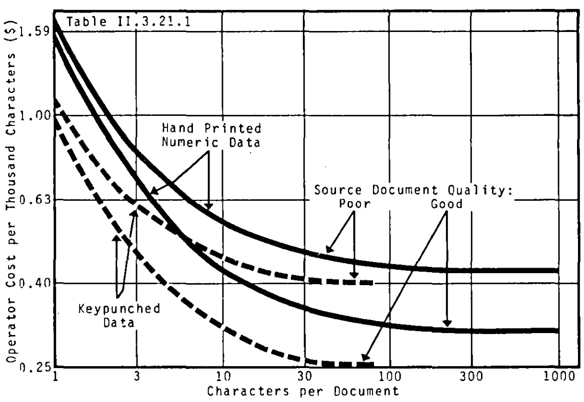



FIGURE 3.21.3 DATA COLLECTION III OPERATOR COSTS (1970) EFFECT OF SOURCE DOCUMENT QUALITY ON COST PER KILOBYTE

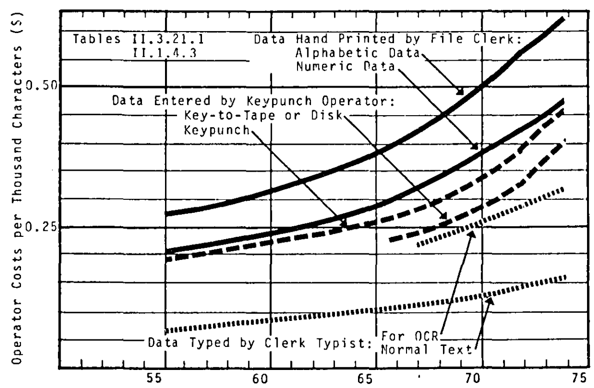



FIGURE 3.21.4 DATA COLLECTION IV OPERATOR COSTS CHRONOLOGY OF COST FOR 100-CHARACTER DOCUMENT

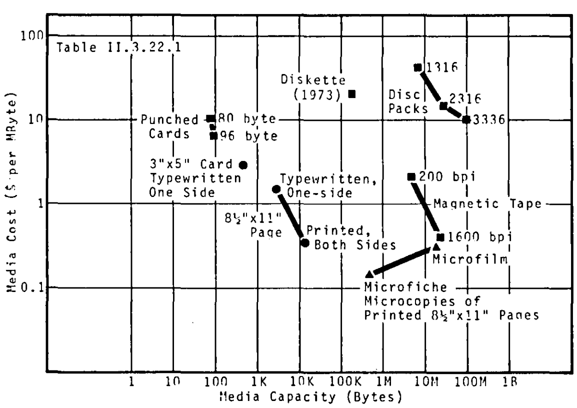



FIGURE 3.22.1 DATA STORAGE I COST AND CAPACITY OF VARIOUS MEDIA (1970)

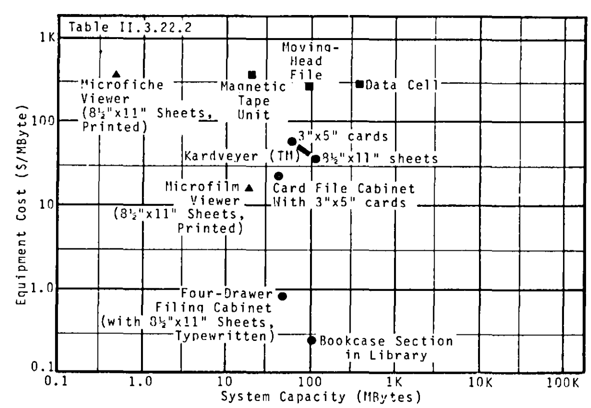



FIGURE 3.22.2 DATA STORAGE II EQUIPMENT COST AND CAPACITY OF VARIOUS SYSTEMS (1970)

Having considered media and equipment costs separately, we now consider them together in Figure 3.22.3, for the principal data storage systems. Furthermore, we extend the capacity of each of these systems, and show the resulting capacity and cost for a range of capacities starting with the basic unit and including units of twice, ten, one hundred, one thousand, etc., times its capacity. For the filing cabinets, an expanded system is simply one or more additional file cabinets full of cards or papers, and the cost per megabyte is thus independent of capacity. Note that the media cost of the four drawer system ($1.50 per megabyte) exceeds the equipment cost ($0.83 per megabyte) with the result that the cost ratio of card to sheet systems is much smaller than it was when we considered equipment cost alone.

For the other four systems in Figure 3.22.3, we increase capacity by adding media only, using an operator to change media when necessary. The cost then is equal to the media cost, plus the equipment cost divided by total media capacity. This latter factor grows smaller with every increment of capacity until finally it is negligible and the cost per megabyte approaches the media cost.

As system capacities increase, the apparent relationships between the different systems change. The microfiche system with 100 fiche, is cheaper than the microfilm system with two rolls of film, and the two systems have very nearly the same capacity. At about 200 fiche or about 10 rolls of microfilm, the two systems are cheaper than the letter-size filing cabinets.

The equipment-plus-media cost per megabyte of computer peripheral systems also drops rapidly as we add tapes to a single magnetic tape unit, or 3336 disc packs to an IBM 3330 disc file. A tape unit with about fifteen tapes is equivalent in cost and capacity to ten card file cabinets; with about 180 tapes, it is equivalent in cost and capacity to 100 four-drawer file cabinets stuffed with 8.5-inch by 11-inch typewritten sheets. An IBM Diskette reader (IBM 3540) is so costly that its price falls off the graph, though a 3540 with 100 diskettes would have roughly the capacity and cost of the magnetic tape unit with one tape. A moving-head file with about twenty disc packs is equivalent in cost and capacity to about sixty card file cabinets; but the high cost of the disc packs themselves ($10 per megabyte) prevents the disc from approaching the cost of the four-drawer cabinet at any capacity. We must, however, keep in mind the fact that operation of the various systems entails other costs besides those of media and storage equipment, and that those additional costs will be much greater for the computer peripheral systems than for the other systems.

**Access Times.** We have so far concentrated our attention only on capacity and price. Let us now look at access time—the time required to locate and read a *single* item chosen at random from the entire file. In Figure 3.22.4 we show the same systems that were plotted in Figure 3.22.2, with access time plotted against capacity. The microfiche user can select a randomly-chosen frame on a fiche substantially faster than the microfilm user, who must run sequentially through half the length of the film. The magnetic tape unit shows up very poorly, of course, for this random-access application, while the data cell and moving-head file show up well. Access time for the Kardveyer (TM) includes time for the operator to key in the drawer address, time for the drawer to reach the operator, and time for the operator to select the desired card. For the filing cabinets, I estimated five seconds for a clerk, standing in front of the cabinet, to select the proper drawer and then the desired document in the drawer. Obviously such a short access time is not feasible unless groups of documents within the drawer are separated by indexed dividers. For the bookcase section, I estimated fifteen seconds for the user, standing in front of the case, to find the desired book and then the proper page in that book. Note that, for the paper systems, the access time must include the time necessary to re-insert the selected media back in the file. For the other systems, the media remains in the equipment and there is no re-insertion time.

As soon as we expand the capacity of the systems, the access times change completely. Figure 3.22.5 shows access time changes for the same systems described in Figure 3.22.3. For the microfiche and microfilm systems, maximum capacity is limited to about four drawers of rolls or cards as shown. Larger capacities would require time for the operator to reach larger files. Note that, except for a one-roll system, the microfiche is both faster than and cheaper than the microfilm system for equivalent capacities—under the various assumptions I have made here. For the filing cabinet systems, access time rapidly comes to depend on the time reguired for the operator to *walk* to the desired cabinet, and is thus directly proportional to the number of cabinets and inversely proportional to his walking speed.

The provision of a library of tapes from which an operator must select the one desired adds, to access time, the time required to rewind the old tape, to remove it, and to load the new one. The time necessary to walk to the tape library, find the tape, and return is, I assume, overlapped with rewind time for moderate-sized tape libraries, and thus does not add to access time. The provision of a similar library of disc packs adds substantially to access time because of the time it takes for the old disc to stop rotating so that it can be removed, and for the new disc to get up to reading speed—times several orders of magnitude greater than the basic unit access time.

The use of these storage systems to access a single, random element of data is certainly possible and is useful in many circumstances. In many others, it is feasible to reduce average access time by collecting a batch of several random requests, sorting them so they appear in the same sequence they will occur in the master file, and then searching through the file once to find all entries in the batch. Figure 3.22.6 gives two estimates of the access time per card to file a batch of s cards in a file containing a total of f cards. The shaded band is from HayeR70, and no derivation or explanation is given for it. (Hayes' plot only extends to a f/s ratio of 10 million, so my extension beyond that range may be improper). The dashed line is based on the filing cabinet system described in connection with the previous figures. It assumes the *total* time to find all s items is five seconds times the number of items (assuming the clerk always takes five seconds to find a drawer and card once he is standing in front of the right cabinet), plus the time to walk from the cabinet containing the first card in the sorted batch to the cabinet containing the last card. The filing time *per item* is plotted, and is dominated by the five-second find times for small ratios. Probably the two estimates (shaded band and dotted line) can be rationalized by arguing that our assumption of a fixed time per card for small ratios is oversimplified, and that the time does increase as the ratio increases; and by further arguing that Hayes' curve was not intended to apply to situations where walking time is a factor, so that the dashed curve is applicable to larger ratios.

Obviously a similar set of arguments and analyses apply to the other filing systems described in previous figures. Generally speaking, all systems get more and more efficient as the batch size increases relative to file size (i.e., as f/s decreases) and the time-consuming operations (searching through a microfilm roll or magnetic tape reel, removing and replacing media) are amortized over a large number of accesses.

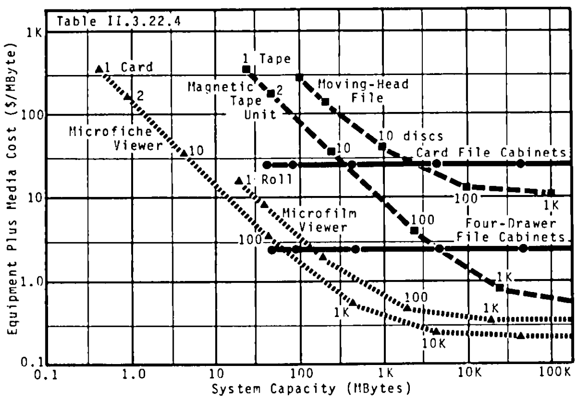



FIGURE 3.22.3 DATA STORAGE III
EQUIPMENT PLUS MEDIA COST & CAPACITY FOR EXPANDED SYSTEMS

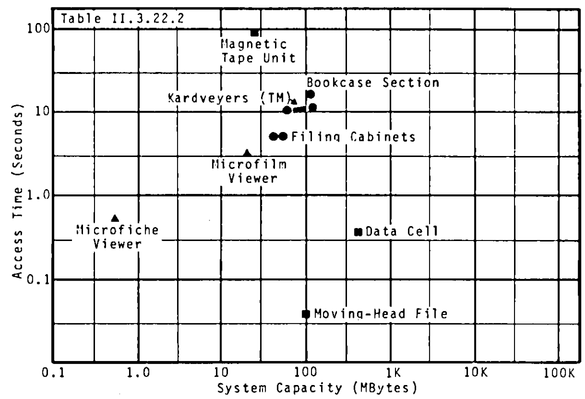



FIGURE 3.22.4 DATA STORAGE IV
ACCESS TIME AND CAPACITY FOR VARIOUS SYSTEMS

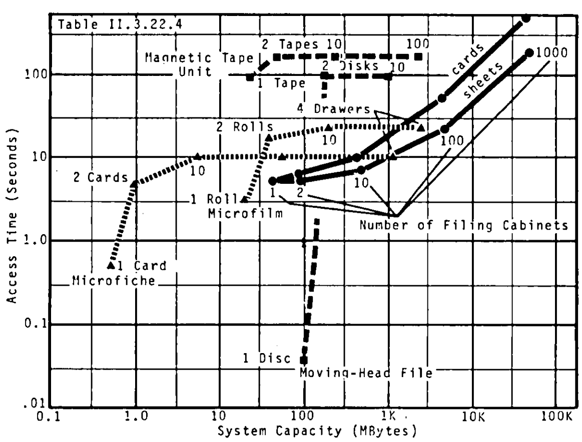



FIGURE 3.22.5 DATA STORAGE V
ACCESS TIME & CAPACITY FOR EXPANDED SYSTEMS

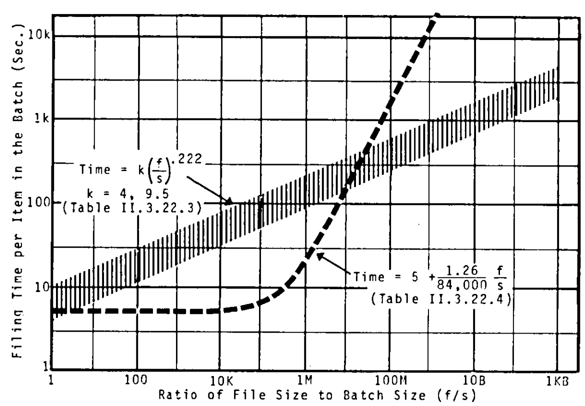



FIGURE 3.22.6 TWO ESTIMATES OF FILE ACCESS TIME
TIME PER CARD TO FILE s CARDS IN A FILE OF f CARDS

## 3.23 DATA DISTRIBUTION COSTS

Data distribution comprises the conversion of data from one form to another, and its transmission from one location to another. The principal distribution systems for computer data are sketched in Figure 3.23.1. Basically the data may be printed locally on a line printer or COM (Computer Output Microfilm) unit, or it may be transmitted by wire to one or more remote sites where it may be displayed or printed on a terminal. If it is printed locally, additional copies can be made and then mailed to users at remote sites. If microfilm is the distribution medium, there must be a viewer at each remote site.

We have compared transmission costs in Section 2.14, and have examined the cost of various conversion devices while reviewing Figure 2.120.3. In this section we will look briefly at the relative advantages of line printers and COM units.

From the computer system point of view, a line printer and COM unit may be considered to be interchangeable. It is possible to procure a COM unit which is plug-compatible with a line printer and which may be driven by the same program which operated the printer, with little or no change. The COM hardware is more expensive than a line printer, but microfilm costs are potentially much lower than continuous forms costs. Thus if printing volume is high enough, a savings in media costs can more than pay for the extra cost of the COM hardware. The relationship between printing volume and costs (excluding processor and personnel costs—including only printer/COM hardware plus supplies and media) is shown in Figure 3.23.2. The dotted lines show the costs of an IBM 1403 line printer, assuming 1972 costs of one-part and of two-part 11-inch by 14-inch continuous forms. Because line-printer capacity in a 360-hour month is 396,000 pages, there is a discontinuity in costs at that volume representing the addition of a second printer. The solid lines represent costs of a CalComp 2100 COM unit printing data in the same format on microfiche cards, 63 pages to the fiche. The solid dots represent the breakeven points—400,000 pages per month if only one copy of each page is required; 80,000 pages per month if each page must be duplicated. (The costs of a microfilm developer and duplicator are included in the COM hardware costs—see Table II.3.23.1.) Comments:

1. Much computer output *must* be printed by conventional means. Paychecks, for example, must be printed on special paper; and some bills are printed on forms which will later be fed into print- or card-readers. Therefore a COM system is usually considered only by system operators who have more than two line printers. For very large installations, one COM unit may replace two or more printers, since its potential capacity is ten times that of a printer (See Figure 2.120.3), and in such situations there can be a saving in hardware cost alone, not even considering media costs.

2. The cost of paper and film is a complex subject, and many factors not shown in the figure influence costs. We will find (Figure 3.25.17) that the average cost of forms for a line printer is around $1000 per month, and we can deduce from Figure 3.23.2 that a forms cost that low will not justify the extra cost of COM hardware. But for high-volume printers we have no statistics on the relative use of one-part and multiple-part forms. Furthermore, the forms cost shown is for standard, blank forms, though many forms in actual use are pre-printed and are much more expensive per page than the blank standard forms. Since most COM units have provision for creating the effect of pre-printed forms by optically projecting an image of the form on the film, the COM potentially has another cost advantage.

On the other hand, the fiche costs shown here assume that there are 63 pages on each fiche. If higher magnification ratios are used, more pages can be recorded and the fiche cost per page will come down. But if an application does not permit as many as 63 pages per fiche, per-page costs will rise.

3. The use of microfilm is not always feasible, for various reasons, even when the print volume potentially justifies it. If the distributed copies must be annotated, for example, microfilm is not practical. There are other problems. It is inconvenient to compare data on one microfilmed page with that on another. Users may find it tiring to look at projected images over long periods of time. Microfilm viewers (whose cost—typically $150 to $200—is not included in the figure) may not be usable in every environment. Single-page printed copies of microfilmed documents can be made, but they are costly (two to ten cents per page) and a printer may not always be available.

4. Conversion from line printer to COM has various hidden computer-center costs not indicated in Figure 3.23.2. Programs may have to be modified to drive the COM unit, and *will* have to be modified to make best use of it. (For example, microfiche is not readily usable unless it is indexed, and the creation and printing of appropriate indices is a programming problem). System changes may be necessary to drive a COM unit at its rated speed. Computer operators must learn how to operate the COM unit, film processor, and duplicator. Procedures must be designed to help the operator keep track of documents in various stages of the COM-developer-duplicator path. Offsetting some of these costs are some equally hidden and intangible benefits—for example, there can be savings in floor space, since bulky forms need not be stored, and in paper handling, since multi-part forms need not be "burst".

Finally, referring again back to Figure 3.23.1, we must remind ourselves that conversion is only one part of distribution costs, and that distribution is only one aspect of system design. We have available an impressive array of alternatives.

## 3.24 DATA MANIPULATION COSTS ●

**Arithmetic.** Finally, let us look at the bare-bones cost of doing the commonest of manipulations: arithmetic and sorting. The time required for a clerk to perform the primary arithmetic is estimated in Figures 3.24.1 and 3.24.2, as a function of the number of digits in the operands. Three modes of operation are included: unassisted "hand calculations" by the clerk, and calculations performed with the help of an electromechanical and an electronic calculator. For each calculation, the time plotted is for the functions of writing down or keying in two operands, performing the calculation, and writing down the results. Add-subtract times increase linearly with the number of digits required, for all methods of operation. Multiplication and division times are likewise proportional to the number of digits in the operands for calculator-assisted operations; but for hand calculations, the time required increases as the square of the number of digits (note log-log scale), with division being moderately slower than multiplication. Incidentally, operating times for the electronic calculator are dominated by the time required to write down a result, for keyboard entry is comparatively fast, and actual computing time is effectively zero. Therefore calculations designed to make it unnecessary to write down intermediate results go much faster than shown, and the calculator's ability to use a previous result as an operand in a subsequent calculation is extremely valuable.

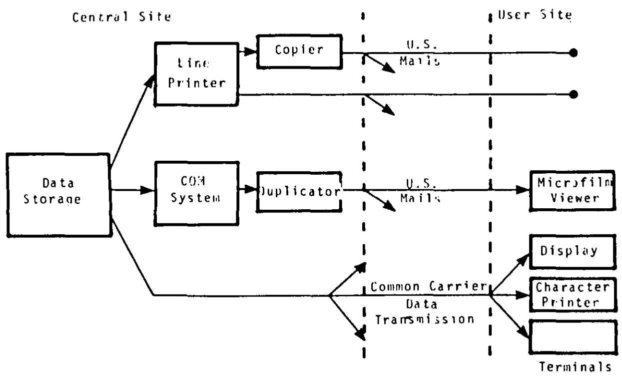



FIGURE 3.23.1 DATA DISTRIBUTION OPTIONS

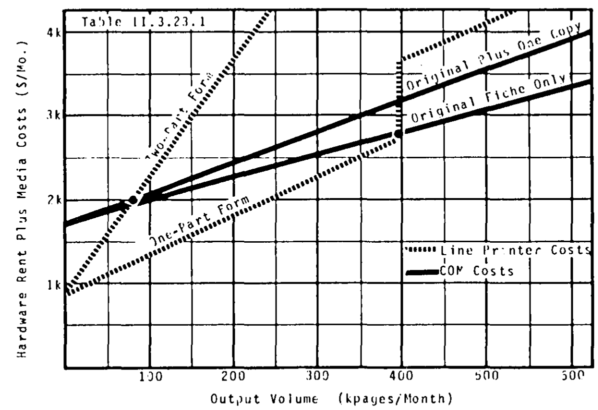



FIGURE 3.23.2 LINE PRINTER AND COM COSTS (1972) HARDWARE AND SUPPLIES COSTS VS. PRINT VOLUME

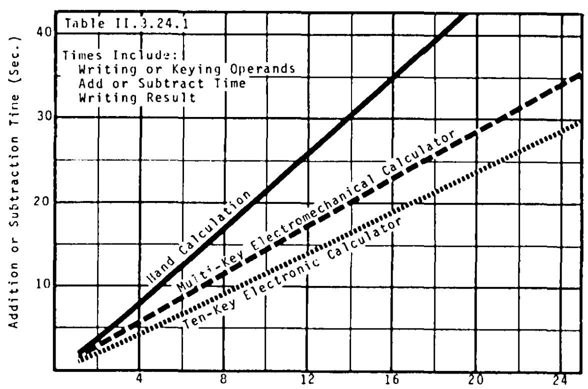



FIGURE 3.24.1 MANUAL ADD-SUBTRACT TIMES

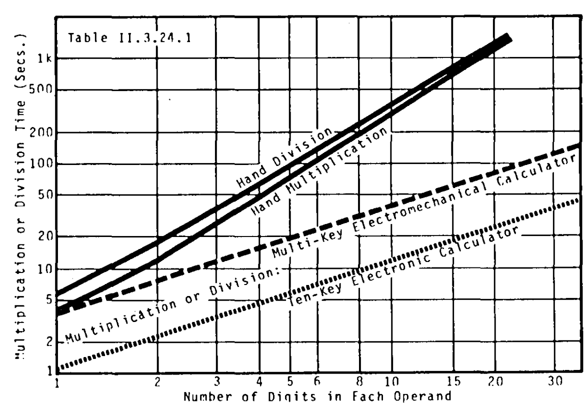



FIGURE 3.24.2 MANUAL MULTIPLY-DIVIDE TIMES

The electronic calculator, introduced in the mid-sixties, thus provided a substantial improvement in clerical productivity to help offset the continuing increases in clerical wages. The result is shown in Figure 3.24.3, where we plot number of eight-digit additions performed for a dollar at clerical wages (solid line). We also show the number of additions performed per dollar by the most popular computers. This data, from Table II.2.11.1, is based on the raw addition time of the machine, and on the rental of the bare CPU—without memory or peripherals. Since the clerical cost curve includes only the raw labor cost, without overhead, both curves shown in the figure understate costs and thus overestimate the number of additions per dollar. But the trends are clear. Clerical performance per unit cost has remained relatively constant over the past twenty years, while computer equipment performance has improved by a factor of 10,000—four orders of magnitude.

We don't buy efficiency, of course, we buy performance. If a forty-gallon water heater is big enough to supply hot water for the family, we buy it, and the fact that a 400-gallon heater costs 20% less to operate per gallon of hot water produced is immaterial. The small data processor, who can get his month's data processed by a few clerks, is not impressed by the fact that some enormous, million-dollar computer performs calculations thousands of times more efficiently than his clerical staff, for he can't afford the million dollars and doesn't need billions of operations per month. He is, however, interested in small systems which might outperform his clerks and whose absolute cost is comparable to that of his clerical staff. As shown in Figure 3.24.4, the bare-bones cost of computer capability has been dropping as clerical costs have risen, and an IBM System 3 processor rents for substantially less than a clerk's monthly salary.

The trends described by Figures 3.24.3 and 3.24.4 are thus critically important contributors to the growth of the computer industry: equipment performance per unit cost has improved by orders of magnitude, and equipment minimum costs have fallen substantially during a period when clerical productivity has remained constant and clerical minimum costs have risen. The result, not surprisingly, has been the increasing penetration of computers into smaller and smaller organizations that we saw in Figure 3.11.8.

Once again it is important to remember that these figures don't tell anything like the whole story about operating costs. The trends they show are without question real; but the complete picture of system operating costs will be the subject of Section 3.25.

**Sorting.** Manual sorting of files stored on separate pieces of paper is a time-consuming and therefore expensive process if the number of pieces to be sorted is at all large. Figure 3.24.5 records estimates of the time required and cost incurred in sorting 3-inch by 5-inch cards, as a function of the number of cards (s) in the batch to be sorted. The shaded area reproduces a curve provided by Hayes (HayeR70), who gives it without derivation or reference. The dashed line records the time required if sorting is done by sorting the original batch into groups of five cards, and then merging the groups five at a time, assuming that the clerk requires two seconds every time a card is handled. For large batches it is substantially more optimistic about sorting time than is Hayes' estimate.

Shaded area and dashed line show that the sorting time *per card* increases as the batch size increases. The total sorting time for a batch thus increases more than proportionally to batch size, as does clerical sorting cost. The dotted line in Figure 3.24.5 shows the clerical (salary) cost of sorting a batch of size s, using the less optimistic estimate of sorting time. Note that an increase in batch size by a factor of ten increases cost by a factor of more than seventeen: in going from a batch size of 10,000 to one of 100,000, we increase clerical cost from $95 to $1650.

## 3.25 SYSTEM OPERATING COSTS ●

In comparing alternatives and in planning systems or system extensions, it is essential that the user take into account *all* the costs he is likely to incur. It is also extremely important that the individuals in organizations which plan, design, and sell equipment, programs, and services understand the user's cost factors and the relationships between them. In this section we will estimate those costs, collecting them together from other parts of the book and adding costs not previously considered. When we reach the end of this section, we should be in a position to estimate complete costs of a data processing system or of an increment thereto, whether the system is entirely clerical or includes both people and data processing equipment.

The situation is as usual extremely complicated, with a horde of variables. And as usual we shall deal in averages, with all the attendent hazards which accrue when we average variables having large ranges and large standard deviations. The principal factors we will try to consider are the variations of operating cost as a function of time, and as a function of system size. First, however, we will take up two cost components which so far we have not adequately discussed: overhead and facilities.

**Overhead.** It is common and convenient to distinguish the direct cost of the individuals who actually produce a product or service from the costs necessary to support those individuals. The support costs, including such things as pension and health benefits, salaries of supervisors and secretaries, rental and maintenance of office space, depreciation of furniture and typewriters, the expense of telephones and office supplies, etc. are normally expressed as a percentage of the "direct labor"—i.e., of the salaries of individuals actually producing the product. One use of the overhead rate is to estimate the cost of some project. We estimate the direct labor cost by estimating the labor hours necessary for the project and then by multiplying by the average wage of those who would do it. The various indirect costs are then estimated by multiplying direct labor salaries by the overhead rate. The implicit assumption, of course, is that all the indirect costs are uniformly incurred by the people who actually work on the project. On the average, obviously, that assumption is justified.

Specific overhead rates vary from situation to situation, depending on what is included, which in turn depends on the purpose for which the rates were established. Figure 3.25.1 gives some idea of that variability by presenting some of the overhead factors which have been used in this book. The lowest rate, for office workers' indirect labor only, includes nothing but "fringe benefits" (pensions, insurance, etc.), supervisors' salaries, and secretarial salaries. The next curve, representing total office workers' overhead, is the sum of the indirect labor factor and other factors which apply to office workers: space, depreciation, telephone, etc. The much higher figures used for customer engineer and factory assembly labor (in the maintenance and manufacturing organizations) are necessary to cover the indirect costs which support those functions but have no counterpart for the office worker. These costs include the salaries of the quality control, purchasing, and manufacturing engineering people in manufacturing, and the training and technical support people in maintenance. They also include depreciation for tooling and test equipment in manufacturing, and travel costs plus depreciation of instruments, tools, and training aids for maintenance. The values and changes shown in the figure are somewhat arbitrary, based on my personal experience and judgement.

We will assume that the office worker overhead factor is applicable to data processing personnel—to file clerks, payroll clerks, system analysts, programmers, and to computer and keypunch operators.

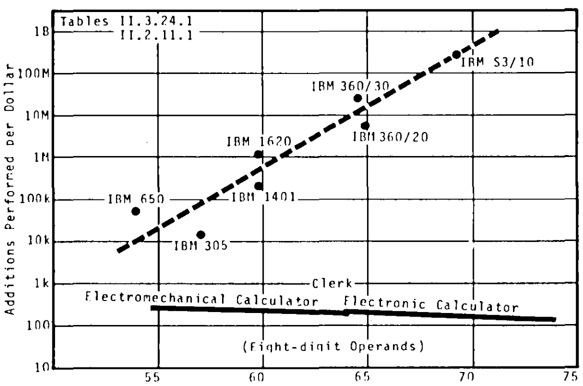



FIGURE 3.24.3 TRENDS IN ARITHMETIC PERFORMANCE/COST
ADDITIONS PER DOLLAR FOR COMPUTERS AND CLERKS

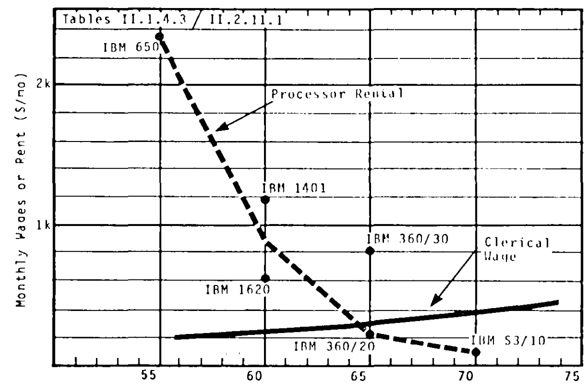



FIGURE 3.24.4 TRENDS IN BASIC MONTHLY COSTS
CLERICAL WAGES AND SMALL SYSTEM PROCESSOR-ALONE RENTAL

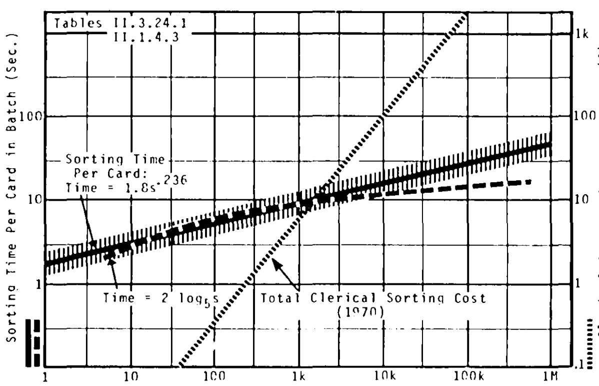



FIGURE 3.24.5 SORTING TIME AND COST FOR 3x5 INCH CARDS
SORTING TIME PER CARD, AND CLERICAL SORTING COSTS (1970)

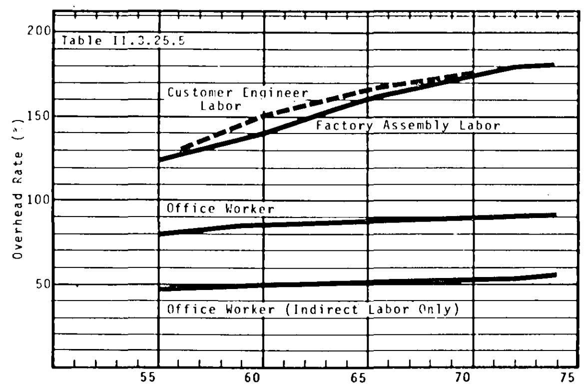



FIGURE 3.25.1 ASSUMED OVERHEAD RATES

**Facility Costs.** As stated above, the cost of space for personnel is included in overhead. The cost of office space for equipment is not, and will be discussed next. We will include, in the facilities costs, the cost of renting this space, the cost of power, and the depreciation of special equipment such as air conditioning systems, false flooring, and power generating or smoothing equipment.

We begin by considering the amount of floor area required to house a computer cabinet which itself occupies one square yard of floor space. Obviously we must provide more than a square yard of floor area, to permit access by operators and maintenance men and to permit air circulation for cooling. But how much more? In the left-hand side of Figure 3.25.2, we see two possible layouts for cabinets having square cross sections, and access doors as wide as a side. The arrangement shown at the top is very generous, permitting all doors of all cabinets to be open simultaneously without interfering with one another. It requires nine units of space (shaded area) for every unit of cabinet space (doubly shaded area). The layout at the bottom, on the other hand, permits all the doors of any *one* cabinet to be open, but would be awkward if two adjacent cabinets required maintenance access simultaneously. It only requires four units of floor space per unit of cabinet area. The layouts on the right side of the figure show similar arrangements for cabinets n times as long as they are wide. Such arrangements are common (magnetic tape files, head-per track files, and internal memory cabinets are usually designed so they can be bolted together, with maintenance only permitted from the front and back) and make efficient use of floor space—as n gets larger, the floor space required per cabinet drops to two to three times cabinet area.

To allow for access, and to provide some space for computer-related activity or equipment (for the air conditioning equipment, for magnetic tape or disc storage, for worktables and chairs, etc.) we will assume that an installation requires 7.5 square feet of space for every square foot occupied by equipment cabinets.

How many square feet do a million dollars worth of data processing equipment occupy? That would seem to depend on what equipment we are talking about. In Figures 3.25.3 and 3.25.4, the space requirements for eight different IBM models from four generations of equipment are plotted as a function of purchase price. In each figure, a system consists of a processor, internal memory, and a set of peripherals including card equipment, a line printer, magnetic tape units (for all but the smallest systems), and moving-head files (for some of the larger systems). A system is plotted as a series of two or three vectors, laid end to end, each representing a major component of the system. Generally speaking, CPU's and internal memory are described by vectors having small slopes, and peripherals by larger slopes. That is to say, processors and memory occupy relatively little space per purchase dollar, and peripherals occupy much space. Figure 3.25.3 illustrates the point very well. Looking at the curve for the IBM 360/65, for example, we see the processor costs about $760K and requires only about 170 square feet of floor space. The next line segment represents $400K of memory, requiring an additional 130 square feet of floor space. And the last and steepest vector describes $540K of peripherals, which occupy 660 square feet of space. Each system is thus described by a line which is concave upwards. Two of the smaller systems are shown in Figure 3.25.3, but they all appear in Figure 3.25.4. (Two system configurations are shown for the 360/30 and 1401. They differ by the peripheral complement included, so they have different "P" vectors.) The "concave up" effect is not as pronounced for the smaller systems and especially for the 650 and 360/30, but it is still there.

In general, the area occupied by a system is determined mostly by its peripheral complement. For small systems the peripherals predominate and system area tends to be directly proportional to system cost. For large systems, CPU and memory cost generate a long, low vector, to which is added a short steep one for the peripherals. In Figure 3.25.5 we plot the end-point for each system vector, along with two lines which will be used in estimating system area—one line for systems whose price is less than $250K, another for the bigger ones. The lines do not describe first-generation systems (650 and 704) very well, and we will make allowances for that fact. And of course the approximations are based on a very small sample of IBM systems only, and may not be at all representative of other systems.

In the next three figures system heat dissipation, measured in thousands of B.T.U.'s per hour, is treated in exactly the same way as we treated system area. In general heat dissipated and area occupied should be closely related (see Section 2.3): there is a limit to the rate at which heat can be removed from a volume, and therefore a limit to the heat dissipation the designers can permit per cubic foot of cabinet; and since cabinet height is generally limited (by the heights of doorways and elevators the cabinet must pass through during installation), heat dissipation is related to cross-sectional area. Except for the first generation vacuum tube 650 and 704 (at 11.4 and 14.1 KBTU/hr./100 square feet) and the liquid-cooled 370/165 (at 23.7 KBTU/hr./100 square feet), the ratio of heat dissipation to area for the systems shown lies between 5.4 and 9.7 KBTU/hr./100 square feet. Figure 3.25.8 summarizes the heat-price relationship for all the systems, along with proposed straight-line approximations. Note that for small systems ($250K and less) the dissipation/area ratio calculated from the approximations of this figure and Figure 3.25.5 is 6.7 KBTU/hr./100 square feet, and for large systems ($440K and bigger) the ratio is 10.0.

Once we know space and heat-dissipation factors, we can calculate all the major facility costs necessary to support an installation. There are three principal parts to these costs:

1. Space. The computer room represents office space which must be leased or else bought and depreciated.

2. Electric power. Since all the heat dissipated by the equipment comes from the consumption of electricity, the system requires 293 watts of electric power for every KBTU/hr. dissipated. In addition, we must supply power to remove this heat from the computer room.

3. Capital costs. The user must not only procure space, but must also improve it. He must provide a "false floor", six to twelve inches above the room floor, to protect inter-cabinet cabling and power wiring. He must of course install an air conditioning system to remove equipment heat. He often installs equipment to improve the quality of incoming electric power (e.g., in many large installations, users install a motor-generator set which isolates the system from fluctuations in incoming power, driving the motor from local utility power, and the computer system from the generator output), and he may install equipment to provide power even when the local supply fails (e.g., in many real-time service systems, users install battery- or engine-driven uninterrupted-power systems, which are switched on automatically when local power is interrupted). The original cost of these various

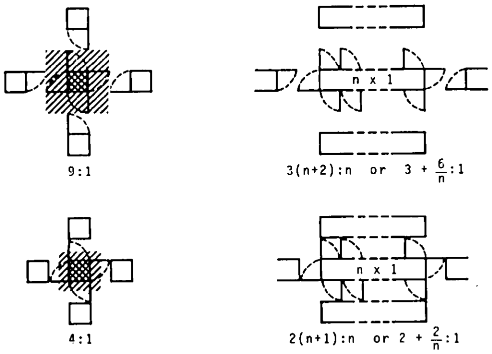



FIGURE 3.25.2 COMPUTER INSTALLATION FACTORS I
EQUIPMENT LAYOUT FOR MAINTENANCE ACCESS

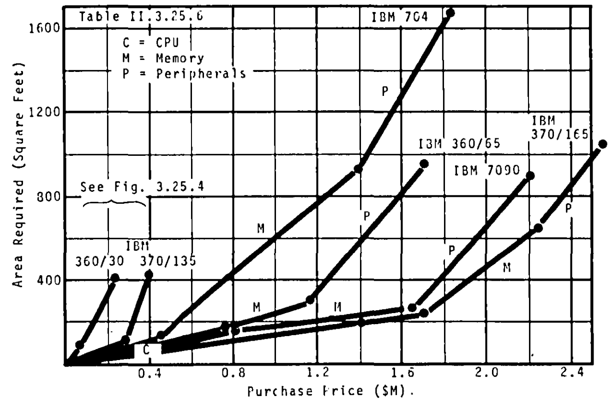



FIGURE 3.25.3 COMPUTER INSTALLATION FACTORS II
COMPUTER ROOM AREA VS. PURCHASE PRICE

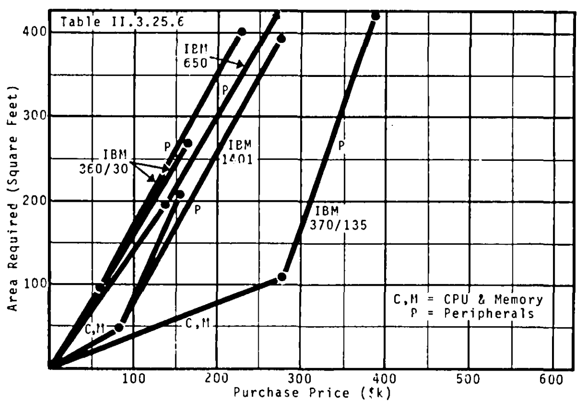



FIGURE 3.25.4 COMPUTER INSTALLATION FACTORS III
COMPUTER ROOM AREA VS. PURCHASE PRICE

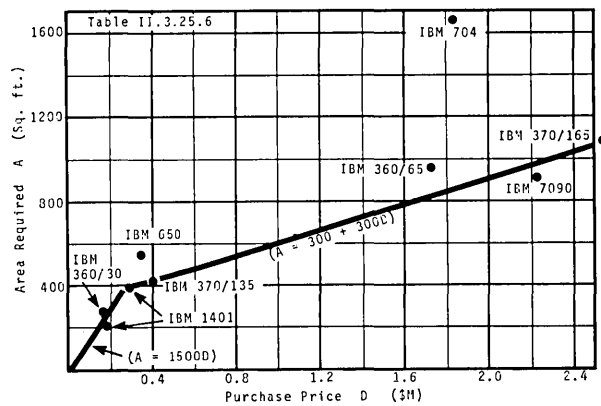



FIGURE 3.25.5 COMPUTER INSTALLATION FACTORS IV
COMPUTER ROOM AREA VS. SYSTEM PRICE

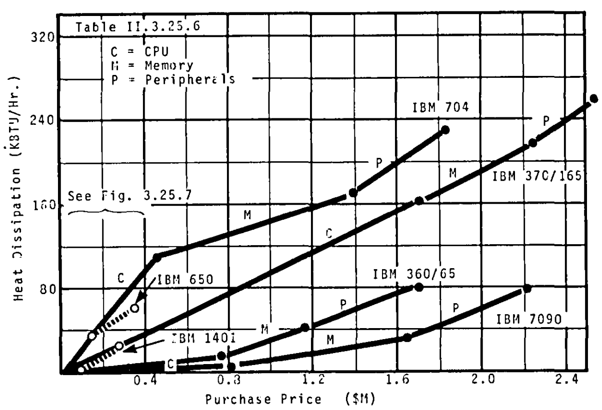



FIGURE 3.25.6 COMPUTER INSTALLATION FACTORS V
HEAT DISSIPATION VS. SYSTEM PRICE

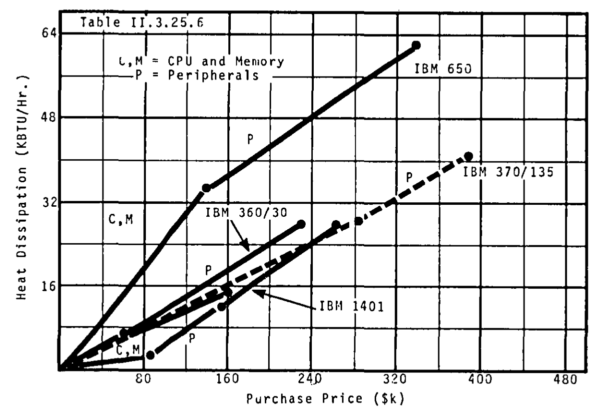



FIGURE 3.25.7 COMPUTER INSTALLATION FACTORS VI
HEAT DISSIPATION VS. SYSTEM PRICE

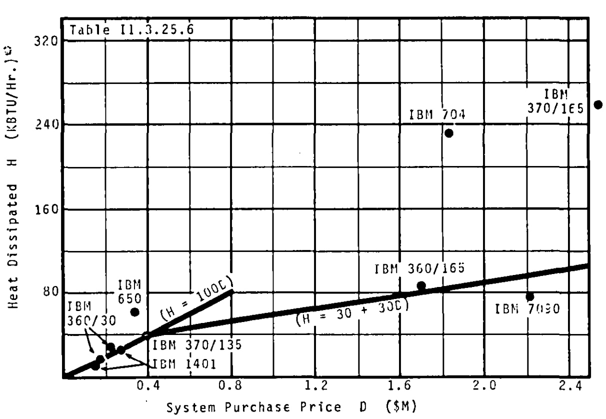



FIGURE 3.25.8 COMPUTER INSTALLATION FACTORS VII.
SYSTEM HEAT DISSIPATION VS. SYSTEM PRICE

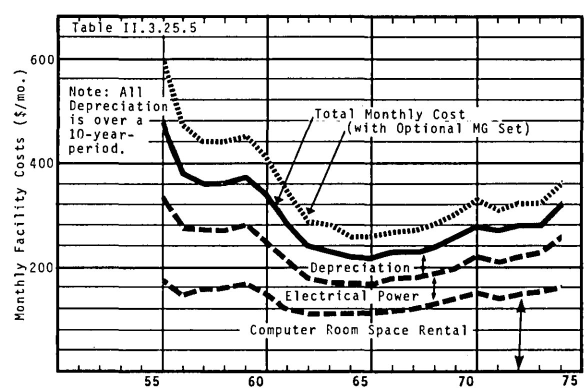



FIGURE 3.25.9 COMPUTER FACILITIES COSTS
FOR AN AVERAGE GP SYSTEM IN THE U.S.

facility improvements are written off over a number of years, and the resulting depreciation represents a third component of facility costs.

In Figure 3.25.9 the various facilities costs are shown, plotted as a function of time, for the average US GP system. Generally speaking, costs per system were high in the fifties because the average system size was large, and first-generation systems were big space and power users. Second-generation costs dropped markedly, both because average system size decreased and also because facility requirements per hardware dollar dropped. In the late sixties the average size increased and the (assumed) slightly higher cost of third-generation facilities added to total costs. Note that provision of a motor-generator set of suitable capacity adds a cost nearly the same as the cost of air conditioning equipment, and therefore nearly doubles depreciation costs.

Total facility costs for an average system are thus somewhere near $300 per month. Since the rental of the hardware for the average system is something like $10,000 per month, facility costs represent a small fraction of the total, and users having medium-sized and large installations are inclined to buy extra capacity (in space, air conditioning, and power generating equipment) because the cost is relatively small and later costs of expanding facilities can be high.

**User's Total Cost.** We now have enough data to construct a picture of the total cost of operating an average processor in the United States. Basically our procedure will be to collect together annual user expenditures on hardware, services, supplies, communications, personnel (including overhead), and facilities, and then to divide by the number of systems (i.e., CPU's) in use. Since, as has been stated before, most of the data presented has had to do with GP systems installed in the United States, it is to that subset of all users of all computers that our results will apply.

As usual, we make various assumptions which must lead to distortions of one kind or another, depending on ones point of view. The very act of averaging leads to one large distortion, for there is no "average" installation, and any given installation is likely to differ substantially, in proportions of various costs, from our average. The size of a system, measured (say) by the value of computer equipment installed, is likely to have a pronounced effect on proportions, and we will treat that subject at the end of this section. Another potential distortion comes about because of our inclusion of an overhead figure to account for labor-related costs. Not everyone has the same idea of what should be included in overhead, or what are reasonable numbers for various overhead costs. A final potentially distorting factor is our handling of the user's hardware costs. We will compute these costs as if all the equipment were leased from the manufacturer–we will figure monthly costs by dividing "value in use" by 44, an average ratio of system price to system monthly rent, including the cost of maintenance. One hazard in that procedure is our use of the number 44. The ratio is different for different manufacturers (see Table II.4.4.2) and of course differs from year to year for a given manufacturer (see Table II.2.11.3, for example). Another hazard is that a given user's hardware costs in a given year may be a simple short term lease, but alternatively may be a long-term lease from a leasing company, or depreciation of equipment bought in previous years, or some combination of all these costs.

Nevertheless and despite the qualifications, our analysis should be helpful in putting things in perspective–in indicating what is important and what is less important, and in suggesting where investigations into cost savings might be worthwhile. And since the rules and assumptions made here are clearly explained and documented, it is possible for an interested reader to re-compute cost distributions using different assumptions, if these do not seem appropriate.

If we consider only the major expense categories, the trends in user costs are as shown in Figures 3.25.10 and 3.25.11. The large Univac systems dominated the scene in the early fifties, and the large number of medium-scale IBM 650's shipped in 1956 accounts for the sudden drop in average costs. Since 1956, total user costs per installation have risen continuously and had doubled by 1973. For the entire period, hardware costs have remained fairly constant in the range $9K to $12K per month, and have fallen from 55% to 25% of total costs. Meanwhile personnel costs have more than tripled. The increase in labor costs is partly due to an increase in the number of people per system, partly due to increased salary rates, and partly due to increased overhead rates. "Other" costs in these two figures includes outside services, software, and facilities.

Another breakdown of the same costs is shown in Figures 3.25.12 and 3.25.13. Here we distinguish the costs more directly associated with running the computer from the costs of preparing and maintaining programs, the cost of data entry, and the cost of communications and terminals. (A more precise analysis might assign some operations and data entry costs to program preparation, which as shown includes only salary and overhead of System Analysts and Programmers.) Note that operations costs have remained fairly constant, and have continuously fallen as a percentage of total costs, while the other classes of costs have grown.

Because the central processor system hardware (processors, internal memory, and peripherals) has been and is the focal point of the user's data processing system, its cost is a key factor in any discussion, even though that cost is less and less important every year in relation to total costs. A useful way of emphasizing the relationships is to show costs as a percentage of the CPU system costs, and this we have done in Figures 3.25.14 to 3.25.16. Looked at in this way the changes are indeed startling: total costs increased from 180% to almost 500% of CPU system costs between 1955 and 1974; direct labor costs from 40% to 160%; computer operators' costs from 10% to 50%; and data entry costs from 25% to 120%.

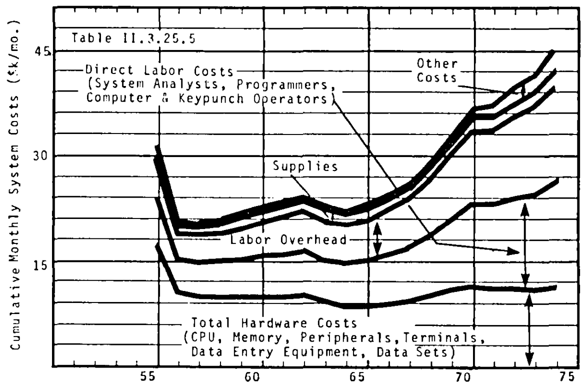



FIGURE 3.25.10 USER OPERATING COSTS I
TOTAL CUMULATIVE COSTS SHOWN BY EXPENSE CATEGORY

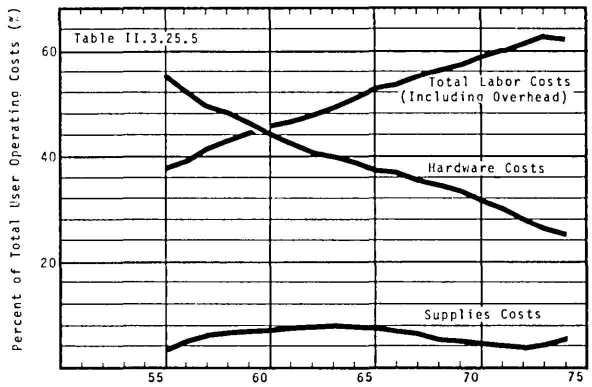



FIGURE 3.25.11 USER OPERATING COSTS II
PROPORTION OF TOTAL COSTS BY EXPENSE CATEGORY

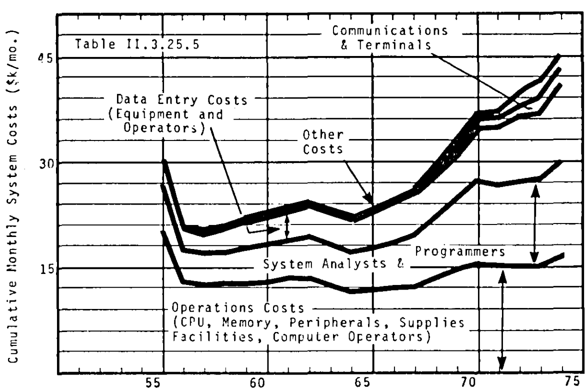



FIGURE 3.25.12 USER OPERATING COSTS III
TOTAL CUMULATIVE COSTS SHOWN BY FUNCTIONAL CATEGORY

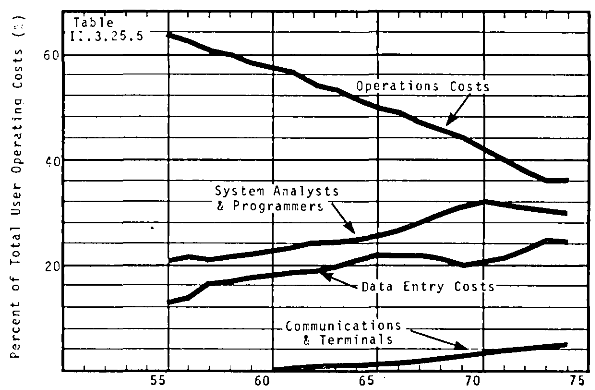



FIGURE 3.25.13 USER OPERATING COSTS IV
PROPORTION OF TOTAL COSTS BY FUNCTIONAL CATEGORY

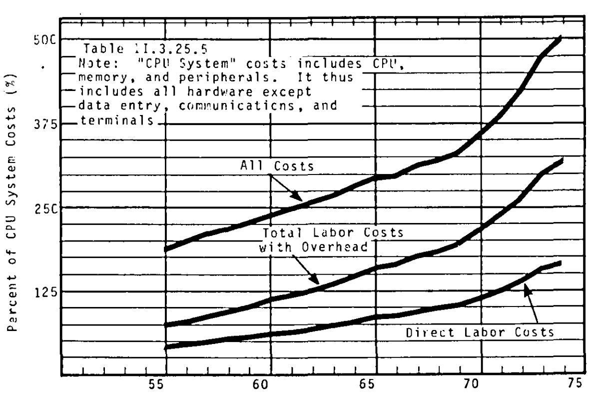



FIGURE 3.25.14 USER OPERATING COSTS V
COSTS AS PERCENTAGES OF CPU SYSTEM COSTS

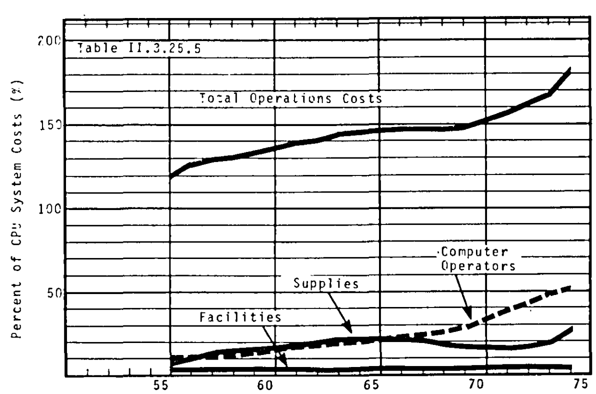



FIGURE 3.25.15 USER OPERATING COSTS VI
COSTS AS PERCENTAGES OF CPU SYSTEM COSTS

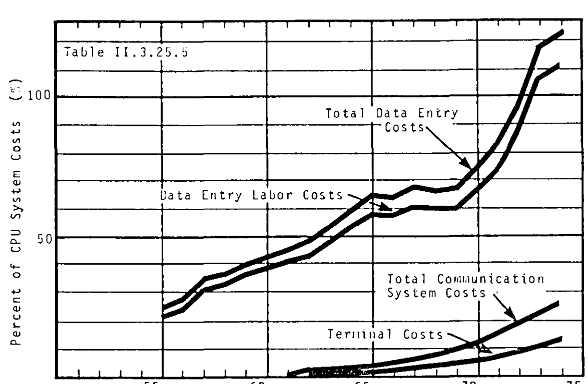



FIGURE 3.25.16 USER OPERATING COSTS VII
COSTS AS PERCENTAGES OF CPU SYSTEM COSTS

This viewpoint of costs has the advantage that it permits us to compare our cost estimates with those published by others. Since other estimates may include fewer or more factors than we include, a comparison of total costs or of a percentage distribution of costs is impossible. But all other estimates include the cost of the CPU system, so components of other estimates may be compared with ours. One such comparison is shown in Table 3.25.1. It covers four different years, three countries, and four independent studies. All columns except the last refer to averages for all US, Japanese, or British (ICL) systems in use—no general average was given in the *Datamation* study, and so I used the cost distribution for a system of average size, which is not strictly comparable. Notable are the very low Japanese salary costs, the consistency of various sources and countries as to supplies and data entry equipment costs, and the evident change of basis in the IDC data between 1969 and 1972. Also notable are the other inconsistencies, which remind us of the large, unstated uncertainty in all data about this industry. The columns labeled "estimated" are the ones plotted in Figures 3.25.14 to 3.25.16.

The cost of data processing supplies is a surprisingly large fraction of total costs (see Figures 3.25.10 and 3.25.15), and those costs are detailed in Figure 3.25.17. The cost of forms for line printers is striking, for we may tend to think of paper as being free. Note the annual cost of paper and cards for printers and punches is comparable to the annual lease prices for those peripherals. And of course the disk pack and magnetic type costs *per unit* are relatively low, but the annual cost per installation is much higher because multiple units are the rule rather than the exception.

**Costs and system size.** We have so far looked at expenses and expense ratios only for the "average" system. Will those ratios (which as we have seen change year by year for various reasons) be the same for a typical large system as they are for a typical small one? The next five figures present data which suggests the answer is a decided "no". For each study, various cost parameters of systems over a range of hardware rental prices are shown.

Two studies, conducted in 1966 and 1968, concentrated on labor costs which are, as we have seen, the major factor in total system costs. The solid lines in Figure 3.25.18 show the ratio of labor costs to hardware rental from those studies. The earlier one, which covered over 2200 sites, shows a very decided reduction in labor costs per dollar of equipment rental as systems grow in size—for very large systems, apparently labor costs were less than equipment costs. The other study, covering a much smaller number of sites, showed no obvious trend and a much lower ratio of labor to hardware costs as a result both of fewer employees per computer and lower wages per employee than was shown in the earlier study. The dashed curve shows the variation in the number of employees per site, for the 1966 study.

Over 1000 US government installations were anlayzed in the data plotted in the next figure, and Selwyn concluded that total costs do indeed fall with hardware size. The top, solid curve shows total expenses—hardware, labor, supplies, etc.—as a percent of hardware rental for all the installations; the bottom solid curve looks only at those installations having one or two computers. The dotted line, whose equation is shown, represents Selwyn's attempt to fit a curve to the data.

The cost trends for Japanese installations are shown in Figure 3.25.20 for two different years. The falling off of total costs with hardware costs was less pronounced in Japan, and there even seemed to be a slight increase in total costs and labor costs per dollar of equipment costs in the middle range of system sizes. We tend to see some indications of that same effect is the 1974 US computer users' budgeted expenditures shown in Figures 3.25.21 and 3.25.22—supplies, data entry equipment, and terminal/communications costs all tend to increase in the middle ranges of system rental as system size increases. Since terminals generally are used mostly on big systems, the terminal cost trend is understandable. But there seems to be no obvious explanation for the increasing proportion of data entry and supplies costs.

## TABLE 3.25.1 USER COSTS AS PERCENTAGE OF CENTRAL PROCESSOR SYSTEM HARDWARE COSTS

| | 1968 | | | 1969 | | | 1972 | | 1974 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated | ICL | Japan | Estimated | IDC | Japan | Estimated | IDC | Estimated | D'mation $8k-$20k |
| Personnel Salaries | 95.7 | 100 | 42.7 | 101.6 | 136.2 | 52.2 | 137.8 | 93.1 | 163.7 | 168.4 |
| Data Entry Hardware | 6.5 | - | 4.5 | 6.7 | 6.7 | 7.6 | 9.8 | 5.6 | 11.6 | 10.8 |
| Supplies | 17.3 | 21 | 19.9 | 16.4 | 19.1 | 19.3 | 16.6 | 10.3 | 26.5 | 19.2 |
| Data Comm. Lines | 3.0 | 6 | 4.4 | 3.7 | 1.6 | 13.3 | 7.7 | 10.8 | 9.6 | 1.6 |
| Terminals | 3.8 | 4 | - | 4.5 | - | - | 8.2 | - | 13.4 | 3.4 |
| Services | 2.4 | 14 | 3.3 | 4.1 | 7.9 | 8.2 | 9.5 | 8.6 | 12.1 | 2.8 |
| Software | 0.6 | - | - | 0.8 | 7.0 | - | 4.3 | 2.7 | 7.1 | 2.8 |
| Total | 129.3 | 145 | 74.8 | 137.8 | 178.5 | 100.6 | 193.9 | 121.1 | 244.0 | 209.0 |

Sources: See Notes in Part II

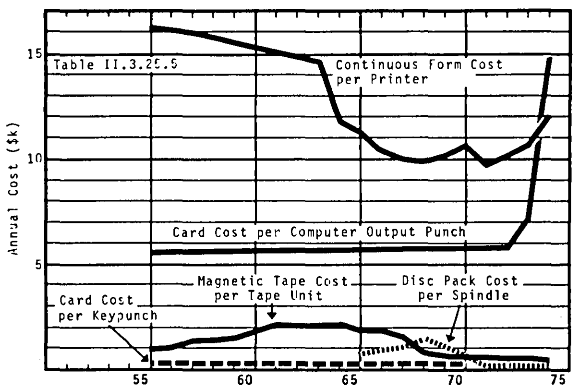



FIGURE 3.25.17 USER SUPPLIES COST
ANNUAL SUPPLIES COST PER UNIT INSTALLED

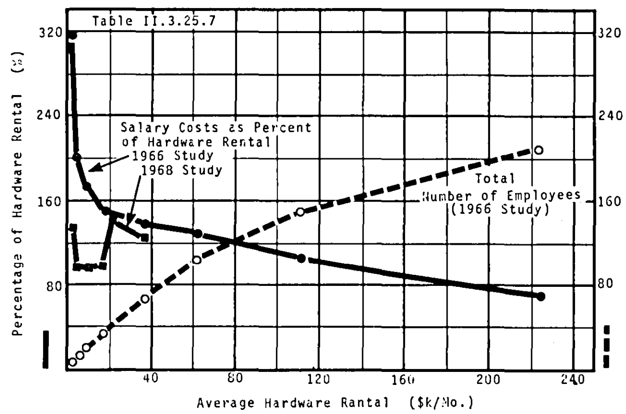



FIGURE 3.25.18 USERS' COSTS AND SYSTEM SIZE I.
SALARY COSTS FROM TWO STUDIES

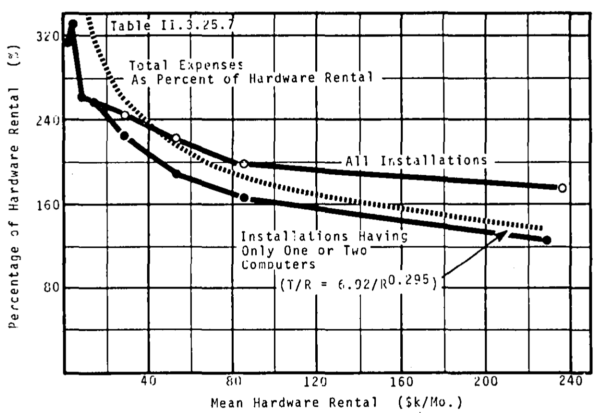



FIGURE 3.25.19 USERS' COSTS AND SYSTEM SIZE II.
TOTAL EXPENSES OF U.S. GOVERNMENT INSTALLATIONS,

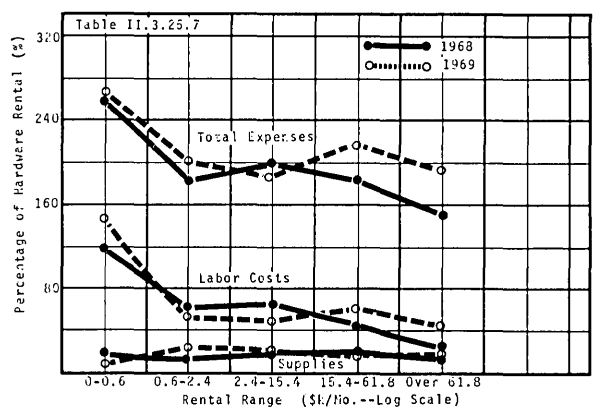



FIGURE 3.25.20 USERS' COSTS AND SYSTEM SIZE III.
EXPENSES FOR JAPANESE USERS IN 1968 AND 1969

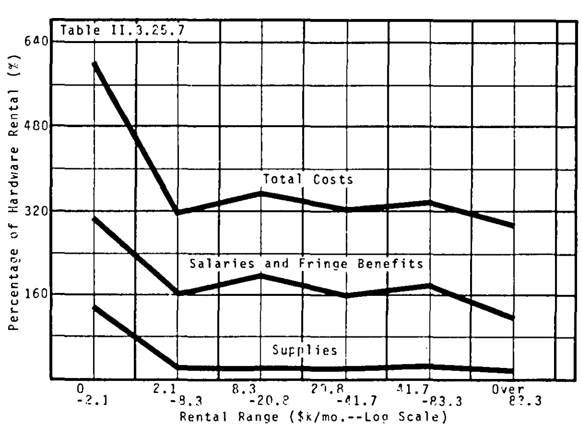



FIGURE 3.25.21. USERS' COSTS AND SYSTEM SIZE IV
EXPENSES PLANNED IN 1974 BUDGETS

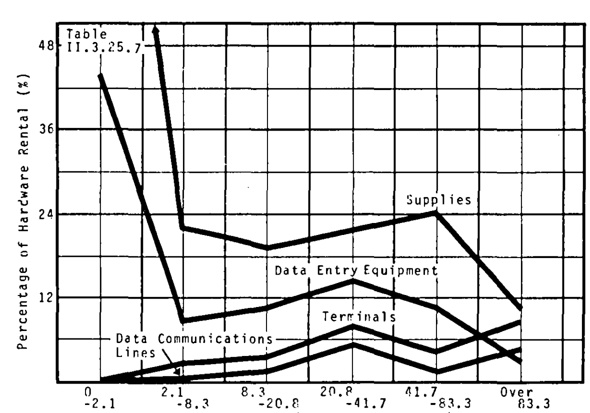



FIGURE 3.25.22 USERS' COSTS AND SYSTEM SIZE V
EXPENSES PLANNED IN 1974 BUDGETS

In the absence of better data on the relationships between cost and size, or of a conceptual model which might help us quantify the relationship, I will ignore the anomolies in the latter three figures, and will assume that Selwyn's relationship holds—that total costs increase exponentially with rental, the exponent being less than one. Figure 3.25.23 shows two curves, either of which might serve to describe the relationship. Each curve has the property that, when applied to the actual 1974 distribution of system size given in Table II.1.31.2, it predicts a total annual operating cost, for all U.S. GP systems, equal to that given in Table II.3.25.5. The dotted curve employs Selwyn's exponent of 0.7. However, it leads to a 7:1 ratio of costs to rent for a $1k/month system, which seems high. I have therefore (arbitrarily) selected the solid curve as representative, and will use it whenever we need to compute total cost from monthly hardware rental. (Note that both curves seem low compared to the "1974 Budget" figures shown in Table II.3.25.4, where for systems with rental greater than $8k per month total costs are about three times rental. However, the cost distribution of Table II.3.25.4, when applied to the known distribution of system size, predicts a total expense level which seems too high.)

It might be argued that $5000 per month is an unrealistically high estimate of the total expenses for a $1000 per month system. To check the reasonableness of the ratio, let us look at Table 3.25.2, where we itemize possible costs for a $1250/month system. We assume it operates only one shift per day, and that total employment consists of one manager (who doubles in system analysis and programming), a programmer, a computer operator, and two keypunch operators. Their 1974 salaries are shown, with the 1974 overhead rate, and the total comes to almost $6600/month. I assume a small organization would pay less than the average wages, and discount the labor costs to $5400, or 432% of system hardware rent, assumed at $1250.

The average 1974 costs for printer paper and cards for a card punch were $1008 and $1216/month. I assume the small installation requires about a third of the average, and so adjust to $750, or 60% of hardware costs. A keypunch at $80/month and facilities costs of $60/month complete the list, and the total has reached 603% of hardware costs. The formula of Figure 3.25.23 predicts a ratio of 598%.

The coefficient 5 in the formula of Figure 3.25.23 was derived for the year 1974. If we assume the exponent 0.8 has not changed with time, we would expect the coefficient 5 would have been lower in previous years, for the average ratio of total to CPU costs has surely been lower (see Figure 3.25.14). However, there is enough uncertainty regarding the relationship between costs and system size that it seems unreasonable to guess how the coefficient (or exponent) has changed, especially over the near term. In the discussions in the next section, we will therefore use the formula of Figure 3.25.23 for the years 1970-1974.

**Summary.** The costs of hardware are but the tip of the iceberg of data processing costs, representing in the early seventies only 20% to 50% of the total, depending on system size. Labor costs represent the largest single component of cost, and they continue to grow while hardware costs shrink. And—most interestingly—total operating costs seem *not* to be proportional to hardware costs, for the operators of smaller systems pay more non-hardware costs per dollar of equipment rent than do the operators of large systems. As we shall see in Section 3.27, this economic factor combined with Grosch's Law has made the big system particularly attractive.

## 3.26 COMPARISONS

We now have in hand enough data to make comparisons of and to draw conclusions about alternative data processing systems. Any such comparisons and conclusions must of course be tentative and conditional, inasmuch as they are based on a great variety of questionable assumptions and conflicting statistics. Nevertheless the general trend and structure of our analyses and theses should be reasonable, and our conclusions can suitably be discounted in proportion to the suspicion with which we regard the data.

**Benchmark Problems.** In Section 2.23 we examined a series of benchmark problems devised and published by the Auerbach Corporation and used by them for many years to compare the performance of different computer systems. Since these problems are typical of many performed by organizations of all sizes, it will be instructive to estimate the cost of doing each in the simplest fashion, using clerical labor only, and to look for the workload which would justify the installation of a computer—the number of benchmark jobs which can be done per month with clerical labor at the same total cost as that of the least expensive computer system. The results of this analysis, for four of the Auerbach benchmarks, are shown in Figures 3.26.1 to 3.26.7. The first of these, for example, shows the monthly cost of processing a file as a function of the number of file transactions handled per month. The sloping lines at the left describe the cost of updating a file written on 3x5 inch cards or their equivalent, stored in a large filing cabinet or in several such cabinets. Two curves are shown, representing operations which differ in the complexity of the work the clerk does in updating the card, and the equipment he has to do it with. A 40-second transaction would involve no computation, and the output data (a change in the master card and the preparation of a 120-byte report on the transaction) would be typed by the clerk. A 10-minute transaction would include 7.5 minutes of calculations and the time necessary to hand-print the output data. The curves show that a single clerk, whose monthly burdened cost was $762 in 1971, could process from about 1000 to 16,000 transactions per month, depending on transaction complexity and assuming he did nothing else during his 40-hour weeks.

The horizontal lines at the top and right side of the figure represent the cost of minumum computer configurations for the file processing job, including all monthly expenses calculated using the relationship of Figure 3.25.23. The Univac 9200 is the least costly machine for which the Auerbach report (AuerCTR71) gave file processing performance figures, and that (card-oriented) system cost about $5300 per month to operate, and could handle up to a million transactions in a 355-hour month. The 9200 thus cost about the same per month as 10 clerks and would presumably therefore be considered by a user whose file processing workload was in the range of 7000 to 110,000 transactions per month. For transaction volumes higher than the million per month the 9200 could handle, more expensive systems can be used, and three are shown, including both a tape and card version of the IBM 360/20. Incidentally, the maximum transaction volumes for the tape systems are very dependent on the ratio of records changed to total records on the tape. The best situation, where every record is changed, is the one shown. If in the IBM 360/20 tape system, for example, only one percent of the records were processed, the monthly transaction volume would drop to about 300,000.

A payroll calculation is a typical file processing application. Every week a set of employee time cards are collected and sorted (costs of which are not included in the figure), and then each is processed against a master employee record containing pay rate, income tax deductions, and other essential data. The output is a paycheck along with certain other reports of the "transaction". If the average transaction took ten minutes, the curves show a single clerk could handle about 1000 per month (six an hour, 48 per day, 240 per week) or a weekly payroll for a 240-employee company.

The cost per 10,000 transactions is shown in Figure 3.26.2, again plotted against the number of transactions handled per month. This graph helps emphasize the enormous range in performance which is possible because of the power of the computer: clerical costs in 1971 were in the range $0.05 to $1 per transaction; given enough work to do, computer costs were in the range of 0.1 cents to one cent per transaction even for small systems, and become smaller still as systems grow bigger.

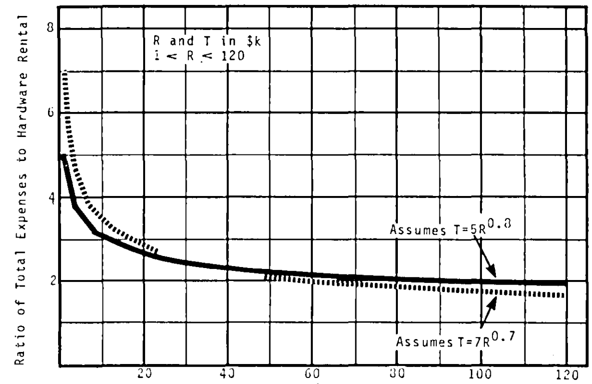



FIGURE 3.25.23 USER' COST AND SYSTEM SIZE VI ASSUMED RATES OF TOTAL COSTS TO RENT FOR 1974

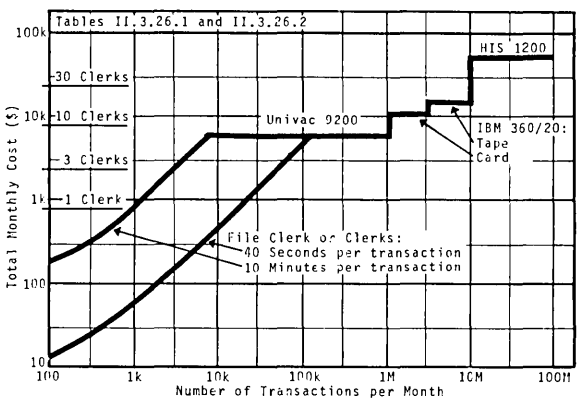



FIGURE 3.26.1 FILE PROCESSING SYSTEM COSTS (1971) I CLERICAL AND COMPUTER COSTS FOR SMALL SYSTEMS

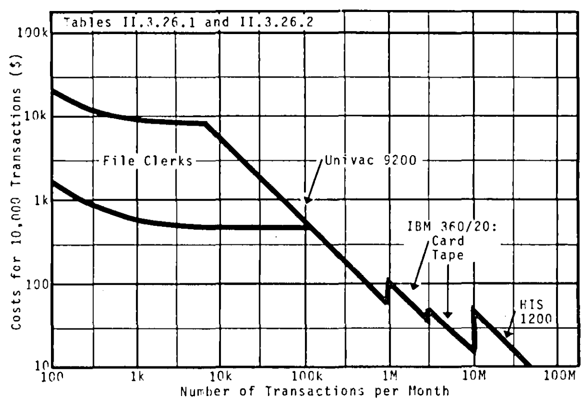



FIGURE 3.26.2 FILE PROCESSING SYSTEM COSTS (1971) II COSTS PER 10,000 TRANSACTIONS FOR SMALL SYSTEMS

**TABLE 3.25.2 OPERATING COSTS OF A SMALL SYSTEM (1974)**

| Item | Unit Cost $/mo | Total Cost $/mo | Adjusted $/mo | Percent of Hardware |
|---|---|---|---|---|
| Personnel | | | | |
| Manager | | | | |
| 1 Programmer | 1213 | 1213 | | |
| 1 Operator | 932 | 932 | | |
| 2 Keypunch Op. | 650 | 1300 | | |
| Direct Labor | | 3445 | 3100 | |
| Overhead at 91% | | 3135 | 2300 | |
| Total Labor | | 6580 | 5400 | 432 |
| Hardware (assumed) | | 1250 | 1250 | 100 |
| Supplies | | | | |
| Av. Printer Paper | | 1008 | | |
| Av. Punch Cards | | 1216 | | |
| Total Supplies | | 2224 | 750 | 60 |
| Keypunch | 80 | 80 | 80 | 6 |
| Facilities | | | | |
| 78 sq. ft. of space | | 35 | | |
| 661 kwh at 2.30 cents | | 15 | | |
| Depreciation | | 10 | | |
| Total Facilities | | 60 | 60 | 5 |
| Total Operating Costs | | 10194 | 7540 | 603 |

For some applications, it is not possible to collect transactions in batches and process them all together. These more interesting applications (real-time inventory control, credit checking, airline reservations, and on-line savings sytems are mentioned in AuerCTR) require that each transaction be processed as it is received, and therefore require a fast-access, high capacity file of some kind. Figures 3.26.3 and 3.26.4 compare the very slow clerical operation of finding and handling a 3x5 inch card with the use of a computer system having a random-access file. Once again two possible clerical systems are examined. In the more expensive one, the file capacity is 100 Mbytes, contained in eleven cabinets of cards, and ten minutes of calculation is required per transaction. In the faster and cheaper one, only 5 Mbytes are stored, in one cabinet, and no computation is required. Four cost-effective computer configurations are also shown, two having 5 Mbyte files and two 100 Mbyte. Breakeven points are in the range of 300 to 1300 peak transactions per hour, with a single clerk able to handle 5 to 100 peak transactions per hour, as shown in Figure 3.26.3. (Actually, a clerk can handle 5 complex transactions per hour *on the average*; but if peak rates exceed five, he will not be able to handle them in real time, which is the presumed requiremnt. In practice, with randomly-generated requests, the peak is two to five times the average.)

Transaction volume is only one measure of system performance for real-time file processing, and Figure 3.26.4 shows a second measure—response time. Clerical systems cannot have response times better than tens of seconds, and so we see a range of 40 to 630 seconds for the clerical systems. (Actual access time to the data, access sufficient to answer a request based on data on a card, would be somewhat less, but still in the range of 10 to 30 seconds.) Computer systems, of course, have much faster response times, as shown. Nevertheless, for many applications a card system can be quite adequate. Many telephone companies, for example, use clerks and card files (generally mechanized card files, like the Kardveyer-TM) to handle business office inquiries and requests.

In the next two figures we look at clerical and computer systems for complex mathematical calculations. Figure 3.26.5 describes the economics when a standard computation (evaluating five fifth-order polynomials, performing five divisions, and extracting one square root) is done once for each input record of ten 8-digit numbers. Figure 3.26.6 shows the situation when the calculation is repeated 100 times per input record. In each example we assume the clerical arithmetic operations are carried out twice, as a check on the results, and that 5% of the calculations are repeated a third time to correct a detected error. Note that the complexity of the "repeat-100-times" calculation is such that a processing rate of a few tens or hundreds of input records per month is enough to justify use of a computer.

Clerical and computer performance on one final task—sorting—is shown in Figure 3.26.7. Using the formulae of Figure 3.24.5, we estimate that it takes a clerk from 32 to 44 hours to sort 10,000 3x5 inch cards. He can thus only carry out 4 or 5 such sorts per month and it doesn't take much of a sorting load (measured in 10,000-item batches) to make a computer more economical than a group of clerks.

Let us complete this exercise in comparisons by first attempting a generalization or two, and then by criticizing the comparisons.

Studying Figures 3.26.1-7 we might conclude the following: that in 1971 the least expensive computer system large enough to do useful work will cost the user $5000 to $10,000 per month, once he has it in operation and properly staffed; that such an installation costs as much as ten to twenty clerks, complete with supervisors, fringe benefits, etc. (all included in their overhead); that the minumum computer system has the capacity to do from ten to 500 times as much processing as a group of clerks of equivalent cost; and that therefore any organization employing ten or more clerks in file processing, computing, and sorting functions should investigate the possible installation of a computer system to reduce his data processing costs.

Having attempted the generalizations, we now proceed to invalidate them with a list of criticisms.

1. As they stand, the comparisons are limited to only two alternatives—the use of clerks, having no tools except file cabinets and calculators, and the use of what we have called the GP class of computers. A rich variety of other alternatives lie between these possibilities. Some of them, like microfilm files or the Kardveyer (TM) we have mentioned. Many others, from the punched-card oriented sorters, collators, and tabulators which first were applied to reduce sorting costs for the US Census Bureau in the 1890's, to the accounting machines which are today used without glamour or fanfare much more widely than GP computers, we have not mentioned. They cost from a few hundreds to a few thousand dollars per month, greatly increase the capacity of an operator to process data, and thus tend to move the sloping clerical-performance lines to the right, making it more difficult to justify the installation of the smaller computers.

2. The computer costs shown include, as we have seen, an allowance for one or more system analysts, whose job it is to analyze the job to be done, and to prepare general procedures—which the programmers then follow in writing instructions for the computer. A file clerk also must be supplied with a set of written procedures, though there are things which can be left to his judgement or initiative. However, the data on which the file-clerk curves are based includes no allowance for systems analysis, unless it can be done by the clerk's supervisor, whose salary is included in the overhead figure. If we included an extra allowance for clerical system analysis, the sloping clerical cost lines would shift upward, and the breakeven point for computer use would occur earler, at a lower transaction rate.

3. The Auerbach data does not cover all GP computer systems, and there are undoubtedly smaller ones whose costs would intercept clerical costs at a lower breakeven point.

4. A determined and disciplined small-computer user, operating his system for only one shift instead of two, and taking the risk associated with dependence on non-duplicated employees (e.g., hiring only one computer programmer/operator, and thus having no ready back-up available if that individual is ill or leaves), may reduce his operating costs below those shown, and thus, once again, reduce the breakeven point.

5. IBM's mid-seventies marketing of small systems has emphasized ease of use. Thus the RPG programming system is widely employed by System/3 users, and the System/32 is sold with applications programs. The programming and operating costs of such systems are undoubtedly much lower than those of the user of the more "conventional" GP computer system, and the breakeven point at which the System/32 is comparable in cost and capacity to a clerical system is correspondingly lower than the breakeven point for the older systems shown here.

## 3.27 SOME CONCLUSIONS

**User Justification.** Now that we have compared the costs of alternative methods of performing some very basic data processing functions, let us consider the way organizations justify the money they spend on data processing. We will begin by describing a completely quantitative procedure and then will comment on differences between that procedure and the one which is generally carried out in practice.

To start with, let us list the arguments which may be advanced to justify the addition of some new specific data processing function or application within an organization. They may include one or more of the following:

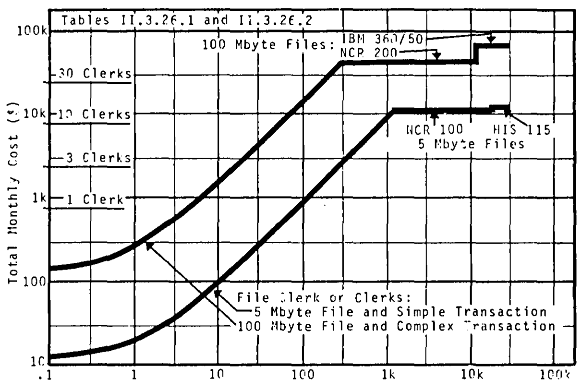



FIGURE 3.26.3 ON-LINE FILE PROCESSING COSTS I CLERICAL AND COMPUTER COSTS FOR SMALL SYSTEMS

1. The function is essential–the organization cannot exist unless this function is performed. Essential functions generally are those prescribed by law (e.g., recording income and expenditures for reports to the Securities and Exchange Commission) or those involving payments for goods or services (e.g., writing paychecks to employees, checks against vendor invoices).

2. The function will give rise to an increase in revenue. For example, an inventory control system may increase revenue by reducing the frequency with which a supplier misses a sale because he is out of stock; a sales analysis function may increase revenue by helping the sales organization anticipate changes in the marketplace.

3. The function will permit a reduction in costs. For example, an improved inventory control system may reduce the size of the total inventory while reducing stock-outs; a labor-distribution analysis may help reduce wasted time by assigning employees to jobs more efficiently; the carrying out of certain design iterations may reduce development costs, or the cost of the resulting product, or both.

The identified benefits must be compared with the cost of processing the data. For essential functions the organization has no choice–the applications must be implemented. For other functions, the lowest-cost method of implementation should be chosen, and its cost compared with the benefits. If the combination of increased revenue and reduced operating cost is greater than the implementation cost, the function should be added; if not, it should not.

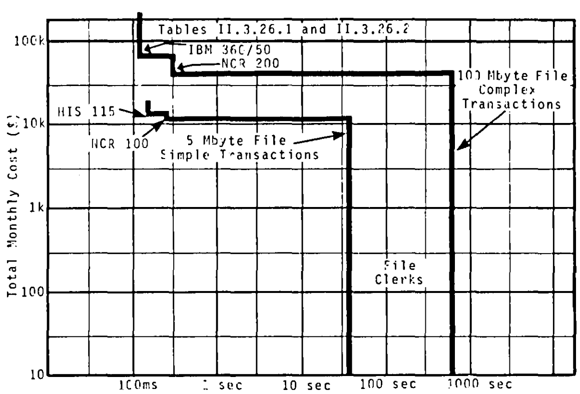



FIGURE 3.26.4 ON-LINE FILE PROCESSING COSTS II. CLERICAL AND COMPUTER RESPONSE TIMES

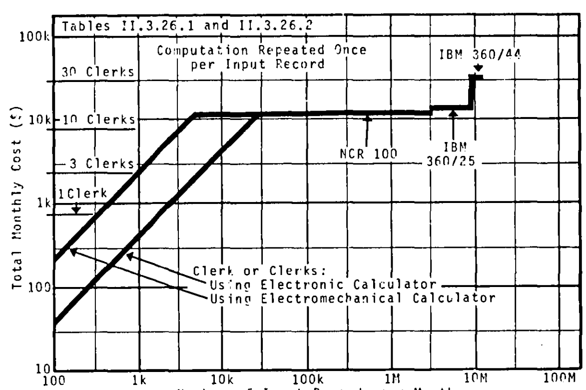



FIGURE 3.26.5 MATHEMATICAL CALCULATION COSTS I CLERICAL AND COMPUTER COST FOR SMALL SYSTEMS

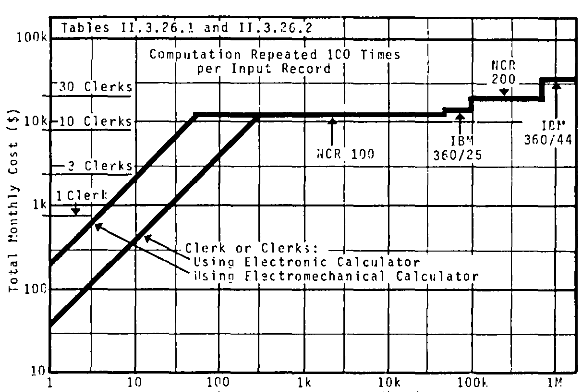



FIGURE 3.26.6 MATHEMATICAL CALCULATION COSTS II CLERICAL AND COMPUTER COSTS FOR SMALL SYSTEMS

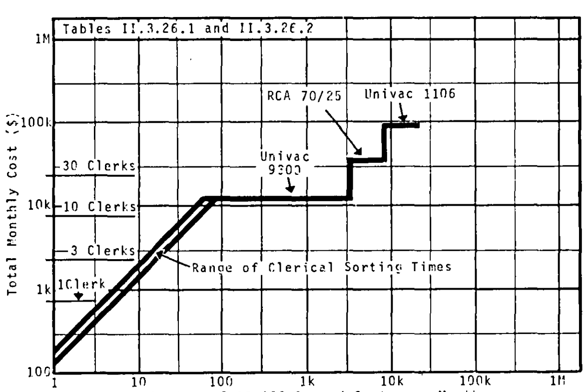



FIGURE 3.26.7 SORTING COSTS CLERICAL AND COMPUTER COSTS FOR SMALL SYSTEMS

The general situation is illustrated in Figure 3.27.1 where we plot the cumulative cost and value of various applications or functions versus the number of functions performed. The dashed line represents the cumulative value of the functions; the dotted line the cumulative cost of implementing them; and the solid line, which is the difference between the other two, represents the net value. The first four functions are essential, and are shown as having no value. Their implementation requires two units of cost, however, so the cumulative net value drops to -2. The next three applications, labelled (1), (2), and (3), have substantial value—one can readily measure the revenue increases or cost reductions they generate—and their implementation costs are minor. The result is a substantial improvement in the cumulative net value. Applications (4) and (5) are also of value, but for each their incremental cost exceeds incremental value, so net value drops. And the last three fall in the category of functions whose value is difficult to quantify but whose cost is non-trivial. Presumably there are a host of such functions available for consideration, and the graph could thus be extended. Note that, after the essential functions appear, other functions are added in a sequence determined by their incremental contribution to net value. And obviously, given these facts, the organization would only implement the essential functions plus functions (1) to (3).

In the analysis illustrated by Figure 3.27.1, the data processing expenses shown are based on the lowest-cost implementation for each function, not requiring an in-house computer. Manual operations, the use of calculators or microfilm or electromechanical filing aids, the use of outside computer services—any system can be chosen to implement each function, and the cost of the cheapest one is shown. Suppose next that the organization wants to consider installing a modest computer system. How should it view the alternatives now, and what new matters must be taken into consideration?

The gross values, computer system operating expense, and resulting cumulative net values for the same functions are shown in Figure 3.27.2, this time plotted against the percentage of computer capacity used. Once again the dashed line represents the value of the functions; the dotted line the cost, assumed to be constant no matter how many applications are implemented; and the solid line the resulting net value. Again the essential functions are shown first, and the others are added in order of decreasing profitability. Note that, though the value of each function is of course the same no matter how the function is implemented, the implementation costs are not the same for computer and non-computer processing, and therefore a listing of functions in decreasing order of profitability will not necessarily give the same sequence—for example, functions (3) and (4) are interchanged in Figure 3.27.2.

Comparing the non-computer and computer situations, we see that where Figure 3.27.1 suggests that we should spend about 2.8 units of cost and implement only the essential functions plus items (1) through (3), giving us a net value of 1.2 units, Figure 3.27.2 indicates a better strategy is to spend 4.5 units on a computer system, implement all functions, and achieve a net value of 2.0 units. And at that point we would still have 10% of the system's capacity unused and available for one or more new applications.

Three comments seem pertinent before we turn to the discussion of the practical difficulties which interfere with this logical approach. First we must remember that one important advantage of the computer is that it can perform functions no other system could perform at any reasonable cost, so that applications one would never consider implementing manually might well be practical and profitable with a computer system. A system which helps increase revenue by giving sales offices access to an inventory record updated in real time is one example. So is one which generates new income by printing the current value of a customer's stock portfolio on the monthly statement from his broker. The simple-minded situation pictured in Figures 3.27.1 and 3.27.2 ignores these unique functions.

The second comment is that the fixed computer system operating expense, shown as a horizontal dotted line in Figure 3.27.2 is an oversimplification of a complex situation. Certainly there are some operating expenses which must be regarded as fixed even for the smallest system: the hardware itself, the facility costs, and the salaries of a minimum staff—a manager/programmer/systems-analyst, a computer operator, and a keypunch operator, perhaps. But the cost of supplies, and the salaries of the additional programmers and operators who would implement new applications and operate the equipment during a second and even a third shift are incremental costs which don't have to be incurred until the workload reaches a certain level. In other words, the horizontal line should start lower at the left, and should have steps in it at points at which new applications require the addition of new resources. The recognition that these incremental costs are required may of course change ones conclusions about the wisdom of implementing all the functions. For example, any significant incremental cost incurred to implement functions (6) and (7) would probably make them unprofitable.

The final comment has to do with incremental programming costs. The programs created by the systems analysts and programmers can be treated in one of two ways: as expense items to be charged off against revenues as incurred; or as investments to be capitalized and then depreciated over a period of time. In justifying a new application, or in comparing the profitability of two possible new applications, the user must take programming costs into account. If he regards his system analyst/programmer costs as fixed, and feels he must retain a group of a given size for program development and maintenance no matter what, he may decide to ignore incremental programming costs and treat them just like he treats machine rental—as part of an ongoing fixed cost. But if his system analyst/programming costs are really variable, implying that he will lay off people if he decides not to add new programs, or hire new people if some formidable new project is approved, then it is appropriate to take incremental programming costs into account when comparing proposed projects. In practice, the expense and difficulty of finding and training people, and the fact that there seems always to be a list of desirable new applications, advances the concept that programming costs are fixed.

The above remarks and figures describe a systematic and logical approach to the problems of deciding which data processing functions are worthwhile, and how they should be carried out. In real organizations, the Ideal is seldom, if ever, achieved or even attempted, for a number of reasons:

1. Data processing does not receive enough management attention. The organization's purpose, after all, is to sell its products and services, and so management tends to regard data processing, along with, say, management development and facilities maintenance, as an important but decidedly secondary function. As a result, there is seldom a general and comprehensive review of data processing operations, and

management attention is more often focussed on problems (why is the software late? what is being done to correct these erroneous reports?) than on fundamentals. The problem is complicated by the fact that various data processing functions are often distributed throughout the organization, so that the total problem is obscured and total costs are not visible. Even if there is a central data processing or computer department, one usually finds files and file clerks and calculators and various forms of data collection, storage, manipulation, and distribution in the various operating departments of the company. "Everyone knows" that the personnel department has drawers of files on employees, that purchasing maintains an extensive card file on vendor performance, that development keeps its own records on project costs because the corporate cost system is always late and doesn't provide data in a useful format. But there is seldom an attempt to look at all these scattered functions as part of a single data processing whole, or to justify the cost of each based on its estimated value.

2. It is extremely difficult to determine the value of many, or perhaps most, data processing applications. The accounting department wants a monthly report on outstanding accounts receivable, sorted by age (i.e., time overdue) and by amount; but it is unwilling or unable to estimate how effective this report will be in reducing the cost of receivables. Or sales wants a report, available early every Monday morning, showing the previous week's sales and returns, sorted by sales department and then by product type; but sales will not promise that revenues will increase by some specified amount as a result of the availability of this data. Or manufacturing requests a new monthly inventory analysis, showing anticipated parts shortages based on current inventory and on the previous three month's usage; but manufacturing managers won't commit to a saving in inventory costs, or to a reduction in late shipments. In fact, as should be evident from these examples, the value of better information is very difficult to establish. And even if the responsible manager is willing to attach a value to a requested new function, it may be very difficult, afterwards, to determine whether his valuation was accurate. If sales did in fact increase after the introduction of the new sales analysis report, can we attribute the increase to the use of the analysis, or did it in truth come about because of the unexpected success of a new product, or of a recent and unique advertising campaign?

More often than not management, recognizing the difficuties, gives up on attempting to value data processing functions, and relies on the recommendations of unit managers and of staff. Arguments over relative priorities are settled rather arbitrarily, based on the collective judgement of senior managers, rather than on the expected value and cost of the projects involved.

3. When an organization is convinced that some new application has value, it is seldom thorough in attempting to find the cheapest way to implement the application. There are numerous well-documented examples of this tendency. Sometimes the organization asks the question, "How can I do this in the cheapest way using a computer?" instead of "How can I do this in the cheapest way?" Sometimes the question is further restricted to "How can I do this using a computer?" and few or no alternative computer solutions are evaluated. Sometimes a function is implemented in one part of the organization in a manner which is cheapest there, although it could have been implemented somewhere else at a much lower incremental cost. (One example of this phenomena is the development project cost report referred to in paragraph one above–it obviously should be cheaper to make the corporate project report timely and useful than to permit the development organization to set up an independent reporting system.) In part, this entire problem arises because of the difficulty of designing systems and estimating their costs: the difficulty encourages people to stop when they have found one solution, and discourages them from investigating several. But more often the problem is simply another symptom of management inattention.

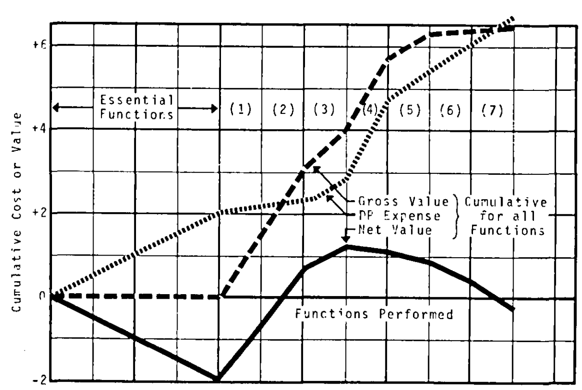



FIGURE 3.27.1 JUSTIFYING DATA PROCESSING COSTS I
PRE-COMPUTER PROCESSING

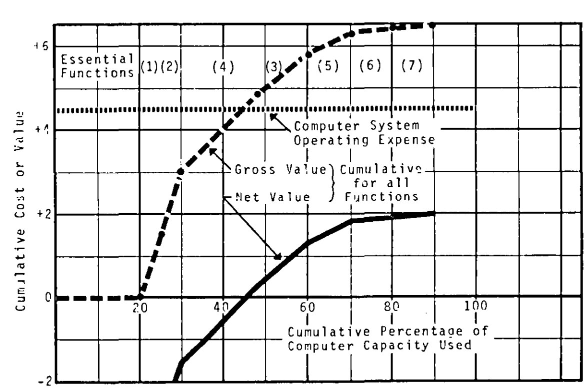



FIGURE 3.27.2 JUSTIFYING DATA PROCESSING COSTS II
COMPUTER SYSTEM PROCESSING

4. Data processing functions are not independent of one another (as was implied by our discussion of Figures 3.27.1 and 3.27.2), and their interrelationships greatly complicate the justification process. Once one has justified the cost of setting up and maintaining a master file for some application, the incremental cost of modifying the file system slightly to perform some new function is small compared with the initial cost of the file. For example, once a microfilm system has been set up to make current engineering drawings and specifications available at several manufacturing sites, it would be relatively inexpensive to make those same drawings available in the field for use by maintenance personnel. The result is that, in justifying projects and making implementation plans, one may have to consider a large number of permutations and combinations of a few new applications in order to decide which set will have the best payoff, and also to determine the best implementation sequence.

5. Once an application has been implemented, it is generally difficult to eliminate it when circumstances change and its value shrinks or disappears. The value of a periodic report, analysis, or calculation may drop for a number of reasons. Reorganizations, changes in the marketplace, changes in internal policies and procedures or external laws and regulations—these and other factors can alter conditions so that the original value drops. Or the individuals who requested the function may decide that they erred, and assigned too great a value to it. But the typical organization contains a great deal of momentum, and it is normally difficult to find the time even to review the current distribution and usage of reports, without bringing up the touchy subject of their value or futility. The result is that, at any given time, there may be a good deal of wasted data processing resources, with a resulting bias to any decision regarding a new function. For example, a newly-proposed application may be discarded on the grounds that its implementation would require a step increase in costs—the hiring of a new clerk or operator, or the leasing or purchase of a new piece of equipment—when in fact the application could be implemented with no change in resources if two now-valueless functions were discarded.

In a sense, all five of the above explanations are manifestations of the first: that the organization's management pays too little attention to the data processing function. The more people in the organization who are aware of the inefficiencies inherent in sloppy justifications of data processing applications, the better off the organization is likely to be. But management's inattention (in part caused by its awe of the mystique of Computing) coupled with the aggressive attitude of most computer salesmen and some data processing managers that every new processing function is good and should be implemented on a computer, leads all too often to immense wastes of time, resources, and money.

In the Introduction we saw one acknowledged example of such waste—the ASTEC teacher credentialling system in California. Table 3.27.1 provides evidence pointing to some others. It describes one batch and four on-line data base systems which give users access to large files on hospital patients, insurance policy holders, employees, credit applicants, and lawbreakers. The files range in size from 19 to 3600 million bytes, and the transaction volume from 24 to almost 6000 requests per hour. Annual operating costs were given, and range from about a dollar to over $35 per transaction.

The bottom portion of the table lists alternative systems, as described in Section 3.26. The personnel and law enforcement systems have such low transaction rates that it seems likely a system consisting of a clerk, a file cabinet, and a telephone would solve the problems at a cost of well under a dollar per transaction compared with the $6.80 and $36.36 actual costs. The batch system is run once a week, and could seemingly be handled by a Honeywell 1200 at a cost of less than 25 cents per transaction compared to the $1.60 shown. Unfortunately, the analysis of Section 3.26 didn't include on-line systems with file capacities over 100 million bytes. But an IBM 360/50 with that capacity could handle the insurance and credit applications at a cost of less than ten cents per transaction. Does it really cost more than ten times as much to increase file capacity from 100 to 3500 million bytes?

The "alternative system" comparisons are undoubtedly unfair, based as they are on such sketchy information about the actual systems. But the great range in actual per-transaction costs is one clue that the users are not all equally efficient. And the figures given here are compatible with those describing the California ASTEC system (GustG71), where a manual system costing 50 cents per document replaced a computer system costing $3.60 per document. It would surely be helpful if more users could compare their costs with those of other users having similar problems. And it is of course essential that management pays attention to data processing plans, insuring that a variety of alternatives is considered for each new application.

**The Market Elasticity of Computers.** There is obviously a great deal of *a priori* evidence that the market for all sorts of data processing equipment is very elastic, and that substantial reductions in the price of equipment or services quickly lead to expanded markets for those products. The histories of the minicomputer, of the IBM System/3, of the electronic calculator, of time-sharing services, and more recently of the integrated-circuit microprocessor all indicate how the introduction of a new product in a new price range stimulates users to invent a host of new applications uneconomical with previous technology, or to convert existing applications from manual or semi-automatic to computer implementations.

The general elasticity curve is shown in Figure 3.27.3. For any given sales price, P, there will be a number of customers, Q, who will be willing to purchase the product. If the price is reduced by an amount p, the curve predicts that an increased number of customers, q, will be induced to buy the product. As the price gets very small, a great many customers find it worthwhile to buy. As the price becomes very large, only a hard core of customers for whom the product is very important will want to buy. An organization could use this curve to help establish a price for a product—but of course it would be difficult to determine the curve's precise shape.

A similar curve specifically applied to the computer marketplace is shown in Figure 3.27.4, this time plotted on a log-log scale (where an inverse relationship like $Q = 1/P$ appears as a straight line). Three reasonable-looking data points are shown, and the straight line connecting them suggests grossly what the market for data processing equipment (and services) looks like. The point at the top left reflects the fact that several million pocket electronic calculators have been sold in the U.S. at around $100 each. The point in the middle describes the tens of thousands of minicomputers which have been sold at an average price of around $35K. And the point at the lower right indicates the several hundred very large systems which have been installed, generally to undertake massive calculations in large organizations. (The point on the elasticity curve for pocket calculators, for example, was determined by assuming that no calculators could be sold at a price of $300, and that 10 million could be sold at a $30 price. Assuming a linear price-volume relationship over this small price range, we can estimate the elasticity at

(10 million - 0) ÷ ($300 - $30)

= 37,000 calculators per dollar.

The other points are similarly calculated.)

**TABLE 3.27.1 DATA BASE SYSTEMS OPERATING COSTS**

| | Units | | | Application | | |
|---|---|---|---|---|---|---|
| | | Medical | Insurance | Personnel | Credit | Law Enforcement |
| **Described System** | | | | | | |
| Operating Mode | | Batch | On-Line | On-Line | On-Line | On-Line |
| Data Base | | | | | | |
| Number of Subjects | M | 1.0 | 3.3 | 0.010 | 35.0 | 0.031 |
| Number of Characters | M | 3500 | 3600 | 20.0 | 3500 | 19.0 |
| Characters per Subject | | 3500 | 1091 | 2000 | 100 | 613 |
| Number of Users | | 50 | 60,000 | 45 | 500,000 | 5000 |
| Transaction Volume | | | | | | |
| per Year | M | 2.5 | 12.0 | 0.050 | 10.0 | 0.055 |
| per Hour | k | 1.20 | 5.77 | 0.024 | 4.81 | 0.026 |
| per User per Hour | | 24 | 0.096 | .53 | 0.0096 | 0.0053 |
| Costs | | | | | | |
| Total Annual | $M | 4.0 | 13.0 | 0.34 | 14.0 | 2.0 |
| per Transaction | $ | 1.60 | 1.08 | 6.80 | 1.40 | 36.36 |
| per kByte | $ | 0.46 | 0.99 | 3.40 | 14.00 | 59.32 |
| **Alternative Systems** | | | | | | |
| System | | HIS 1200 | IBM 360/50 | One Clerk | IBM 360/50 | One Clerk |
| Annual Cost | $k | 550.8 | 817.2 | 39.6 | 817.2 | 39.6 |
| File Capacity, Characters | M | 3,500 | 100.0 | 20.0 | 100.0 | 19.0 |
| Transaction Volume | | | | | | |
| Potential, per Year | M | 3.5 | 64.0 | .125 | 64.0 | .125 |
| Assumed, per Year | M | 2.5 | 12.0 | .050 | 10.0 | .055 |
| Cost per Transaction | $ | 0.22 | 0.07* | 0.79 | 0.08* | 0.72 |

* These costs are not strictly comparable with those of the described systems, above, because the file capacity provided is only 100 million bytes compared with the 3500 million of the described systems.

For sources, see Part II.

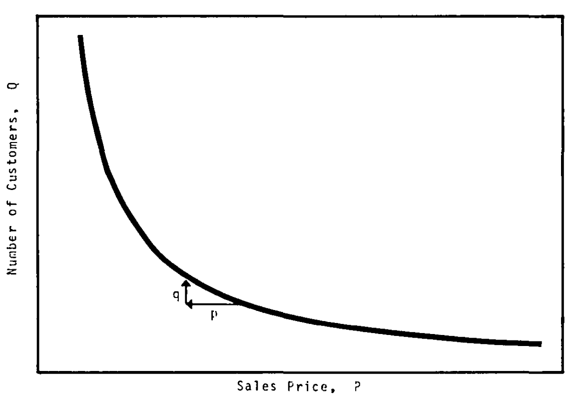



FIGURE 3.27.3 MARKET ELASTICITY I
THE GENERAL CASE, ON A LINEAR SCALE

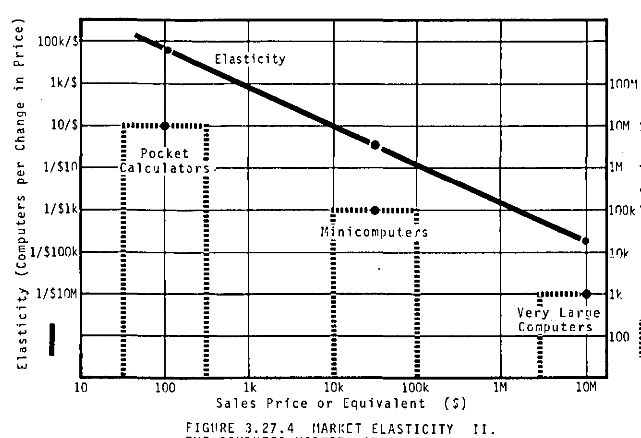



FIGURE 3.27.4 MARKET ELASTICITY II.
THE COMPUTER MARKET, ON A LOG-LOG SCALE

There is another way of looking at market elasticity, that takes system performance into account. In the last section, in discussing the users' justification for computer purchases, we observed that a rational user can establish a value for his various applications, can list them in order of decreasing value, and can then plot cumulative value as a function of cumulative data processing power or computer performance required. Such a curve is shown as a dashed line in Figure 3.27.5, and is comparable to the dashed line in Figure 3.27.2. Furthermore, in our discussions of system performance, we observed that one can describe a computer system in the same coordinate system, and that its characteristics are generally represented by a curve which is concave upward—it has some given performance at its minimum price, but to obtain successive increases in performance one must add a more-than-proportional price until finally one reaches a maximum configuration and performance. The curves shown in Figures 2.23.1-2 are typical, though they represent only the hardware cost of system operation. We want to include all operating costs (which will shift the curves up and will tend to reduce the differences in cost between large and small systems), and the result, for three computer systems C1, C2, and C3, is shown in Figure 3.27.5.

Studying the four curves in this figure, we conclude that this particular user (dotted line) can economically make use of system C1, but not system C2 or C3: any expenditure on system C1 in the range from $A to $B per month will provide enough computer capacity to satisfy the user at a price less than the value to him of that capacity; but system C3 provides too little computer power to be useful, and system C2 is too costly to justify.

For simplicity we can replace the user and computer curves by points, located near the middle of the bend. (In a moment, we will greatly expand the scales on the x- and y-axis of these figures anyway so the curves will shrink towards points.) The result, for the same three systems and the same user (U1), is shown in Figure 3.27.6. Note that any user whose applications plot as a point lying in the shaded area, can profitably use system C1. There is, of course, a similar shaded area for system C2 and another for C3. Where these areas overlap, more than one system will profitably satisfy a user. For example, in Figure 3.27.6, user U2 could profitably apply any of the three systems, though he presumably would choose the cheapest, C3, to maximize his net value.

It would be possible, evidently, to plot a point on this coordinate system for every organization or individual having a data processing requirement. Users U1 and U2 represent two such points, but obviously a graph for all potential U.S. users would contain literally millions of dots. We can represent the potential market for data processing equipment and services by dividing the surface of the graph into squares, and counting the number of user dots in each square. We can further estimate the value of this potential market by summing the values of all the dots in each square. A subjective, personal estimate of the U.S. market, expressed in this fashion, is shown in Figure 3.27.7. Each square on the chart represents a value/capacity range, from the user's point of view, or a price/performance range, from the supplier's point of view. In each square where there is a significant potential market I have entered two numbers. The first estimates the number of potential users, to the nearest factor of ten. It is intended to be a conservative estimate—in other words, I expect the actual number of potential users will lie between the number shown and a number ten times as big. The second number in each square estimates the potential value of the equipment or services the users would employ, if all of them acted. It is expressed in dollars per month and is found by multiplying the number of users by the *lower* of the two values which bound the square in question. Since this value is based on a conservative estimate of the number of users multiplied by a conservative estimate of value per user, it is probably on the low side. On the other hand, if we want to consider it as a measure of potential sales in the marketplace, it may be reasonable: users will certainly choose systems whose rental is *lower* than the value of their application, to allow for operating costs.

By way of rationalizing the estimates, let me make some remarks. At the top of the figure I show the few hundreds of large and sophisticated users in each of the high-performance ranges whose data processing workload is so critical to them that they can afford to pay over $100,000 per month for computing functions. The business data processing functions of the country's largest corporations, and the scientific calculations needed by our largest aerospace companies and by such government agencies as the Atomic Energy Commission and the National Aeronautics and Space Administration fall into this category. The next two horizontal bands, covering the rental range from $1K per month to $100K per month, describe the market for the mainstream of GP systems. The big markets here are the tens of thousands of firms with revenue over (say) $5M which can pay over $10K per month for computing capacity in the range from 10K to 100K operations per second, and the hundreds of thousands of smaller firms which can afford $1K per month for 1K to 10K operations per second. It is these markets which are generating and will generate computer industry revenues in the range of over $100M per month.

The next horizontal strip, including users who can pay $100/month to $1000 per month, describes the minicomputer market. We know that there are a few hundreds of thousands of minicomputer users, because 100,000 minis were in use by the end of 1974. Note that I speculate that there are a few million potential users who need capacity in the range 1K to 10K operations per second. These include the industrial and government users who have been buying minicomputers, but also include the families who would be willing to pay $100 per month or more for a minicomputer which had educational, entertainment, and data processing functions. The tens-of-millions market, in that same performance range, for minis which cost $10 to $100 per month, includes the larger number of families who would pay less for similar but more modest functions.

Finally, there is the already-developed market for pocket calculators. A few tens of millions of these machines have already (1976) been sold to students, housewives, and husbands as well as to accountants, engineers, and small businessmen, at prices ranging from $30 to $500—which is roughly equivalent to $1 to $10 per month. (The chart is intended to represent a view of the data processing market, and does not include the market where microcomputers will be used as invisible, fixed-function components—in the automobile industry, for example.)

In Chapter 2 we observed that it is possible to represent the average price and performance of the systems introduced in any particular year by a line. The slanted lines in Figure 3.27.8 represent system price and performance for the years 1954, 1962, 1966, and 1971 and were copied from Figure 2.11.8. The horizontal and vertical lines extending from the left- and right-hand ends of the slanted lines thus defined the potential markets for equipment in each of those years. For example, the potential market in 1954 is indicated by the shaded area: any user whose data processing value and requirements plotted as a point in the shaded area in 1954 would presumably be a potential customer for one of the computers available at that time. The lines describing the 1962 and 1966 machines mark off successively larger areas, each encompassing all the potential customers of the previous era and adding new ones as well.

The number of potential users in each price/performance range is copied from Figure 3.27.7 to 3.27.8, in the region of interest. The very earliest machines were applicable only to the few thousand users shown within the shaded area. By 1962 the advent of the second generation systems had greatly broadened the potential market, both at the high-performance end and in the range of the big mini ($1K to $10K per month, 100 to 1000 operations per second), where there were potential applications numbering in the tens of thousands. Then the minicomputers introduced in the mid-sixties opened up the even larger potential market for $1K-to-$10K systems having speeds in the range of 1 Kops to 10 Kops. My estimate of potential markets seems to be at least superficially consistent with the actual numbers of systems installed in each of the three years, as shown in the table in the lower right corner of the figure.

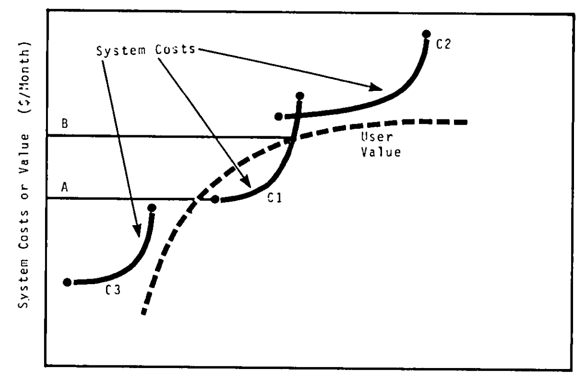



FIGURE 3.27.5 COMPUTER CAPACITY AND USER REQUIREMENTS I
IN THE PRICE RANGE BETWEEN A & B. SYSTEM C1 SATISFIES THE USER

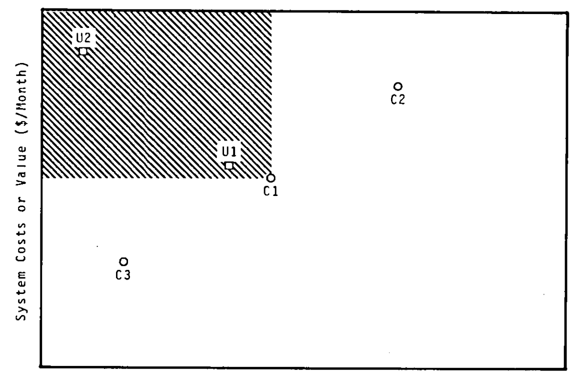



FIGURE 3.27.6 COMPUTER CAPACITY AND USER REQUIREMENTS II
SYSTEM C1 PROFITABLY SERVES ALL USERS IN THE SHADED AREA

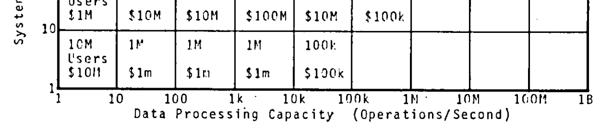



FIGURE 3.27.7 AN ESTIMATE OF THE DP MARKET IN THE U.S.
POTENTIAL USERS IN VARIOUS PRICE/PERFORMANCE RANGES

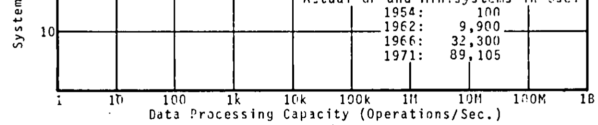



FIGURE 3.27.8 THE U.S. DATA PROCESSING MARKET

The viewpoint of the data processing marketplace which is embodied in Figures 3.27.7 and 3.27.8 provides us with some insight into a variety of special situations and problems. For example:

1. There are a great many (probably a few hundred thousand) accounting machines installed in the U.S. which serve a large segment of the market we have been discussing. These machines, which are keyboard-driven and execute complex transactions in response to operator entries, became increasingly sophisticated in the early seventies. Their performance lies in the range between 10 and 1000 operations per second, and their price is generally in the range of $100 to $1000 per month. We have not discussed this important class of products at all partly because they have been uninteresting compared to the glamourous stored-program computer and partly because there is little data available about their population and usage. However, their increasing complexity and sophistication and the advent of ever-cheaper GP machines like IBM's System/3, mean that the operator-oriented and programmer-oriented machines will more and more often directly compete with one another for an important segment of the total market.

2. The electronic pocket calculator, sold (1974) in every stationery store in the U.S. is also beginning to encroach on this marketplace. Already there exist calculators with limited programmability; and it seems quite possible that their designers will find ways to add features and capabilities which will increase their usefulness to small organizations and thus help them compete (in some situations) with accounting machines and computers.

The situation is illustrated in Figure 3.27.9, where the slanted lines represent assumed price/performance curves for calculators, accounting machines, and small business computers in 1974. If we assume the users are all rational, each will procure the system which solves his problems at lowest cost. Thus the calculators will attract many customers (within the shaded area) whose applications are so important to them that they could afford an accounting machine or even a computer. And the market for accounting machines is limited to those users whose value/capacity points lie above the dotted curve but outside the shaded area; while that of the small business computers depends on users lying above the dashed line but not above the dotted one.

3. Many users subscribe to computer time-sharing services. Originally such services provided only computational power, which the user employed by writing programs. Newer services are based on proprietary specialized programs which solve common business or scientific problems—bookkeeping programs, order-handling programs, text-editing programs, and statistical programs are examples. Typically customers pay from $100 to $2000 per month for a capacity somewhere in the range of 100 to 1000 operations per second. Suppose such a service is provided by a central computer renting for $8000 per month (point A in Figure 3.27.10). Total operating costs, from the formula of Figure 3.25.23, would then be $26K per month, plotted as point B. Such a system, having a capacity of about a million operations per second, can typically provide service for about 100 users at any one time—from 100 full-time users to 1000 users who sign on for short periods totalling one-tenth of full time. The system operator can thus provide a service of 1% to 0.1% of system capacity at 1% to 0.1% of system operating cost, and these operating points are shown as C and D in Figure 3.27.10. Taking into account the facts that system overhead reduces the capacity available to users, that the system operator must make a profit, that time-sharing operating costs are somewhat higher than those of an ordinary installation, and that it is difficult to maintain a full roster of customers all the time, we might estimate the *price* for time-sharing services should be described by points E and F. And if we add to this price the $100 monthly charge for a terminal, we finally reach the user costs shown at G and H.

Since the time-sharing service supplies processing capacity to an operator at a keyboard, its cost can be compared directly with that of the calculators and accounting machines. The result, shown in Figure 3.27.10, indicates that time-sharing services are very competitive, providing processing capacity in the range between that provided by accounting machines and small computers at costs substantially less than either. Note that, if our analysis accurately describes the facts, rational customers would never use accounting machines—an appropriately designed time-sharing service can supply 1000 operations per second at $200 per month, which is the same as the cost of the cheapest and least capable accounting machine.

The curves shown in Figure 3.27.10 still do not represent a fair comparison of the relative costs of the systems described, because they do not include the operating costs of the small business computer, or the salary and overhead costs of the people who operate the keyboard systems—the time-sharing terminal, the accounting machine and the calculator. Figure 3.27.11 shows the effect of these costs: the dotted lines represent the pure hardware costs, and the solid lines the system costs. Three important points are illustrated in this figure. The first is that the non-linear relationship between machine rental and total operating costs given in Figure 3.25.23, when combined with Grosch's law (machine performance is proportional to the square of rental), leads us to conclude that total costs of GP systems increase with the 0.40 power of performance. In other words, a small system running in the "traditional" fashion, with keypunch and computer operators, programmers, and systems analysts, is disadvantaged because small systems both provide less performance per hardware dollar, and require more auxiliary costs per hardware dollar, than their larger counterparts.

Second, because they require no computer or keypunch operators, programmers, or special facilities, the operating costs of accounting machines, calculators, and time-sharing services are substantially less than those of GP systems, and there tends to be a large discontinuity in total costs vs. performance between the four types of processing system. However, the burdened cost of an operator is so large compared to equipment cost that it dominates total costs for very primitive systems.

Third, time-sharing systems seem to be very competitive with small stand-alone systems (accounting machines and calculators) and with GP systems. This situation is a direct result of the non-linear relationship between total operating cost and performance, from which one concludes that the larger the time-sharing system, the lower the cost per user. However, as time-sharing costs go down, the cost of the local terminal becomes the dominant factor. And as processors and bulk memory (e.g. floppy disks) become cheaper, calculators and accounting machines will become more powerful and GP systems less costly. In other words, there will be less and less difference between the cost of a simple terminal and of a very powerful small computer; and it is likely that the use of such small stand-alone systems will grow much faster than the use of time-sharing services.

4. Finally, let us consider the problems which a

manufacturer must solve when he introduces a new generation of computer products. To begin with, let us assume he is marketing five machines, which span a price/performance range and cover a major segment of the marketplace, as shown by the solid lines and shaded area of Figure 3.27.12. Several years have passed since those machines were first introduced, and his engineers have developed a new, higher-speed, lower-cost technology and a new family of products, which could be introduced with the characteristics shown as dotted lines in the figure. What considerations influence the manufacturer's introduction of these new products?

A first consideration is competition. Inventive and effective competitors, with capital available for development, can produce a family of machines similar to those indicated by the dotted lines and could thus offer existing customers better performance at a lower price. The threatened or actual existence of these competitive products encourages introduction of the new generation.

A second factor is that improved products attract new customers. Three classes of new potential customers can be distinguished, all of them of course in the area between the dotted curves and the shaded area. Users whose applications plot in the region identified by A represent potential customers whose computing load was too heavy to be handled by the previous product line. Those in the area labelled B have applications with so little value that the previous product line could not be justified. And the remainder, in the area labelled C, require price/performance ratios lower than those available with the earlier generation.

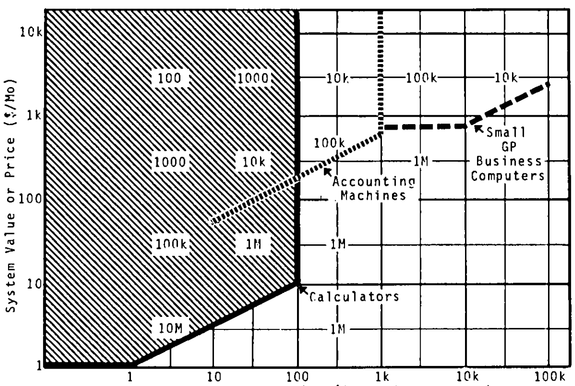



FIGURE 3.27.9 COMPETITIVE TECHNOLOGIES COVERING A COMMON MARKETPLACE

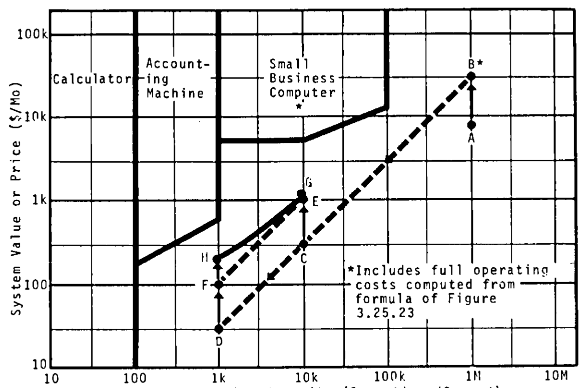



FIGURE 3.27.10 TIME-SHARING SERVICES COMPARED WITH VARIOUS ALTERNATIVE SYSTEMS

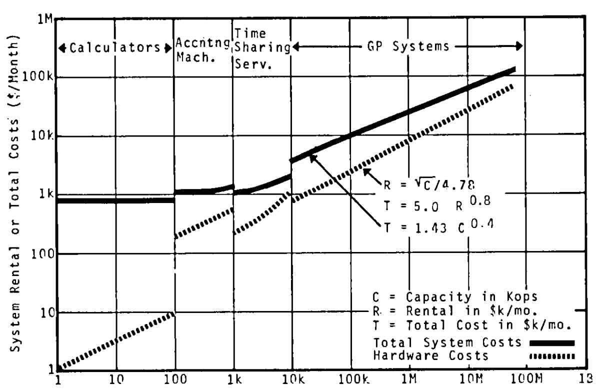



FIGURE 3.27.11 COMPETITIVE TECHNOLOGIES HARDWARE COSTS AND TOTAL COSTS (1972)

The third consideration is the effect the introduction of the new systems will have on existing customers who are renting or leasing equipment from the manufacturer. The new systems, priced as shown in the figure, make it possible for a customer who is leasing (say) a 50 to have his system replaced by one that is both cheaper and more powerful, as shown by the arrow. Wholesale replacements of that type could be very painful for the manufacturer. If the equipment being returned is not fully depreciated, the manufacturer may face the prospect of having to take a loss by junking it—he cannot sell or lease it at a discounted price without jeopardizing the 50's still being leased by his other customers. Even if the equipment is fully depreciated the exchange is painful simply because of the resulting reduction in gross income.

Of course the change to the new generation cannot take place overnight. It takes time to manufacture hundreds or thousands of new systems, so the old generation will not disappear immediately, even if the users all ordered cheaper, more powerful replacements the day they were announced. It also takes time for the users to develop plans and to decide what to do. And the passage of time helps the manufacturer, both by keeping his old machines profitably on lease a while longer, and by reducing the likelihood that the user will order a cheaper system (since new applications may develop in the interval, and the user will plan to implement them on the new system).

Nevertheless, a reduction in lease income is a danger the manufacturer must worry about. And there are various steps he can take to protect himself. First, he can urge his sales people to sell the customers on the idea that they should plan exciting and valuable new applications, to take advantage of the new computing power available to them. If users are thinking "new functions" rather than "save money", they are likely to increase their monthly rental bill rather than reduce it. Second, the manufacturer can price the new systems in such a way that users find it difficult to reap cost benefits. For example, he can set prices on all but the smallest system so that users are constrained only to order large system configurations—he can establish the size of the minimum internal memory at a very high level, resulting in a very large minimum-cost system. Thus by adjusting prices and by limiting the equipment configurations offered he can make the new systems, which *could* provide the price and performance shown in Figure 3.27.12, give the more limited improvements indicated by the dotted lines in Figure 3.27.13. The result has the advantage that it reduced the potential loss in revenue from customers who are "trading down". It has the disadvantages that it eliminates some potential customers (compare the areas labelled A, B, and C in Figures 3.27.12 and 3.27.13), and that it may not be feasible if there exists an active and aggressive competitor who will offer equivalent systems without the artificial constraints. Of course, the manufacturer may in time permit a wider range of configurations, and wind up ultimately with the pricing (and potential market) of Figure 3.27.12.

One problem remains: the main object in offering the smallest system is to attract new customers who can't afford the old 20—customers identified by B in Figure 3.27.12. But how can the manufacturer attract these customers and still not lose revenue by having his 20 and 30 customers "trade down"? One solution to this problem is to design the smallest system in such a way that it is not compatible with the previous generation. If, for example, the new small system (labelled "3" in Figure 3.27.13) is not program compatible with the 20 and 30, and in addition uses (say) a non-standard size punched card, then 20 and 30 customers with modest applications who would like to trade down will find it difficult and expensive to do so. New customers, on the other hand, having no existing investment in software or in card forms and procedures, can readily adapt to the new system.

Figures 3.27.5 through 3.27.13 provide a viewpoint of products, market, and market elasticity which is useful in giving us a way of looking at potential data processing markets and the relative importance of various products. Obviously, however, it oversimplifies a very complex set of factors and must be interpreted with care. It is a conceptual model which can give us a qualitative picture of the marketplace, not a quantitiative one, and one can argue that I have gone too far in putting numbers on the graphs. We must keep in mind the facts that users don't really assign values to their applications, that products really cannot be characterized by a single simple parameter like operations per second, and that everything is in a continual state of change—users' (theoretical) values, product characteristics, and product prices. The world, in short, is very complicated.

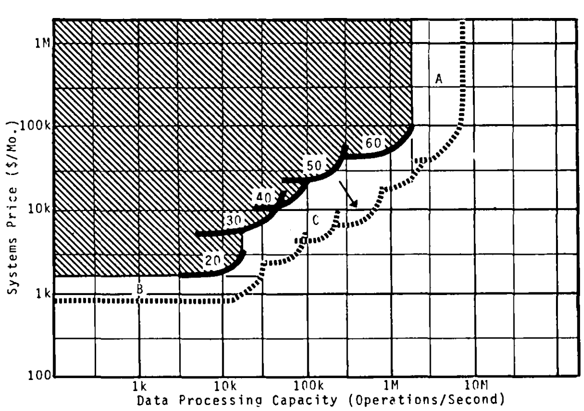


FIGURE 3.27.12 INTRODUCING A NEW GENERATION I

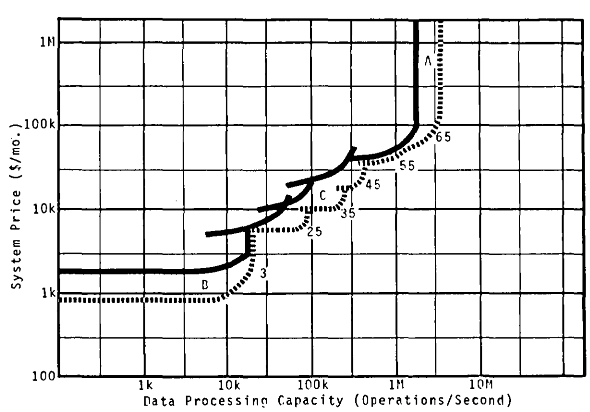


FIGURE 3.27.13 INTRODUCING A NEW GENERATION II

## 4.0 Costs ●

Now that we have some modicum of understanding of the growth of the data processing industry, the development of its principal products, and the general economics of data processing applications, we are ready to examine questions about costs. In the sections which follow we will study the costs of designing, manufacturing, marketing, and maintaining data processing systems and devices. In each case our approach will be to identify and quantify the principal elements of cost, and then to show how these costs have changed with the introduction of new technology, the steady increase in labor costs, and the continuing evolution of tools developed to improve productivity.

## 4.1 Manufacturing Costs ●

We will begin by reviewing the manufacturing costs of those components and subsystems which are and have been critical to the growth of the industry. Specifically, we will analyze:

4.11 Logic Costs. These are the costs of the electronic assemblies which perform computations, implement procedures, make decisions, etc. Central processors, input/output processors, and peripheral controllers are constructed entirely from such subassemblies.

4.12 Integrated circuits. Logic and memory costs have been drastically reduced with the introduction of the integrated circuit, and we have only begun to see the results and implications of the use of this technology. To appreciate what has happened, and what may happen in the future, it is essential that we understand the important elements in the cost of manufacturing IC's.

4.13 Magnetic core memories. The minute magnetic core, laboriously woven into assemblies by the thousand, has dominated the market for high speed internal computer memory over a period of 15 years despite the development of half a dozen more sensible technologies. We'll examine this phenomenon in detail, both as an example of economically motivated engineering ingenuity and to understand better what further improvements may be practical.

4.14 Electromechanical peripherals. The diverse devices which have been and are used for data input, output, and bulk storage have played a key role in the growth of the industry, as we have seen. Despite their diversity, we shall discover they have a good deal in common.

Before launching the first cost discussion, I must remind the reader that the figures here presented are educated guesses and approximations, intended to present a clear, consistent, but admittedly simplified picture of how manufacturing costs have changed with time. The impossibility of presenting precise costs for any product arises from various causes:

1. Definitions of cost vary from organization to organization depending on what is included besides direct materials and labor. Some other things which may or may not be included are:

..Overhead labor costs, for such things as supervision and management, manufacturing engineering, quality control, purchasing, shipping and receiving, inventory and production control, sustaining engineering, etc.

..Depreciation, of general facilities and of specific tooling for the product whose cost is in question.

..Development costs, depending on whether they were written off as incurred or were capitalized.

..Testing costs, of various subassemblies and of the completed device in a system.

..Miscellaneous non-labor costs including utilities, small parts (screws, wire, etc.), loss and wastage, etc.

..The cost of engineering changes requiring rework of in-process and completed products.

..Start-up or "learning" costs during first production of a new product.

Depending on the procedures of each individual company, some of these costs may be charged to General and Administrative expenses, to Research and Development (R & D), or to manufacturing overhead instead of being allocated directly to the product in question.

2. The real cost (assuming some common definition of what cost is) varies from organization to organization depending on such things as:

..Experience in developing and manufacturing the product.

..Efficiency and productivity of manufacturing.

..Investment in special tooling for manufacturing, assembly, and test of the product. Productivity and tooling investment are factors influenced by the expected and actual production rate for the product.

3. Manufacturing cost is, of course, a factor of critical importance to a company. If an organization knew its competitor's exact costs, it would have an advantage in establishing prices, in planning product and market development, and in allocating funds to product improvement. Companies are, therefore, quite properly most secretive about their costs. And incidentally the data given here was not provided by and is not representative of actual costs of any specific company.

Having acknowledged the impossibility of presenting reality, and having hedged in advance against the differences any specific organization will note between its own costs and the figures shown here, we can proceed. The approach will be to define the major elements of each technology, to discuss the principal factors which have affected the cost of each, and to estimate those costs along with total costs, for a given production rate. In general, the production rate chosen will approximate that of a medium-sized manufacturer in the year in question.

## 4.11 LOGIC COSTS ●

Electronic technology in the computer field is the practical science dealing with equipment which handles information represented by electrical signals. Where electronic technology interfaces with magnetic or electromechanical technologies, analog signals predominate. But in processing units and controllers, where calculations are carried out and decisions are made, the binary voltage levels of flip-flop and gates are important. It is the system costs of these logic elements that we will discuss first.

**Elements of Electronic Technology**

We will regard electronic technology as having four parts as shown in Figure 4.11.1. *Components* are the active and passive electronic parts which create and transform signals, and include vacuum tubes, transistors, diodes, integrated circuits, resistors, capacitors, transformers, etc. Each component has a set of electrical terminals, and the detailed circuit and logic design of a system is accomplished by deciding how these terminals will be connected to one another. That part of the technology which effects these electrical connections is the *interconnect* system, which include such diverse things as soldering and wire-wrapping techniques, printed circuit boards, connectors, wire, and cables. The interconnected components will not function until electrical power is present, and the *power supply system* takes raw utility power, converts it into whatever form is required by the particular component technology chosen, and distributes it to appropriate points in the system.

Finally, the components, interconnects, and the power system must be supported, protected, and cooled. The mechanical elements which provide structural strength, which prevent accidental damage both during shipment and from the normal activities of people moving about in the computer room, which keep out dust and dirt, which remove the heat generated by components and the power system, and which incidentally give the system its aesthetic appearance, are called the *packaging system.*

Note that this quaternary categorization of technology is a somewhat arbitrary one. Components themselves include miniature interconnect and packaging technology. Parts of the interconnect system play a role in supporting or protecting—the printed circuit boards, for example, support components as well as connecting them, and are often included with packaging in other published discussions of technology. The power supply system is itself made up of interconnected components and could be lumped in with the rest of the electronics. So the four elements are themselves intertwined. And certainly we could find other ways to analyze the cost of electronic technology—looking at materials and labor in each of several catagories, for example. But the four subdivisions chosen have the advantages that they are functionally important and distinct, and are directly related to design and manufacturing operations. Let's see how each has developed during the period of growth of the computer industry.

**Components.** Figures 4.11.2 through 4.11.4 record the history of component costs over the past twenty years. Vacuum tubes, resistors, and capacitors represent very mature technologies in this time interval, and their prices are correspondingly fairly stable, or rising, as shown in Figure 4.11.2. Discrete semiconductors, on the other hand, were developed and first introduced to large scale production during this period, and Figure 4.11.3 indicates that prices have fallen precipitously as manufacturing techniques improved and as sales volume increased. (EIA statistics show over 450,000,000 receiving tubes shipped in 1955, compared to about 3,000,000 transistors. By 1970 receiving tube shipments had dropped off to about 230,000,000, while transistor shipments had increased to over 900,000,000.)

In the early 1960's, the integrated circuit first became available as a commercial component. It was orginally developed under government funding for use in missile and space programs, where its small size, low power consumption, and inherent reliability made it uniquely valuable. But it was soon apparent that those same features had advantages in commercial applications, and, more important, that integrated circuit manufacturing processes offered the prospect for declining costs of a family of increasingly complex devices. This technology will be the subject of Section 4.12, but some net results are shown in Figure 4.11.4 where are plotted the EIA figures for the average cost of a bipolar digital IC and an MOS IC, along with estimated trends for three high-volume components containing the equivalent of one, two, and four flip-flops, respectively.

The resulting component cost of a flip-flop is shown in Figure 4.11.5 for five different technologies: vacuum tube, germanium transistor, silicon transistor, and bipolar and MOS integrated circuits. (The discrete component flip-flops are assumed to be very simple circuits, each containing nine resistors, three capacitors, and two tubes or two transistors. Other assumptions are given in the notes to Table II.4.11.1.)

The above figures, and our ensuing discussion of logic technology, say nothing about component or system speed. In general, and as one might expect, increases in system speed (within certain prescribed limits) can be achieved at any given time by increasing the cost of a technology— by making circuits more complex, by reducing their physical size, by supplying more power per logical function, by controlling interconnect impedances and by buying higher cost, higher speed components. The very interesting and important trade-offs which can be made between speed and cost deserve attention and are of utmost importance to an organization which is developing an electronic technology for a family of systems; however, it is a subject which has not been treated extensively in the literature, and which we will not have time to pursue.

**Interconnects.** Interconnect technology has evolved and improved in response to pressures for better reliability, manufacturing and maintenance convenience, lower costs, higher speed, and greater design flexibility. The printed circuit board (PCB) has played a key role in this development and, as we shall see, represents the single biggest interconnect cost item. We shall also, but more briefly, discuss the technology used to connect components to PCB's, connector technology, the arts which have been developed to interconnect connector pins, and the problem of system cables.

A printed circuit board is a sheet of plastic, usually fiberglass, containing holes in which component leads can be inserted; copper conductors connecting these holes in a pattern determined by the designer; and the male portion of a connector which enables the completed board to be plugged into a system. The connecting lines are generally fabricated by starting with a plastic sheet having a sheet of copper laminated to it, printing a circuit pattern on the copper, and then etching away all the copper not included in the circuit pattern. The principal factors determining PCB costs are:

1. The size of the board. A big board obviously has a higher material cost than a smaller one. However, a small board has other cost advantages. Four 4-inch by 5-inch PCB's can be simultaneously fabricated on one piece of copper-clad laminate, with the result that four such boards incur about the same handling costs as one 10-inch by 10-inch board. In addition, yield considerations favor the smaller board. A single defect which might cause the rejection of a 10-inch by 10-inch board would also cause the rejection of one of the four 4-inch by 5-inch boards, but might leave the other three small boards flawless.

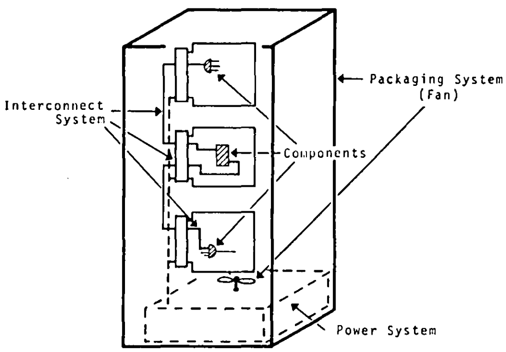



FIGURE 4.11.1 ELEMENTS OF ELECTRONIC TECHNOLOGY.

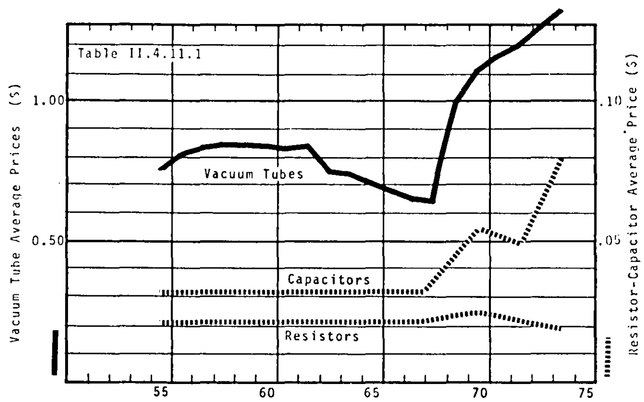



FIGURE 4.11.2 AVERAGE PRICES OF ELECTRONIC COMPONENTS.

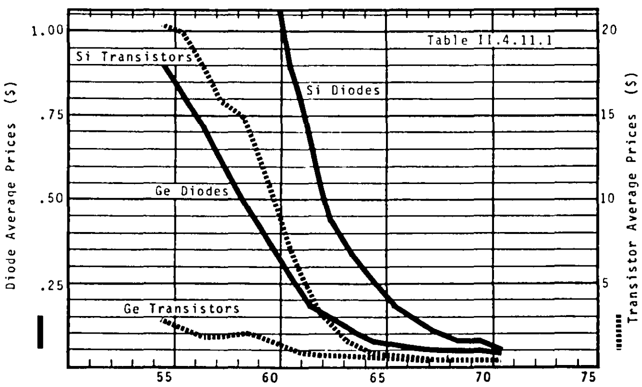



FIGURE 4.11.3 AVERAGE PRICES OF DISCRETE SEMICONDUCTORS.

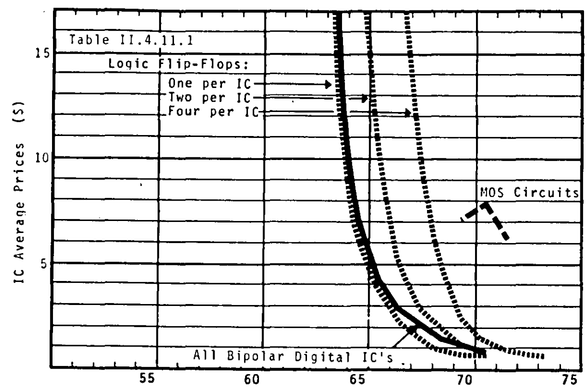



FIGURE 4.11.4 AVERAGE PRICES OF DIGITAL INTEGRATED CIRCUITS.

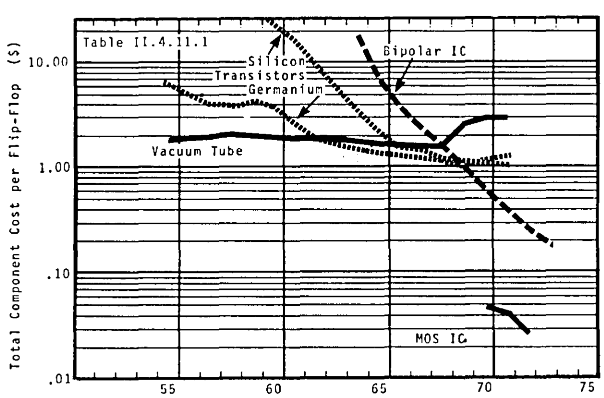



FIGURE 4.11.5 COMPONENT COST PER FLIP-FLOP

2. Line Width and Spacing. The number of components which can be placed on a square inch of printed circuit board surface is generally limited by our ability to connect circuits to the components, not by the area occupied by the components themselves. There is, therefore, a continuing pressure to increase the density of conductors on PCB's, either by changing line width and spacing of the etched copper lines, or (as will be discussed in the next paragraph) by adding circuit layers. As the line width is reduced, however, processing problems and board costs increase.

3. Number of printed circuit layers. The simplest PCB contains just one layer of copper circuitry—and virtually all the boards used in the late 1950's were single layer boards. The next step was to permit a second layer of copper on the other side of the board, and to etch circuits on both sides, selectively connecting these circuit layers together with copper which is chemically deposited in the holes drilled or punched in the PCB. This second layer of circuitry added greatly to manufacturing cost and complexity, but also permitted the designer to interconnect a greater number of components per square inch of printed circuit board. The advantages of an additional layer have since the mid-1960's encouraged PCB manufacturers to produce boards having three or more layers. A four-layer board, for example, is fabricated by manufacturing two two-layer boards, bonding them together under pressure, and finally drilling holes and depositing the copper which makes electrical connections between the various layers. Needless to say, the additional process steps required and the waste resulting from process complexity (misalignment of the boards when they are bonded together, for example) lead to substantial increases in board costs as the number of layers increases.

Table 4.11.1 provides a rough picture of PCB manufacturing costs in 1970. The table is arranged to display the cost make-up of four different PCB's representing four different levels of complexity. The first, typical of production in the late 1950's, measures four by five inches, has etched lines 30 mils wide, and provides circuitry only on one side of the board. The second differs from the first only in that it contains circuits on both sides of the board, and represents production in the early sixties. The third provides an increase in interconnect capability by halving line width to 15 mils; and the fourth and last board measures ten by ten inches and has four circuit layers. The last two PCB's are typical of production in the late sixties and early seventies, respectively.

The simplified cost analysis of Table 4.11.1 may be described with reference to the first column. A production batch, typically 100 to 500 boards, passes through various processing steps and reaches a final test and inspection stage. The total set-up and processing direct labor attributable to the batch is divided by the number of boards in the batch, the result being .15 hours. At a labor cost of $3.75 per hour and a 175% overhead rate, the labor cost is thus $1.53. The basic cost of fiberglass material with copper laminated on one side was about $1.20 per square foot in 1970, and 20 square inches cost $.17, to give a total cost into final inspection of $1.70. The 1970 yield for this very simple board is 100%, and all the boards which reach final inspection are shipped, so the total board cost is $1.70.

Let's now examine labor and material costs and yield for each of the four boards in turn. Labor times for the two two-layer boards are successively higher than for the single-layer board for several reasons: additional silk screening and hole-plating process steps are required; in-process inspection time increases as complexity increases; and each board requires more holes drilled than its predecessor, to take advantage of the increasing interconnect density. The large board in the last column would require four times as much labor as the board in the third column simply because the latter are fabricated four at a time, and the former one at a time. In addition, it is commonly estimated that a third layer adds 50% to labor time, and each additional layer 20% more.

Material costs for the last three boards are based on a cost of $1.60 per square foot for fiberglass clad with copper on both sides.

Finally, as board complexity increases, yield falls. Boards are typically rejected because of open or short circuits in the etched wires; because of defects in the plated-through holes; or because multiple layers of circuits are not properly aligned with one another. And each of these defect mechanisms tends to get worse as board complexity increases.

In Figure 4.11.6 we show how the costs of these four boards have changed since 1955. Reductions in cost have come about because of improvements in both labor productivity and in yield, despite increases in labor rates. Capital investments in numerically controlled drilling machines, material handling equipment, and the facilities required to make it possible to process several small boards simultaneously on one large sheet of laminate are typical of the improvements which have been made. The increased plant investment is of course reflected in an increased overhead rate.

A completed circuit module, ready for use in a system, is fabricated by inserting components in a printed circuit board, connecting the components to the board mechanically and electrically, and testing (and if necessary repairing) the resulting assembly. Table 4.11.2 gives an indication of the times required for module fabrication—test time and cost will be considered later in connection with a specific module configuration. Component insertion is assumed to be a manual operation, though some manufacturers (notably IBM), have made use of automatic insertion machines for some components. The connection of components to a printed circuit board is assumed to be carried out using a flow-soldering process, where a circuit card with components installed is placed for a short time, component side up, in contact with a pool or fountain of molten solder. The solder flows into the holes in the board, and when it hardens the components are electrically and mechanically connected, all in one operation. In the early days, each board was manually dipped in a pool of solder; subsequently labor costs were reduced by placing boards on a conveyor which carried them through the solder. Once soldered, each board must be manually inspected, reworked when necessary, and inspected again. Inspection reduces subsequent testing costs by correcting gross errors; and also identifies defects such as carelessly-made solder joints which electrical testing cannot detect but which may subsequently cause trouble.

A completed circuit module plugs into a connector, and connector technology will be considered next. The principal improvements in connector technology during the past two decades have been in reliability (through a better understanding of failure mechanisms and better control over connector materials and shapes), in pin spacing (where the desire for increased circuit densities has led to a reduction in pin spacing from 0.2 inches to 0.15 inches and less), and in costs (where high volumes have permitted manufacturers to design and use special tooling to aid productivity). I have been unable to find a history of connector costs, and have made the assumption that the 1974 cost of a connector could be estimated by using the formula

Connector Cost = \$.19 + (\$.019 x number of pins).

Furthermore, I have assumed that connector prices have increased at a uniform annual rate since 1955, when they were about 68% of 1974's price. The resulting cost history is described by Figure 4.11.7.

### TABLE 4.11.1 PRINTED CIRCUIT MANUFACTURING COSTS IN 1970 ●

| Board Dimensions: | | 4"x5" | | | 10"x10" |
|---|---|---|---|---|---|
| Conductor Width: | | .030 inch | | .015 inch | |
| Layers: | | One | Two | Two | Four |
| Board ID: | | A | B | C | D |
| Labor Hours To Final Inspection | hrs. | .15 | .29 | .39 | 2.84 |
| Labor Cost | $ | 1.53 | 2.98 | 4.03 | 29.28 |
| Material Cost | $ | .17 | .22 | .22 | 2.22 |
| Subtotal | $ | 1.70 | 3.20 | 4.25 | 31.50 |
| Yield | % | 100 | 95 | 85 | 70 |
| Total Costs | $ | 1.70 | 3.40 | 5.00 | 45.00 |

Source: A PCB Manufacturer

### TABLE 4.11.2 MODULE FABRICATION LABOR REQUIREMENTS (Minutes)

| | Any | Printed Circuit Board Type* A | B | C | D |
|---|---|---|---|---|---|
| Component Insertion | | | | | |
| Vacuum Tube Socket | 0.35 | | | | |
| Device With Two Or Three Leads | 0.1 | | | | |
| IC Package | | | | | |
| TO-5 Can (10 pins) | 0.5 | | | | |
| 16-pin DIP | 0.25 | | | | |
| 24-pin DIP | 0.5 | | | | |
| PCB Soldering | | | | | |
| Flow Soldering | | .7 | .4 | .4 | 1.0 |
| Inspection | | 1.1 | 1.6 | 2.1 | 7.0 |
| Repair | | .7 | 1.0 | 1.5 | 4.0 |
| Total | | 2.5 | 3.0 | 4.0 | 12.0 |

*Note: For definitions of PCB types, see Table 4.11.1.
Source: A module manufacturer

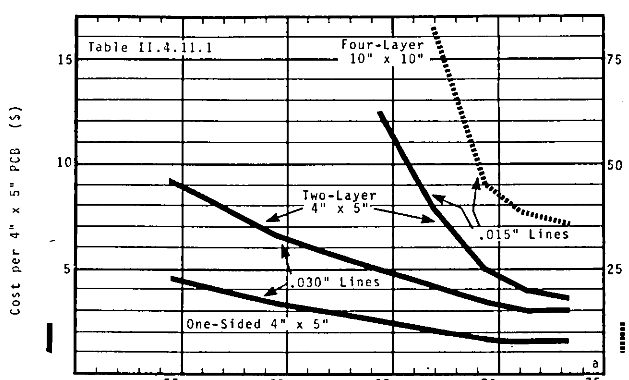



FIGURE 4.11.6 PRINTED CIRCUIT BOARD COST TRENDS

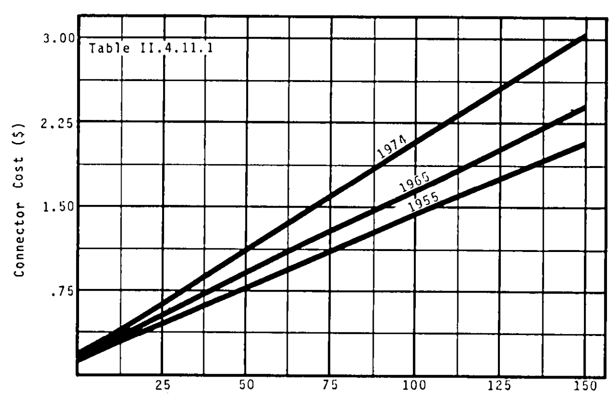



FIGURE 4.11.7 CONNECTION COSTS

We now must turn to the costs of making electrical connections between the connectors—the "backwiring" connections. Several technologies have been used to make these connections, and the important cost parameters are summarized in Table 4.11.3. Originally, wires were manually cut to the required length, their ends were stripped of insulation, they were crimped around the connector pins and then soldered. At an early date some of the labor involved in these operations was eliminated through the development of a machine which cut wires to a prescribed length, stripped their ends, and stamped them with identifying numbers. However, the labor content remained high, and the reliability of the connection, being very dependent upon the skill of the solderer, was difficult to control in a situation where the number of connections to be made was increasing at an alarming rate.

The taper pin interconnection system was invented to solve this problem. It consisted of a small tapered pin which crimped onto the end of a wire, a correspondingly tapered socket on the connector, and tools which crimped pin to wire and which jammed the pin into the socket. The result was a uniformly reliable connection which required less labor per pin than was necessary for the solder connection. (The taper pin also had the advantage that it could easily, neatly, and reliably be changed in the field by maintenance personnel when field changes had to be made.)

Meanwhile, the Bell Telephone Laboratories had been working on a technique that would still further reduce connection costs. The new technique eliminates the taper pin and the time required to connect pin to wire, and consists simply of a tool which strips insulation from a wire and wraps it tightly around a connector pin. This "wire wrap" technology makes very reliable connections, and is widely used. Wire wrapping can be carried out by an operator who uses a hand-held tool. However, if production volume warrants, cheapest connections can be made through the use of automatic wire wrapping equipment, controlled by punched cards or magnetic tape. Some insight into the economics of automatic wire wrap is given in Table 4.11.4, which shows the dependency of per-wire costs on shift usage and indicates the anticipated effect of a newly-introduced Automatic Wire-Wrap (AWW) machine. A cost history of all the technologies is plotted in Figure 4.11.8. The AWW figures there were based on three-shift operation of the old machine with two operators on every three machines. In general, note that as the use of automatic equipment lowered labor costs, wire has become an important factor in connection cost.

One final possible technology for interconnecting connector pins should be mentioned: the printed circuit board. The very high wiring densities required can be achieved with today's fine-lined, multilayer boards; however, such boards are difficult to make and are therefore expensive, and they must compete with very low-cost wire wrapping techniques. Furthermore, they have the disadvantage that they cannot easily be modified in the field; it is much easier to remove a wire than it is to cut through a copper line on a multilayer printed circuit board. For these reasons, printed circuits are not widely used for back panel wiring, and will not be further considered here.

The last interconnect topic to be discussed is a difficult one, physically untidy, and often overlooked. As we shall see, equipment is packaged in cabinets of a size chosen so that they can conveniently be shipped and moved through doors, hallways, elevators, etc. When a system reaches a certain size, it no longer fits in one cabinet; and large systems may in fact occupy tens of cabinets. The technology which connects these cabinets electrically is called *cabling*, and has the following properties:

1. It can easily be disconnected and reconnected, to permit easy shipment and installation, and to make it easy to reconfigure systems after installation.
2. It allows some variability in distance covered, so that two cabinets sharing common signals in a large system can be physically separated by as much as 100 feet.
3. It permits some considerable flexibility in the number of connections made between cabinets. It is difficult to design a system so that cabinet interconnections are uniformly distributed, and in a large system there are invariably some subsystems which control or communicate with many others and which in consequence must radiate cables to many other cabinets. The physical design of the cabinet, and of the cable connectors, must permit such concentrations.
4. It must introduce the minimum of attenuation, distortion, delay, and noise into the high speed signals being transmitted. This requirement dictates that signal wires be shielded and that cabling impedances be carefully controlled. It often leads to the provision of two or more cabling technologies to handle signals with different data rate or transmission delay requirements.

Cabling complexity dictates the use of a false floor, which as we have seen contributes an appreciable fraction of the facilities costs of an installation. Cost of the cable itself is difficult to estimate, and I know of no systematic study of cable costs and cost trends. I will assume that cabling costs are 5% of interconnect costs whenever a system includes two or more cabinets.

**Power supply system.** As new components have been developed, system power requirements have changed markedly, as shown in Table 4.11.5. The vacuum tube is a high voltage, high power device which required heater power as well as d.c. power for the signal circuitry. (Heater power is not, however, shown in the table.) Germanium-diode gates transmit large voltage swings and dissipate a fair amount of power. Transistors have no heaters, operate at a relatively low voltage, and require a modest signal voltage swing. The progression through these component technologies led to a substantial reduction in flip-flop and gate power requirements; and as transistor technology progressed, power requirements dropped even further as indicated by the difference shown between germanium and silicon circuits. Finally, the introduction of the integrated circuit led to still further reductions in both voltage and power. The early Small Scale Integrated (SSI) circuits required roughly one-third the power of the discrete silicon circuits. Medium and Large scale integrated circuits (MSI and LSI) display a further and continuing reduction in power requirements per gate. This reduction comes about because circuits internal to the integrated circuit require very little power, and the IC power required tends to be proportional to the number of circuits in the IC package which are connected to output pins, rather than to the total number of circuits. It is this factor which accounts for the low power per gate for the MSI technology shown in the table.

The manufacturing cost of a power supply system is a complex function of a great many variables. The cost of the power conversion system, which takes raw a.c. power as input and provides regulated d.c. power, varies as a function of input and output voltages used, required output voltage regulation, and, of course, output power requirements. A variety of other factors can influence cost: Is more than one output voltage required? Are there constraints on the size and shape of the power supply? Must there be special controls for sequencing the application of power or removal of power to various parts of the system? Must a voltage be slaved to ambient temperature, to compensate for the effect of temperature on some circuit?

**TABLE 4.11.3 BACKWIRING AND POWER SUPPLY INTERCONNECT TECHNOLOGIES AND COSTS**

| Technology | Cost Per Wire (Two Pins) Labor Minutes | Material $ | Deprec'n $ |
|---|---|---|---|
| **Backwiring** | | | |
| Soldering Connection | | | |
| Manual Wire Preparation | .95 | .02 | |
| Automatic Wire Preparation | .65 | .02 | |
| Taper Pins | .50 | .05 | |
| Manual Wire Wrap | .30 | .02 | |
| Automatic Wire Wrap | .08 | .02 | .011 |
| **Power Wiring** | | | |
| Soldered Connection | 1.6 | .03 | |

Note: See Table 4.11.4 and notes to Table II 4.11.1 for further details. Materials include wire cost of 1 cent per foot and taper pin cost of 1.5 cents. Labor figures from HartF64.

**TABLE 4.11.4 AUTOMATIC WIRE WRAP COST ANALYSIS**

| Machine: | | | Old | | New |
|---|---|---|---|---|---|
| Shifts: | | 1 | 2 | 3 | 3 |
| Machine Cost | $k | 175 | 175 | 175 | 70 |
| Production Rate | wires/hr. | 500 | 500 | 500 | 1100 |
| Production Time | hrs./yr. | 2080 | 4160 | 6240 | 6240 |
| Depreciation Cost | | | | | |
| Per Year | $k | 35 | 35 | 35 | 14 |
| Per Wire | cents | 3.4 | 1.7 | 1.1 | .20 |
| Labor Per Wire | | | | | |
| Full | min. | .12 | .12 | .12 | .054 |
| One Half | min. | .06 | .06 | .06 | .027 |

Notes:
The new machine was announced in 1972. Depreciation is based on five year life. Labor figures are for one operator per machine and per two machines.

**TABLE 4.11.5 POWER REQUIREMENTS FOR MAJOR TECHNOLOGIES**

| | | Vacuum Tubes | Transistors Ge | Si | IC's SSI | MSI |
|---|---|---|---|---|---|---|
| Supply Voltage | Volts | 200 | 20 | 12 | 5 | 5 |
| Signal Swing | Volts | 100 | 15 | 3 | 2 | 2 |
| Gating Circuits | | Diode and/or | Diode and/or | DTL nand | TTL nand | TTL nand |
| Power per | | | | | | |
| Flip-Flop | mw. | 5000 | 300 | 150 | 100 | 50 |
| Gate | mw. | 400 | 175 | 40 | 30 | 6 |

Note: SSI = Small Scale Integration–Six or fewer gates per chip. MSI = Medium Scale Integration –Seven to 100 gates per chip. Source: survey of module manufacturers' brochures.

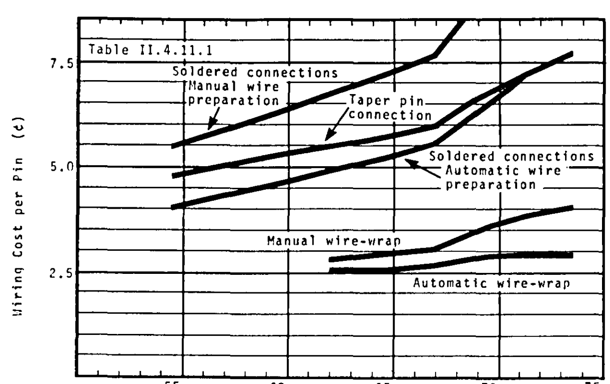



FIGURE 4.11.8 BACKWIRING TECHNOLOGY COST HISTORY

Power supply technology has obviously changed over the years, just as has logic technology. Vacuum tube rectifiers and regulators have been replaced by semiconductors, and printed circuits are often used in place of wire harnesses and hand-soldered connections. However, it appears that the largest component of power supply manufacturing costs is still the cost of labor. And in the absence of a good study or survey of the subject, I established a very simple formula which seemed a reasonable estimate of the cost of manufacturing a five- to fifteen-volt, 0.1% regulation supply in 1972. I then estimated earlier and later costs on the assumption that they followed the changes in labor and overhead costs. The result is shown in Figure 4.11.9. It assumes that the cost of a supply can be represented by the formula

$$C = a + bP$$

where P is the output power, a is the cost of a very low-power supply, and b is the incremental cost of additional capacity. The assumed upper limit of 500 watts of power supply cabinet is arbitrary. Very large power supplies are heavy and difficult to handle; and small modular supplies have the advantage that a relatively empty cabinet of electronics can be shipped with a small supply, and additional small supplies can be shipped later if the customer orders additional electronics.

Total power system costs must include the cost of making electrical connections between the power conversion equipment and the connector pins which supply power to the circuit modules. This interconnect system must supply moderate amounts of power at low impedence, must be inexpensive, and must lend itself to field expansion and modification. Though a great variety of techniques are used by different manufacturers to effect this connection, we will adopt a very primitive one, assuming connections are made by routing individual wires from the power supply to each connector and soldering them in place. The cost of this operation is shown on the last line in Table 4.11.3. For simplicity's sake, we will assume that each connector requires two such wires, one for power and the other for ground.

Finally, we must make provision for the cost of packaging the power supply in a system. Power supply cost shown in Figure 4.11.9 includes a packaging cost for the power subassembly itself; but we will see in the next section that in estimating system cabinet costs we must take into account the volume of the power supply. As power technology changed, the volume occupied per watt fell, along with the cost per watt. However, the effect of this change on total system cost is slight, and I will assume power supply volume has been constant at 2.5 cubic inches per watt.

**Packaging** The packaging system has three major components: a cooling system, module mounts, and a cabinet. We will discuss the purpose and cost of each of these in turn.

Some form of cooling system is required in every technology. We design our equipment to be as compact as possible because compactness leads to low cost, because short signal paths permit faster circuits and thus better performance, and because we want to conserve our customers' expensive floor space. The resulting high component densities generate relatively large amounts of heat per cubic inch of package. Since high operating temperatures reduce circuit tolerances and shorten component lives, it is necessary for the designer to make careful provision for heat removal when he plans an electronic technology. In practice, this usually means that circuit modules are mounted in vertical columns, to promote the natural upward flow of heat, and that fans are provided to bring in ambient air, force it past the components, and then remove it from the package. In some very large, very fast systems, power and heat densities are so high that elaborate liquid cooling systems are necessary (See Section 2.3).

We will assume that a forced air system is both necessary and sufficient for our purposes; that a cooling assembly consists of a filter to remove dust and dirt from incoming air, a motor and fan, a baffle to distribute air uniformly in the package, and suitable structural members to hold this assembly together; that the assembly occupies two cubic inches of package volume for every watt which must be removed; and that the assembly cost has increased with labor costs, reaching $0.10 per watt by 1974.

The module mount is an assembly whose functions are:

1. To provide support for the component-interconnection system. Module connectors, cable connectors, and interconnector wiring are installed on the module mount which also includes guides to help insure circuit modules are inserted properly in the connectors, and retainers to hold them firmly in position, once inserted.

2. To promote component cooling by allowing free passage of air past the components. The module mount obviously must be designed so that it is suitably compatible with the cooling assembly.

3. To facilitate assembly and wiring operations during manufacture. Specifically, the mount is generally designed to be compatible with whatever manufacturing tooling is used to wire connector pins together.

4. To facilitate system maintenance. The module mount must make it easy to remove and replace modules, and to connect an oscilloscope to any connector pin. Various combinations of hinges and/or drawers are often used to make such access easy and still achieve a high component density in the package. The module mount may also contain markings or legends which help the maintenance man identify and distinguish modules and locate signal wires and pins.

The module mount (not including the connectors or the connector wiring, which are part of the interconnect system) is the most expensive part of the packaging system. Its cost is a function, of course, of the number and size of modules it can accomodate. I will define module volume, Vm, as the area of the printed circuit board multiplied by the required spacing between connectors. A collection of 4-inch by 5-inch modules mounted one-half inch apart thus each occupies a module volume of ten cubic inches. Using the same linear formula that we employed for power supplies, we assume the cost of a module mount can be approximated by the formula

$$C = c + dVm$$

I once again started with some 1972 data, assumed that costs have a very high labor content, and that a cost history could be approximated by maintaining proportionality with the history of labor costs. The resulting assumed family of module mount cost curves is shown in Figure 4.11.10. The somewhat arbitrary upper size limit of 700 cubic inches is justified by the fact that bigger assemblies beget structural problems and are inconvenient to handle and manage during manufacture. When a system is big enough that module volume is over 700 cubic inches, it generally contains two or more separate module mounts.

The last packaging entity is the cabinet. Its functions are to support the module mounts, cooling system, and power system mechanically; to protect them during shipment and operation from mechanical damage and from dust and dirt; to present a suitable and attractive appearance to the customer and user; to facilitate maintenance operations on the enclosed assembly; and to help make the equipment easy to transport and to relocate. The cabinet basically contains a sturdy frame, often equipped with integral handling hooks and wheels; integral beams to which other assemblies can be bolted usually in a variety of ways; and doors, sides, and tops, suitably fitted and decorated.

Cabinet costs are generally a function of the volume enclosed. (A rational argument could be set forth, and supported by empirical data, to the effect that costs are proportional to the outside area of a cabinet; but for our purposes the dependence of cost on volume seems good enough and is easier to use.) Figure 4.11.11 displays my approximation of a history of cabinet costs, based again on a 1972 fit to empirical data and extrapolations tied to labor cost trends. The abscissa of this graph is the total volume contained within a cabinet, computed by multiplying the three *outside* cabinet dimensions together. How is that volume related to module volume, power supply volume, and cooling system volume as previously defined? As one might expect, a cabinet contains a good deal of empty space. A study of representative cabinets indicates that, in a typical large (25 cubic feet) cabinet the space actually occupied by the power system package, the cooling system package, and the modules (using Vm, or module area times module spacing as the measure) is only one-fourth the total. The other three-fourths is occupied by structural members (including the module mounts), parts of the interconnect system (connectors, wire, and cables), and air. For smaller cabinets, the proportion of unused space is much smaller—the usable volume in a three-cubic-foot cabinet is one half the total volume, compared to one-fourth for a big cabinet. The small cabinet permits a high packing density simply because it provides more maintenance access area per unit volume than does the large cabinet. In a small system cabinet, maintenance access is permitted through the top as well as the four sides. In a large system, the cabinet top is too high to be accessible; and usually cabinets are adjoined to one another so that maintenance access is generally only available from the front and back. Thus in large cabinets, empty space is used to permit and simplify access to modules and connectors.

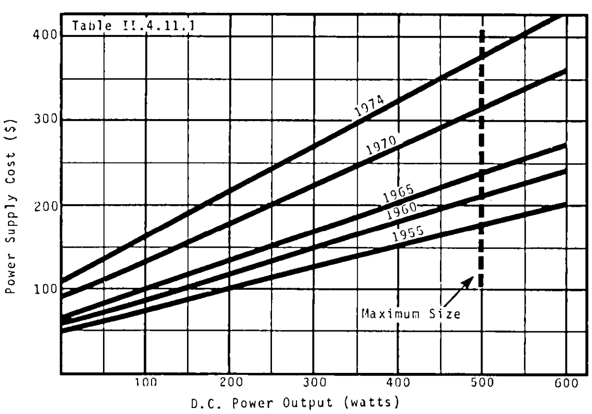


FIGURE 4.11.9 POWER SUPPLY COSTS

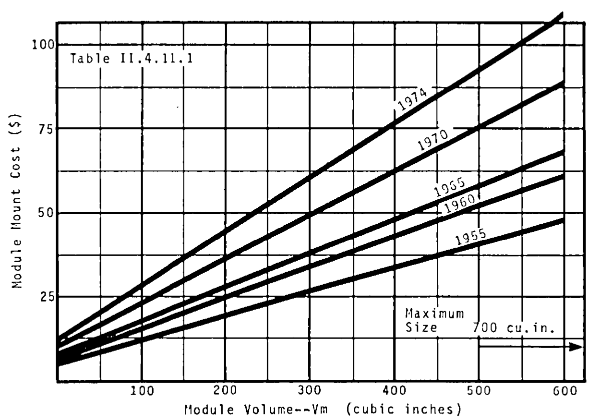


FIGURE 4.11.10 PACKAGING COSTS --- MODULE MOUNTS

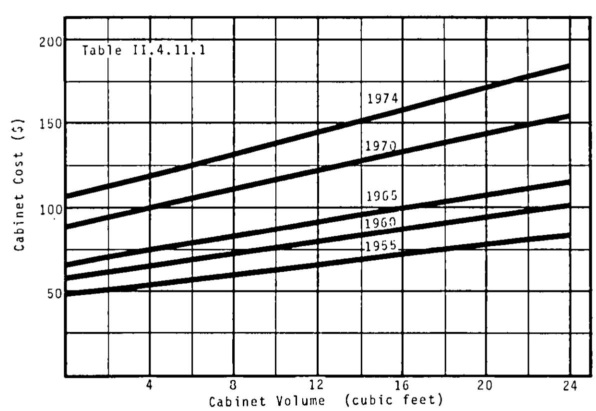


FIGURE 4.11.11 PACKAGING COSTS -- CABINETS

**System Assembly and Test.** One additional cost must be discussed, though it does not correspond to a part of the electronics structure of Figure 4.11.1. Once the modules are completed, the power supply assembled, and the connectors attached to the module mounts and wired, it is necessary to assemble the entire system in a cabinet and to check it out, correct assembly errors, replace bad components, and prepare it for shipment. The times required for the principal tasks are estimated in Table 4.11.6. Note in particular that the time required to locate and correct errors and failures is assumed to be a non-linear function of the number of failures which exist; and that we assume a one-cabinet system must be operated for eight hours (in addition to the time required to locate and correct errors and failures) to provide some assurance that it contains no marginal or intermittent circuits.

**System Costs**

The foregoing formulae and figures are the principal ingredients for a cost model of electronic systems. Using those ingredients, we can see how technology changes have affected the total manufacturing costs of such systems, and the distribution of those costs among various cost centers or expense types. We will do this by visualizing several different but comparable systems built of different technologies, and by estimating the cost of each one as a function of time.

The results are, of course, no better than the model, and in particular no better than the accuracy of the cost figures for components, interconnects, power, and packaging as given above. In defense of those figures, I can only say that they seem to pass the test of reasonableness, and represent real historical figures whenever I could find them, and a concensus of the opinions of expert friends and associates where hard data was unavailable. In general, the paucity of this kind of economic data in the engineering literature is dismaying.

The system whose cost history we will trace is a processor containing a number of flip-flops, in various arithmetic and control registers, along with an associated number of gates to supply combinatorial logic. It is difficult to find data on the logical complexity of processors, but Table 4.11.7 displays the results of an analysis of one published design and four others. Note that the number of gates per flip-flop ranges from thirteen to twenty and has been increasing, that the average number of inputs per gate lies between two and one half and three and has apparently been decreasing, and that selling prices per flip-flop have been falling, as one would expect.

We will assume that our processor is manufactured using seven different technologies, and will show how the manufacturing cost in each technology has changed as the years have passed. Table 4.11.8 summarizes the system and technology characteristics which form the basis for the analysis, describing the assumptions made and the resulting principal system characteristics. (As usual, additional detail is provided in Part II.) The technology parameters were chosen with the idea that they would be representative of typical (not "best", or "advanced") manufacturing and engineering practice at key dates during the past twenty years. We examine the cost of a one-cabinet system. The number of flip-flops per system is dependent on component density, and the number of gates per flip-flop and inputs per gate are arbitrarily established at 17 and 2.7 respectively. Given these arbitrary parameters, we estimate other system characteristics. The number of circuit boards and signal pins required was derived from a set of assumptions about logic partitioning which took into account printed circuit board size, complexity, and number of signal pins. System power per flip-flop was derived from the data in Table 4.11.5, and module volume per flip-flop from printed circuit board area and spacing. The cabinet is assumed to contain twenty-four cubic feet—e.g. to measure two feet wide, two feet deep, and six feet high. However, we assume only twenty cubic feet are used at the time the unit is shipped; twenty percent additional electronics can be added in the field after the system is installed.

**TABLE 4.11.6 SYSTEM ASSEMBLY AND TEST REQUIREMENTS**

| Item | Units | |
|---|---|---|
| Assembly Time | | |
| Install One Connector | Seconds | 20. |
| Install Module Mount | Minutes | 2.0 |
| Attach and Check Power Supply | Minutes | 5.0 |
| Plug in One Module | Seconds | 15. |
| System Test | | |
| Proportion of Total Wiring Connections | | |
| Wiring Errors (Manual Wiring) | % | 0.5 |
| Bad Solder Joints | % | 0.05 |
| Proportion of Total Components Bad | % | 0.05 |
| Time to Locate and Correct | | |
| f Errors or Failures | Minutes | $5f^2$ |
| Time to Exercise One-Cabinet System | Hours | 8 |

Source: M. Phister estimate

**TABLE 4.11.7 PROCESSOR COMPLEXITY ●**

| Processor:<br>Peak Shipment Date:<br>Technology: | LGP-30<br>1957<br>Vacuum tubes | M<br>1964<br>Transistors | N<br>1968<br>SSI | O<br>1968<br>SSI | P<br>1973<br>MSI |
|---|---|---|---|---|---|
| CPU Selling Price | $18k* | $75k | $15k | $150K | $6k |
| Number Of: | | | | | |
| Flip-Flop | 15 | 200 | 150 | 400 | 100 |
| Gates | 187 | 3000 | 2500 | 8000 | 2000 |
| Gate Inputs | 553 | 8500 | 6800 | 21000 | 5000 |
| Gates Per Flip-Flop | 12.5 | 15.0 | 16.7 | 20.0 | 20.0 |
| Inputs per Gate | 3.0 | 2.8 | 2.7 | 2.6 | 2.5 |
| Inputs Per Flip-Flop | 36.9 | 42.5 | 45.3 | 52.5 | 50.0 |
| Selling Price per Flip-Flop | $1200* | $375 | $100 | $375 | $60 |
| Flip-Flops per $100k Price | 83 | 267 | 1000 | 267 | 1667 |

Sources: LGP-30 from S. Frankel in Trans. on Electronic Computers, 3/57. Others from private sources. * LGP-30 price includes (magnetic drum) memory. Other prices are for processor only.

**TABLE 4.11.8 SYSTEM AND TECHNOLOGY CHARACTERISTICS ●**

| | Units | 1955 | 1960 | 1965 | 1967.5 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|
| **Components** | | Vacuum tubes Ge Diodes | Ge Trans., Ge Diodes | Si Trans., Si Diodes | Bipolar IC's SSI | Bipolar IC's SMSI | Bipolar IC's MSI | Bipolar IC's MSI |
| Flip-Flops/Package | no. | | | | 1 | 2 | 4 | 4 |
| Gates/Package | no. | | | | 2 | 4 | 8 | 8 |
| **Interconnect** | | | | | | | | |
| Printed Circuit Boards | | A | A | B | B | C | D | D |
| Size | in. | 4x5 | 4x5 | 4x5 | 4x5 | 4x5 | 10x10 | 10x10 |
| Spacing | in. | 1.2,.75 | .75 | .5 | .5 | .5 | .5 | .5 |
| Layers | no. | 1 | 1 | 2 | 2 | 2 | 4 | 4 |
| Line Width | in. | .030 | .030 | .030 | .030 | .015 | .015 | .015 |
| Pins | no. | 12 | 22 | 34 | 50 | 70 | 150 | 150 |
| Backwiring Technology | | Hand solder | Hand solder | Taper pins | Manual wire-wrap | AWW | AWW | AWW |
| **Power** | | | | | | | | |
| Per Flip-flop | mw. | 5000 | 300 | 150 | 100 | 50 | 50 | 50 |
| Per Gate | mw. | 400 | 175 | 40 | 30 | 15 | 10 | 6 |
| **One-Cabinet System** | | | | | | | | |
| Flip-Flops | no. | 58 | 147 | 447 | 662 | 1294 | 4238 | 6214 |
| Module Area | sq.ft. | 46.8 | 59.9 | 96.8 | 94.7 | 95.3 | 62.8 | 60.4 |
| Flip-Flops/Module Area | no./sq.ft. | 1.2 | 2.5 | 4.6 | 7.0 | 13.6 | 68.6 | 102.9 |
| Total Power | watts | 679 | 482 | 371 | 404 | 394 | 933 | 945 |
| per Flip-Flop | mw. | 11800 | 3275 | 830 | 610 | 305 | 220 | 152 |
| per Component | mw. | 152 | 43 | 11 | 64 | 76 | 133 | 119 |
| per Cabinet Volume | w/cu.ft. | 28.3 | 20.1 | 15.5 | 16.8 | 16.4 | 38.9 | 39.4 |
| Total Components | no. | 4460 | 11304 | 34374 | 6289 | 5215 | 7035 | 7954 |
| per Flip-Flop | no. | 77 | 77 | 77 | 9.5 | 4.0 | 1.7 | 1.3 |
| per Module Area | no./sq.ft. | 95 | 189 | 355 | 66 | 55 | 114 | 132 |
| Signal Pins | no. | 3027 | 7737 | 20518 | 31252 | 45714 | 13172 | 12876 |
| per Flip-Flop | no. | 52 | 52 | 46 | 47 | 35 | 3.1 | 2.1 |
| **Costs** | | | | | | | | |
| Total Cost | $k | 5.92 | 7.88 | 15.23 | 20.04 | 16.5 | 14.22 | 12.67 |
| per Flip-Flop | $ | 102 | 53.6 | 34.1 | 30.3 | 12.8 | 3.35 | 2.04 |
| Components | % | 42.5 | 40.1 | 42.0 | 58.1 | 38.3 | 50.7 | 45.3 |
| Power | % | 6.6 | 4.9 | 3.4 | 2.9 | 4.1 | 5.1 | 6.2 |
| Packaging | % | 9.4 | 9.8 | 6.0 | 5.0 | 7.2 | 7.1 | 8.4 |
| Interconnect | % | 38.3 | 34.8 | 45.7 | 33.3 | 49.1 | 35.9 | 38.5 |
| Printed Circuit Boards | % | 26.1 | 18.6 | 22.9 | 14.3 | 20.8 | 23.8 | 24.0 |
| Assembly & Test | % | 3.2 | 10.4 | 2.8 | 0.9 | 1.3 | 1.3 | 1.5 |
| **Labor Cost** | | | | | | | | |
| Power Wiring | $ | 121 | 180 | 332 | 351 | 418 | 61 | 63 |
| Module Assy/Test | $ | 351 | 594 | 1502 | 1850 | 2395 | 927 | 1033 |
| Backwiring | $ | 135 | 282 | 667 | 665 | 314 | 102 | 107 |
| System Assy/Test | $ | 190 | 818 | 432 | 172 | 208 | 178 | 190 |
| Total | $ | 797 | 1874 | 2933 | 3038 | 3335 | 1268 | 1393 |
| per Flip-Flop | $ | 13.7 | 12.7 | 6.56 | 4.59 | 2.58 | 0.30 | 0.22 |
| as percent | % | 13.4 | 23.7 | 19.2 | 15.2 | 20.2 | 8.9 | 11.0 |

Source: See Tables II.4.11.2 to II.4.11.6

Given these details about each of the seven systems, we can apply the various cost models described earlier in this section, compute a total cost for each system, each year, and divide that cost by the number of flip-flops in the cabinet. The resulting system cost per flip-flop in each technology is plotted as a function of time in Figure 4.11.12; and for each technology the distribution of costs amongst the four elements of technology are shown in Figure 4.11.13. (Note in the latter figure that the height of each bar in each column is proportional to the fraction of total manufacturing costs represented by the dollar costs appearing in that bar.) Comments:

1. The total cost per flip-flop dropped by a factor of 50 between 1955 and 1974, as is shown at the bottom of Figure 4.11.13. (Note that the selling price per flip-flop of the systems shown in Table 4.11.7 dropped by a factor of twenty.)

2. The cost of a given technology typically falls rapidly during its early years, finally reaching a stable value from which it tends to rise. (See Figure 4.11.12.) The early fall occurs as a result of reductions in component and printed circuit costs; and those reductions are possible because, at the beginning of the technology cycle, manufacturers are struggling to gain control of component and PCB manufacturing operations, and yields are rising. (Note that this effect is accentuated during the first one to two years of a new technology because of the "manufacturing learning curve" of the organization which puts the system together. It takes time for people to learn how to handle, assemble, and test a new family of components, parts, and subassemblies; and consequently initial costs are substantially higher than ultimate costs. This effect is not included in our model.) Ultimately yields reach a stable point, and the increased cost of labor takes over and drives costs up.

3. Components and printed circuit boards together have accounted for over half of total cost in every technology. Packaging, power supply, and system assembly and test costs together have accounted for less than a quarter of the total, and more recently for less than 15% of the total. However, note that, for each technology, these proportions change with time. The cost distributions shown in Figure 4.11.13 are for the years shown, assumed to be the years near when each technology was in widespread use.

4. The advent of MSI has led to a revolutionary set of changes in the way processors are constructed. Referring to Table 4.11.8, we see the number of flip-flops in a cabinet has increased steadily from 58 to over 6200 in twenty years. All systems except the last two were constructed of relatively small modules, and the modules' arrangements were chosen so that relatively few types of module, each fairly general in applicability, could be used to construct the systems. The uniqueness of a design, then, was in the way the backwiring, interconnecting these modules, was laid out. The number of signal pins per flip-flop, also shown in the table, remained fairly constant.

As component and PCB technology progressed, we reached the point where substantial savings would result from the use of large IC's and big, complex modules. However, these modules could no longer be general-purpose ones—in other words, the uniqueness of the product was increasingly transferred from the interconnect on the backwiring to that on the integrated circuits and PCB's. The results, shown in Table 4.11.8, were great reductions in signal pins per flip-flop (hence backwiring labor) in power wiring per flip-flop, and in module assembly and test labor per flip-flop. And even though unit printed circuit board costs were much higher, PCB costs *per flip-flop* fell precipitously.

5. In Table 4.11.7 we see that a miniprocessor in 1973 contained 100 flip-flops; and Table 4.11.8 indicates that 100 flip-flops could be mounted on between one and 1.5 large modules. If memory were implemented using 1024-bit bipolar memory IC's, it is clear that a processor with 8,192 16-bit words would occupy three or four such modules. Such systems are typically packaged in small cabinets; and although there is less waste space in such cabinets, for reasons discussed earlier, the use of conventional packaging and power supply design techniques would lead to very high proportional costs for those system elements, compared to component and interconnect costs. As a result, manufacturers of small computers have been more imaginative than is my model: module mounts and cabinets have in effect been combined, for example, and power supplies may be mounted on a PCB which is also used to interconnect the modules. If we take the next step and implement the processor in a microprocessor chip, add some read-only memory, and use 4096-bit chips for internal memory, we can package a processor with 16 kwords of memory on a *single* module, and must be even more imaginative to reduce power and packaging costs.

We shall see that the increasingly complex modules have implications regarding design and maintenance costs. They also give rise to manufacturing problems: they are very difficult to test comprehensively; they are difficult to repair because multilayer boards are hard to repair; and they make engineering changes much more expensive than such changes were when they could be implemented by moving a backpanel wire.

6. Note that system cost has dropped for a great variety of reasons. We've seen already (Figure 4.11.5) how component costs per flip-flop have fallen. In Table 4.11.8 we see that power requirements per flip-flop have dropped by almost two orders of magnitude, obviously permitting a reduction in power costs per flip-flop. We also see the number of flip-flops per square foot of module area has increased by a factor of 85; and that fact, along with reduced space between modules and increased cabinet volume available because of reduced power requirements, has increased the flip-flop "density" from two to over 250 per cubic foot of cabinet volume, contributing to a reduction in packaging cost. Finally, reductions in components, PCB's, and signal pins per flip-flop have helped reduce labor costs, as have the changes in interconnect technology described by Figure 4.11.8.

7. The widespread use of microprogramming to implement processor control logic has implications not included in our simple model. In a microprogrammed machine, the bits in a read-only memory serve to replace some discrete gates, and potentially reduce component counts and system costs.

8. We can compare some of the ratios in our model to ratios obtained from other sources. The relationship between selling price per flip-flop (Table 4.11.7) and our cost data has already been noted. Table 4.11.8 indicates that power dissipation for the technologies in our model lies in the range of fifteen to forty watts per cubic foot of cabinet volume, or 51 to 137 KBTU per hour per cubic foot. These figures seem low compared with those for typical processors and memories, as shown in Figure 2.3.3. However, the data in that figure includes dissipation in the power supply itself,

where our model refers to D.C. logic power only; and the data in Section 2.3 includes memories as well as processors. Looking at processors alone, three of the ten listed in Table II.2.11.1 have power dissipation in the range 50 to 100 KBTU per hour per cubic foot, and another three are in the range 100 to 150.

Finally, we can compare our figures for labor cost with those published by the Department of Commerce in its analysis of the Electronic Computing Industry (SIC Code 3573–see Table II.4.10.1). According to the Department of Commerce, production wages in the industry are about ten percent of shipment value. According to our model, labor costs have ranged from nine to twenty-four percent of manufacturing cost (see Table 4.11.8). If manufacturing cost is fifteen to thirty percent of shipment value, the model figures convert to from 1.4% to 7.2% of shipment value, which appears to be very low. However, the Department of Commerce data covers all computer equipment including peripherals and memory, whose labor content is almost certainly higher than that of processors. In addition, the Department of Commerce labor costs include much labor (foremen, shipping and receiving personnel, quality control inspectors) which we include in overhead to what we call "direct labor".

9. One set of ratios identifies a critical problem area which has been brought on by integrated circuit technology. Note that component density per square inch of module area reached a peak with discrete silicon transistor technology and has since fallen off. The drop is caused by two factors: components themselves have grown in size as we moved from the TO-5 to the dual inline package, and as DIP's themselves have gotten bigger; and it has become increasingly difficult to lay out complex interconnections on printed circuit boards–even multi-layered, high-density boards.

The fall-off in density is thus caused by interconnect problems. Putting it another way, we are limited these days by topological difficulties–by the difficulty in finding a way to make a large number of electrical connections between pairs of points which could physically be located very close to one another. (The 90 IC's which occupy an average 100 square inch module in our MSI system together occupy about a square inch of silicon.) The integrated circuit designer himself has the same problem as he increases IC complexity–a subject we will treat in the next section.

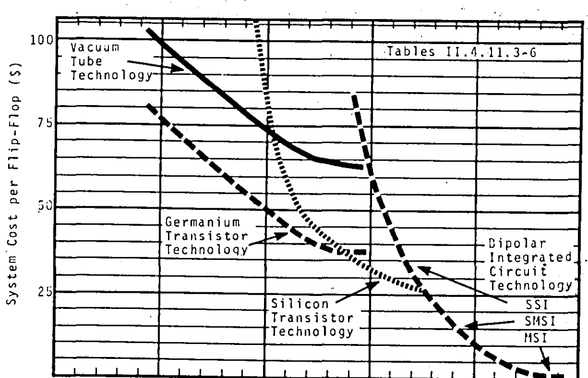



FIGURE 4.11.12 SYSTEM COST OF A FLIP-FLOP IN DIFFERENT TECHNOLOGIES I.

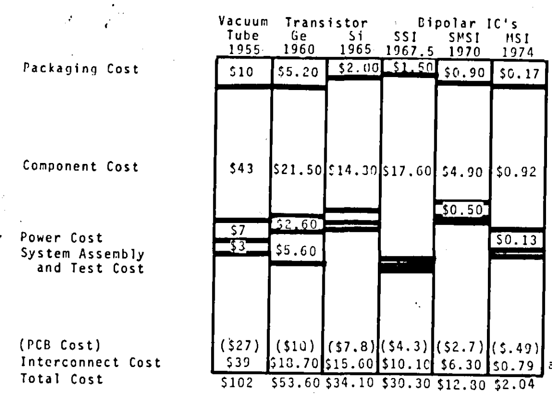



FIGURE 4.11.13 SYSTEM COST OF A FLIP-FLOP IN DIFFERENT TECHNOLOGIES II

## 4.12 INTEGRATED CIRCUIT COSTS ●

In the last sections we saw that the emergence and improvement of the integrated circuit has had a revolutionary effect on the cost of electronic logic systems, both because of the low cost of the components themselves, and also because their use has reduced the costs of power, interconnects, and packaging to a remarkable degree. As the "component" has evolved from a transistor to a flip-flop to a register to an arithmetic unit to a microprocessor, many design functions originally in the hands of the system manufacturer have moved to the province of the IC manufacturer. In order for us really to understand and appreciate the implications of this state of affairs, it is necessary that we have some understanding of the economics of IC design and manufacture.

The most important elements of an integrated circuit are shown in Figure 4.12.1. The component consists of a silicon chip one-sixteenth to one-half inch square which actually contains all the electronic circuit components, connected together; an interconnect system tying terminals on the chip to the external leads; a package which protects the chip, helps dissipate heat, and supports the chip and leads; and the external leads or terminals themselves, which connect the component electrically to other circuits, and simultaneously serve to support it mechanically. (The component shown, containing a single chip, is called a monolithic IC. For some purposes several chips may be mounted and interconnected in a single package, often with other miniature components. These "hybrid" IC's, generally used in low-volume, special applicaitons, will be briefly discussed later.)

The integrated circuit manufacturing process, shown schematically in Figure 4.12.2, starts with the growing of a cylinder of pure crystalline silicon which is then cut, sausage-like, into slices or "wafers" roughly 0.03 inches thick. Ten to fifty wafers undergo a series of processing cycles which create tens to hundreds of identical chips on each wafer, each chip containing tens to thousands of interconnected circuit components—transistors, resistors, diodes, etc. Five to ten process cycles are generally required to treat a wafer. In each cycle, a specially-designed mask is used to deposit photochemically a protective pattern on the silicon. The next steps in the cycle diffuse impurities into or deposit material on or etch material away from the area not covered by the protective material, and a final step removes the protective material so that a new cycle can begin, with a new mask. Each cycle creates a number of sub-circuit elements (e.g. transistor bases or resistor segments), a protective layer of some kind, or a metallic connection between previously-created elements.

When the last process step is complete, the wafer is inserted in a special tester equipped with probes. An operator positions the probes on the terminals of each chip in turn, and the tester performs an elementary test, marking any bad chips with spots of paint. The ratio of good chips to total chips on the wafer at this point is called the *wafer yield*, and is as we shall see an extremely important process parameter.

The wafer is now cut, and in subsequent manufacturing steps each chip (sometimes referred to as "bar" or "die") is handled individually. The good chips are mounted on and bonded to the header portion of the package (see Figure 4.12.1). Using a special tool and working with a microscope, a worker attaches a lead to each terminal on the chip and to the corresponding terminal on the header—he moves the tool into position directly above one terminal, presses a button, and the tool drops to the terminal, "welds" one end of the lead to it simply by applying pressure and heat, and then lifts away from the chip. The worker then moves the tool into position above the other terminal, and the tool repeats the operation, welding the other end of the lead and then cutting the wire so the process may be repeated. The mounted chip is then inspected visually and units with bad connections or damaged chips are rejected. The ratio of good chips to total chips inspected at this point is called the *packaging yield.*

The last steps in the manufacturing process call for the mounted chips to be capped, marked, and to undergo final test. For high-reliability (and high-cost) IC's, a cap is installed and the air is removed from the package before it is sealed. For lower-cost units, a plastic top is molded on. Automatic equipment is used for either operation. Furthermore, automatic equipment is used to feed the finished IC's into a tester which cycles each through an extended series of tests, rejecting any which fail. The ratio of good units to total units tested here is the *final test yield.*

To understand how IC manufacturing costs have evolved since the early sixties, when the first commercial units became available, we must first examine IC geometry and then must study the cost of each of the various steps in the manufacturing operation.

**IC Geometry.** As we shall see in a moment, the cost of an individual IC is very much dependent on chip size, and the cost per function is dependent on the number of circuits (gates, flip-flops, inverters, etc.) which can be packed onto a chip of a given size. We will therefore begin by studying the geometric factors which affect IC production.

Because the wafer is the unit handled in the critical first stages of production, wafer diameter is an important parameter. Process costs (masking, diffusion, etching, etc.) are independent of wafer size, so the larger the wafer, the smaller the process cost will be per unit of silicon area. Figure 4.12.3 shows the changes which have taken place in wafer size. The transistors fabricated in the late fifties were laid out on one-half inch wafers, the first IC's used one-inch wafers, and every four years or so since there has been an increase in wafer size. These changes are both expensive and disruptive for the plant which introduces them, for many tools, fixtures, and process units must be replaced or modified to handle larger wafers.

The number of chips which can be laid out on a wafer is strictly a function of wafer and chip size, and can be estimated using the formula shown in Figure 4.12.4, with the result plotted in that figure. The second term in the formula is a correction factor to account for the fact that some area around the perimeter of the wafer is necessarily unusable when one is attempting to lay out rectilinear chips on a round wafer. Note that, for a given chip size, this lost area becomes less important as the wafer grows larger—another advantage for the large wafer.

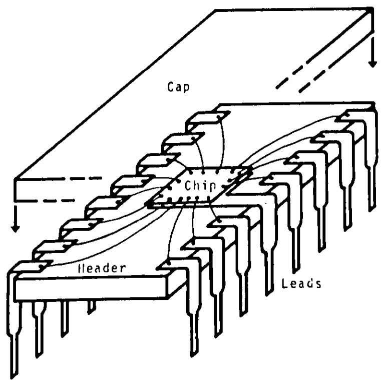



FIGURE 4.12.1 INTEGRATED CIRCUIT CONSTRUCTION

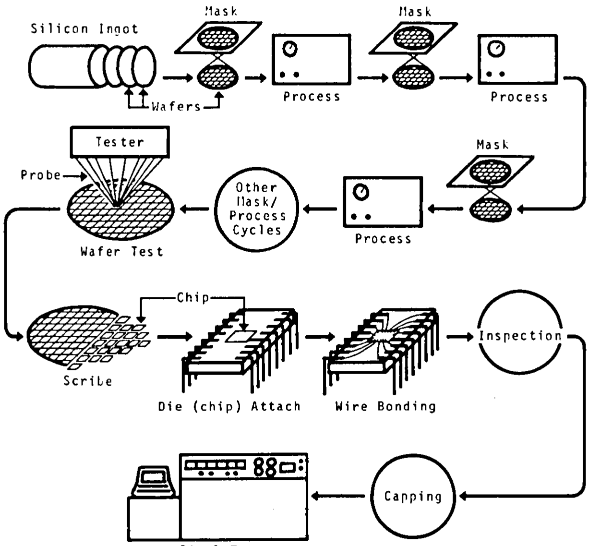



FIGURE 4.12.2 INTEGRATED CIRCUIT MANUFACTURING

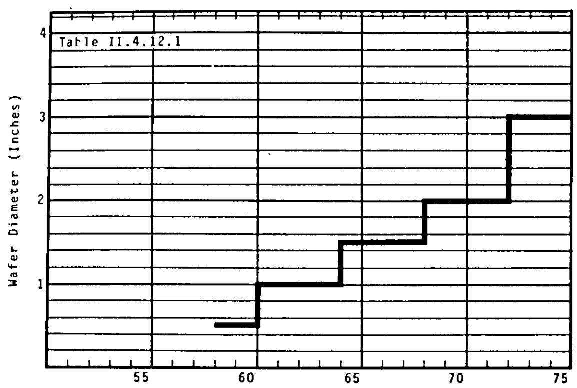



FIGURE 4.12.3 INTEGRATED CIRCUIT GEOMETRY I
TRENDS IN WAFER DIAMETER

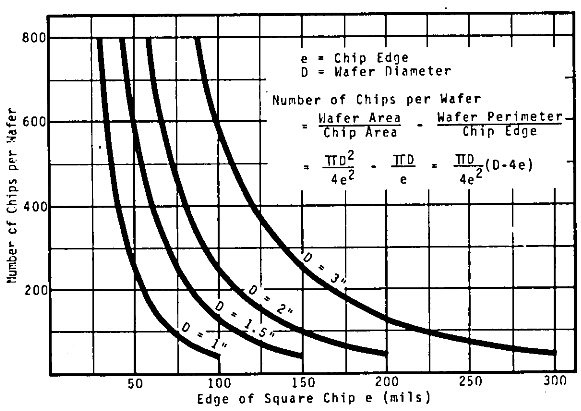



FIGURE 4.12.4 INTEGRATED CIRCUIT GEOMETRY II
NUMBER OF CHIPS WHICH FIT ON A WAFER

The next important geometric factor is the amount of silicon area actually required for a component. The average area has been dropping for a number of reasons—as a result of improvements in photo-optical techniques, in silicon materials technology, in component design, and in component power requirements. Figure 4.12.5 displays our assumed value for average area. Note that MOS components occupy considerably less silicon area than do bipolar components.

Not all of the area on the chip can be used for components. Part of the area is occupied by metallic lines interconnecting components, part by space necessary to isolate circuit components from one another, part by the "pads" or terminals to which the external lead wires are bonded, and part is simply wasted because of the topographical problems involved in laying out complex circuits. The ratio of total component area to total chip area is called the *stacking factor*, and has been increasing as indicated in Figure 4.12.6. This increase in layout efficiency is the result of several factors: larger chips mean that proportionally less area need be assigned to lead wire "pads"; multiple interconnect layers improve layout flexibility; more components per chip give the designer more layout options, and better design aids make it easier for him to select the best option. The combined improvements in stacking factor and component area have led to even more striking improvements in the effective area occupied by a component, as shown by the dashed lines in the figure.

Finally, if we take into account the number of components required to implement a given logic or memory *function*, we can compute the silicon area required for that function. The reciprocal factor of functions per square inch of silicon is plotted in Figures 4.12.7 and 4.12.8. Note that MOS circuits are substantially more dense than bipolar ones, and that MOS density is in the range of 100,000 functions per square inch. (The discontinuity in density which occurred between 1968 and 1970 is a consequence of the similar discontinuity shown in Figure 4.12.5.)

**A Cost Model.** With these various geometric factors in mind, we are ready to examine IC manufacturing costs. A simple model is shown in Figure 4.12.9, and is characterized by the three yields described earlier. If a wafer containing n chips is fabricated in the wafer processing operation, the number of good chips leaving final test is only n multiplied by the three yields, as shown by the diagram at the top of the figure. To compute a cost per chip, we must multiply the manufacturing cost in each of the three stages by the number of chips entering that stage, and then divide by the total number of good chips produced. The resulting calculations are shown in the rest of Figure 4.12.9.

Looking first at the formula for processing cost per chip, we see cost is basically a function of wafer cost, chips per wafer, and the three yields. The number of chips available per wafer is strictly a geometric function, as we saw in connection with Figure 4.12.4. The cost of a processed wafer is determined by the number of process cycles the wafer must undergo, by the degree of process automation available, and by the proportion of wafers which are spoiled by processing problems. Cost per square inch has generally been falling, as indicated by the dotted line in Figure 4.12.10. But wafer area has increased faster (as we saw in connection with Figure 4.12.3), so that wafer cost has risen as shown by the solid line.

Of the three yields, the first is the most critical and is plotted in Figure 4.12.11. A variety of models of wafer yield have been reported over the years (see, for example, MurpB64, NoycR68, and PricJ10), and the formula shown is a composite one suggested by R. Seeds. The 80% maximum yield is assumed constant with time, a general function of process problems. The coefficient k is the average number of defects per unit area on the silicon wafer. The formula is derived in a calculation which assumes that any chip with one or more defects is a bad chip. The defect ratio k changes from year to year as photoengraving technology and silicon crystal-growing technology improve, and the values shown were derived assuming a uniform improvement rate of 15% per year.

There seems to be no model for packaging and test yield. Both have improved over the years as difficulties were identified and overcome, and as tooling and techniques improved. An estimate of the net result is indicated in Figure 4.12.12. Obviously actual yields vary from organization to organization, and in general packaging and final test yields are not the same. But the trends shown seem reasonable.

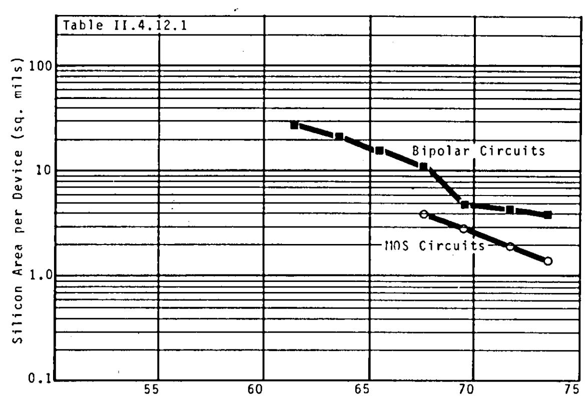



FIGURE 4.12.5 INTEGRATED CIRCUIT GEOMETRY III
TRENDS IN COMPONENT AREA REQUIREMENTS

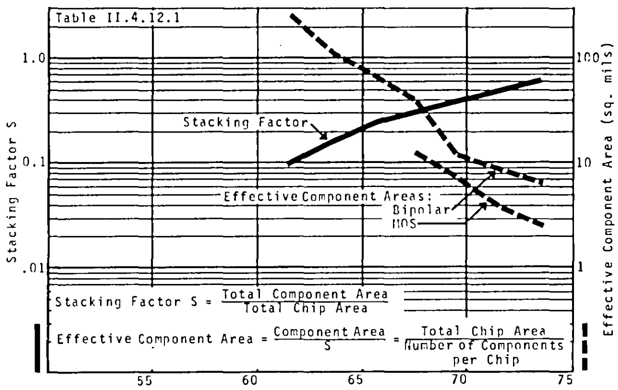



FIGURE 4.12.6 INTEGRATED CIRCUIT GEOMETRY IV
TRENDS IN LAYOUT EFFICIENCY

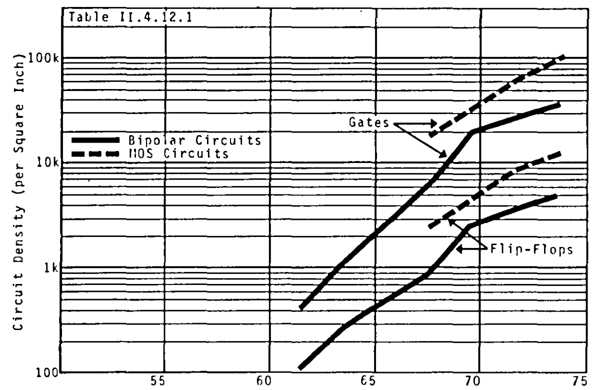



FIGURE 4.12.7 INTEGRATED CIRCUIT GEOMETRY V
LOGIC CIRCUIT DENSITY--GATES AND FLIP-FLOPS PER SQUARE INCH

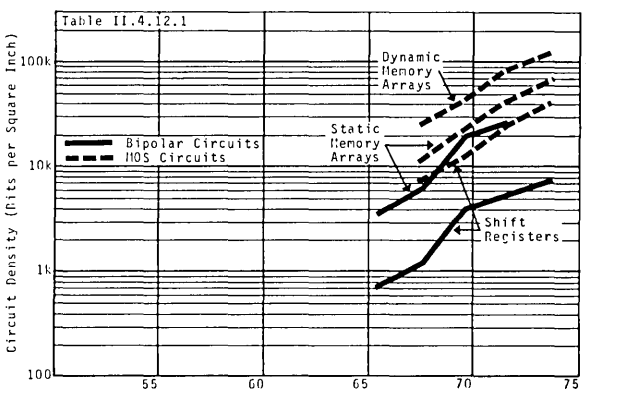
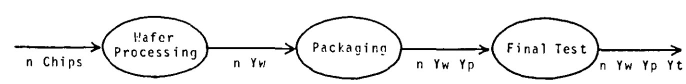



FIGURE 4.12.8 INTEGRATED CIRCUIT GEOMETRY VI
MEMORY CIRCUIT DENSITY--BITS PER SQUARE INCH




IC Manufacturing Cost per Chip

= Processing Cost + Packaging Cost + Test Cost

Processing Cost

$$= \frac{\text{(Cost of Processed Wafer)}}{\text{(Chips per Wafer)} \times \text{(Wafer Yield)} \times \text{(Packaging Yield)} \times \text{(Test Yield)}}$$

$$= \frac{Cw}{\frac{\pi D}{4e^2}(D-4e) \times \frac{0.80}{\left[1 + ke^2\right]^3} \times Yp \times Yt}$$

Packaging Cost

$$= \frac{\text{(Cost of IC Package)} + \text{(Cost of IC Connections)}}{\text{(Packaging Yield)} \times \text{(Test Yield)}}$$

$$= \frac{P + C}{Yp\ Yt}$$

Test Cost

$$= \frac{\text{(Cost of Testing Finished IC)}}{\text{Test Yield}} = \frac{T}{Yt}$$

Number of Gates per Chip

$$= \frac{\text{(Chip Area)} \times \text{(Stacking Factor)}}{\text{(Area per Component)} \times \text{(Components per Gate)}} = \frac{e^2 \times S}{Ac \times Ncg}$$

IC Manufacturing Cost per Gate

$$= \frac{Ncg\ Ac}{S\ Yt}\left[\frac{4\ Cw}{\pi Yp}\ \frac{\left[1 + ke^2\right]^3}{0.80}\ \frac{1}{D(D-4e)} + \frac{1}{e^2}\left(\frac{P+C}{Yp} + T\right)\right]$$

FIGURE 4.12.9 INTEGRATED CIRCUIT COST MODEL

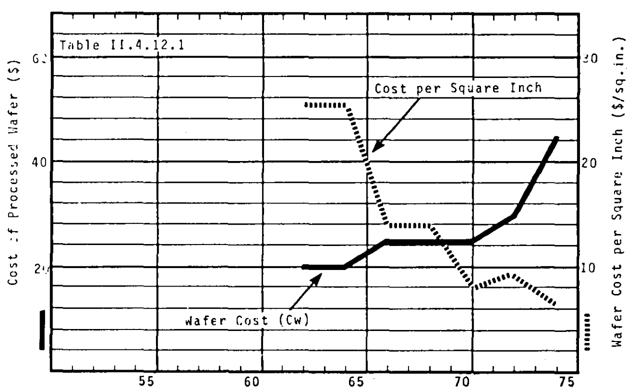



FIGURE 4.12.10 COST OF PROCESSED WAFER (Cw)

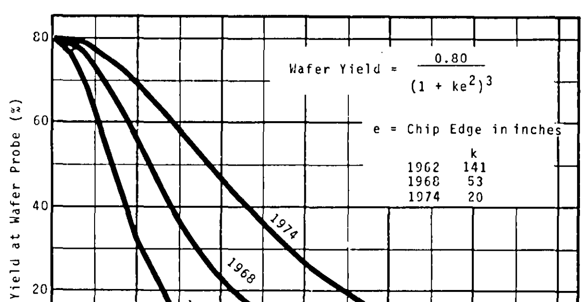



FIGURE 4.12.11 WAFER YEILD

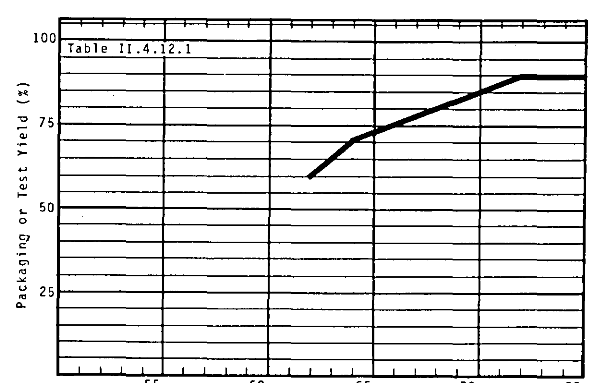



FIGURE 4.12.12 PACKAGING AND FINAL TEST YIELD

Packaging costs include the cost of the parts on which the chip is mounted, along with the cost of mounting the chip and connecting wires from pads on the chip to leads on the package. The parts cost is a function of the particular package used and especially of the production volume for that package. As is indicated in Figure 4.12.13, a variety of packages have been in use, and the number of pins available has been increasing. We will discuss the various package types in more detail in connection with Figure 4.12.20. The total time required to mount and connect the chip must include a fixed set-up time and an incremental connection time proportional to the number of IC pins to be connected. Improvements in tooling have led to a reduction in connection time as shown in Figure 4.12.14.

Similarly, improvements in test equipment, and particularly the development of mechanisms which reduce operator time by loading the IC's into the tester automatically, have led to major reductions in test costs, as shown in Figure 4.12.15. Though test costs have come down, test complexity has increased because of the great increase in the number of gates per IC. A single-gate IC of 1962 could be given a complete test, wherein all its input-output conditions were checked, in a few microseconds. A 1974 computer-on-a-chip might contain 1000 gates and 50 flip-flops, and a partial test which did no more than cause the flip-flops to step through all possible states would take about three years at 0.1 microseconds per step. Since it is no longer feasible to exhaustively test an IC (as it has never been feasible exhaustively to test a computer), some relatively simple set of exercises, consisting of a few million operations and requiring only a few seconds, is selected. Generally such tests are quite effective in weeding out faulty components.

We now have all the data necessary to employ the cost model of Figure 4.12.9. The first observation to be made is that, at any given stage in the history of IC development, there has been an optimum chip size which results in a minimum IC cost per gate. The optimum arises because of the fact that, at any given time, packaging and test costs are fixed, independent of chip size, while processing cost increases sharply with chip size because of the way wafer yield drops off. The key parameters are illustrated in Figure 4.12.16 for the year 1974. The number of gates per chip increases as the square of the chip edge (note the log-log scale). The total cost per chip is the sum of a constant packaging cost, which dominates chip cost for small chips, and a rising processing cost, which dominates the total for large chips.

The resulting cost per gate is plotted as a function of chip size in Figure 4.12.17, for the years 1962 and 1968 as well as 1974. For the same years, total chip cost and total number of gates per chip are shown in Figure 4.12.18. In both figures the optimum operating point is marked with a large dot, and its principal characteristics are noted. Comments:

1. Cost per gate fell by a factor of 2,000 between 1962 and 1974. The drop in price between 1962 and 1968 was greater than between 1968 and 1974 because most of the improvements in components per gate, packaging and test yields, and package costs took place in the earlier period. In addition, the connection process was assumed to have been carried out in the U.S. in 1962, and at some foreign location having access to lower-cost labor in 1968 and 1974. Such overseas assembly has been common since the mid-sixties, especially for the least complex, lowest-priced IC's.

2. The wafer yield at the optimum operating point is generally in the range 15%-35%. Incidentally, we must keep in mind that this yield, computed from the formula of Figure 4.12.11 and based on the defect ratio, is an average technology yield for all processes at all plants. A particular manufacturer starting production on a particular 125-mil chip early in 1974 may find his initial yields are only 5% to 10%. By analyzing the causes of the low yield and making appropriate changes to his process (and perhaps to the design of the chip) the manufacturer should be able to improve the yield to the 25% to 30% range by the end of summer. And continuing improvements may permit him to operate at 35% to 40% by the end of the year—with attendant reductions in his manufacturing cost for that part. In other words, the yield history for a particular part will show an improvement with time which starts well below the defect-calculated yield and may end above it.

3. IC production in 1962 was in a precarious state, as is clear from Figure 4.12.18. The minimum-sized chip, large enough for a single gate, was 50 mils on an edge, and a chip that size was on the steep edge of the yield curve (see Figure 4.12.11) where small perturbations in materials or process would cause rapid deterioration in yields and correspondingly large fluctuations in cost. That kind of situation is not at all unusual during the start-up phase of any new technology.

4. The price set for an IC in the marketplace is dependent on its cost, of course, but also upon the demand for the part and the availability of equivalent parts. If an IC manufacturer develops some new and very useful IC, he can and does offer it for sale originally at a price which will give him a very comfortable profit even while he is in the start-up, low-yield phase of production. The success of such a part will attract the attention of competitors, and in due time equivalent parts will be offered for sale at the same or at a lower price. When the production volume from these second sources reaches the point that customers can depend on them, the original manufacturer will have to lower his prices, and prices generally will fall to a level perhaps as low as twice the manufacturing cost from an original level four or five times that cost.

5. As was mentioned in connection with Figure 4.12.16, the cost calculations assume a fixed packaging cost. In fact, as the chip gets larger it reaches a point where package costs must increase, either to provide more signal pins for a complex chip, or to accomodate a physically large chip. To be consistent with the package prices shown in Figure 4.12.13, we should introduce a step increase in package cost for chips with edges longer than 130 mils. Since the optimum chip in 1974 was smaller than that, the omission of this step increase does not affect the results.

From the very beginning, IC's were used to store data. Individual flip-flops, then shift registers and counters, and then simple flip-flop matrices became available and were used by designers for various functions. Fast-access arithmetic registers, which had been unusual even in the most powerful computers because flip-flops were so expensive, became commonplace as integrated circuit flip-flops lowered the cost of storing a bit of information. And as IC technology continued to improve, it became clear that it would ultimately challenge the magnetic core for use in primary internal memory. In the late sixties ICs began to be used as cache or buffer memories, reducing the average time taken by a CPU to read from core memory by storing a copy of recently-used information. And starting in the early seventies, the cost of IC memory elements had fallen to the level that permitted manufacturers to offer them as alternatives to or replacements for core memory.

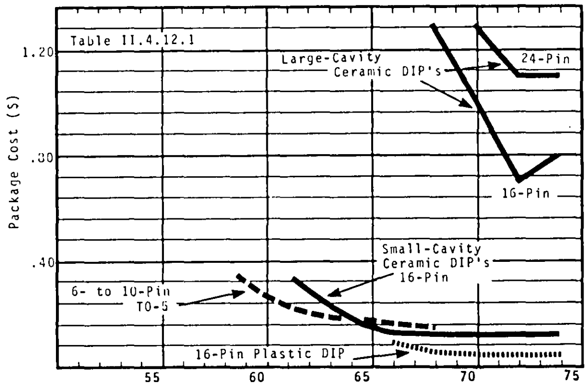



FIGURE 4.12.13 PACKAGE COSTS

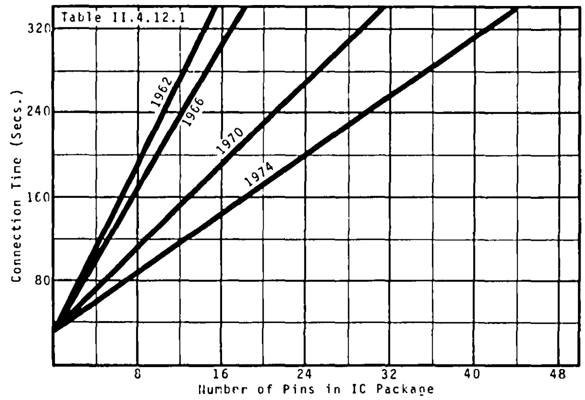



FIGURE 4.12.14 IC CONNECTION TIME IN DIFFERENT YEARS SET-UP, DIE-ATTACH, AND WIRE BONDING TIMES

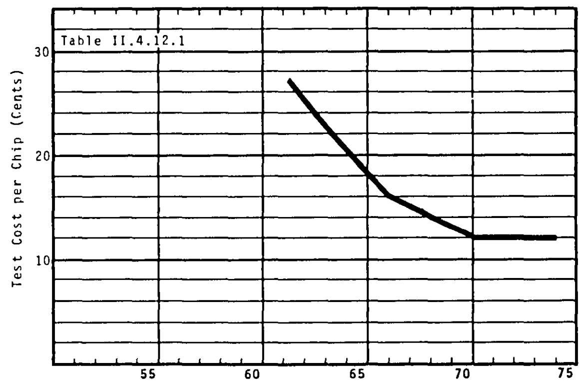



FIGURE 4.12.15 THE COSTS OF FINAL TEST

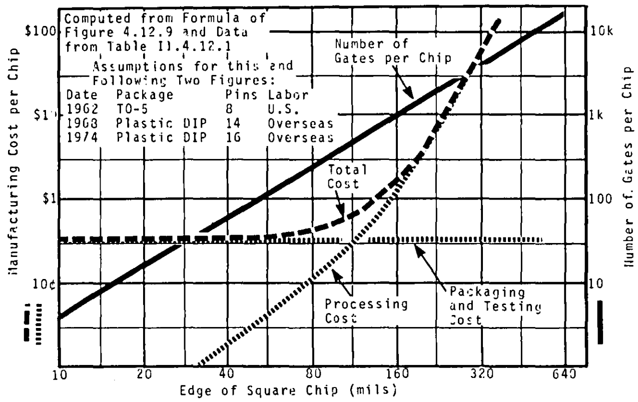



FIGURE 4.12.16 BIPOLAR IC COMPLEXITY AND COST (1974) I CHIP COST AND NUMBER OF GATES VS. CHIP SIZE

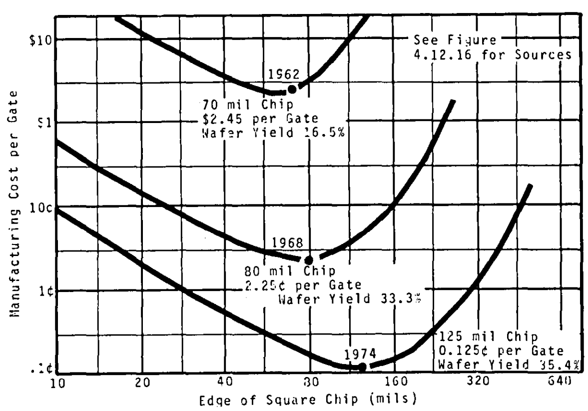



FIGURE 4.12.17 BIPOLAR IC COMPLEXITY AND COST II COST PER GATE VS. CHIP SIZE

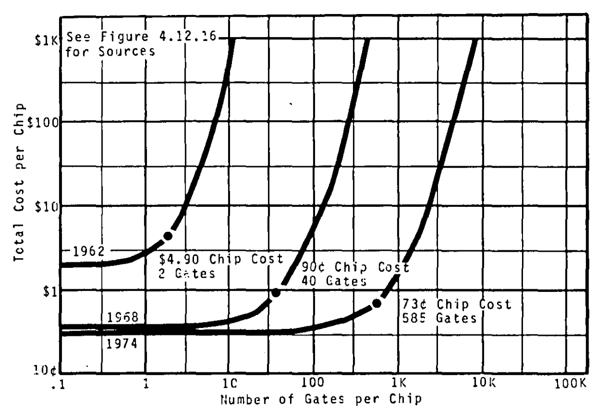



FIGURE 4.12.18 BIPOLAR IC COMPLEXITY AND COST III CHIP COST VS. GATES PER CHIP

The cost model of Figure 4.12.9, when applied to bipolar and MOS memory chips, gives us the cost curves of Figure 4.12.19. Although bipolar IC's were first used for registers and for buffer memories, it was the slower MOS elements which first were used directly as internal memory—by IBM, in the first System 370 processors. The first commercially-available IC which really competed with the magnetic core was a 1024-bit dynamic MOS memory chip, so called because data is stored as an electrical charge which must be periodically regenerated even when the system is not accessing data. As indicated by the figure, 1970 technology permitted the 1024-bit chip to be manufactured for around $4.50, with a corresponding *price* in the range of one cent per bit ($10.24 per chip). The bipolar 1024-bit chip reached that point about three years later, and by 1974 the 4096-bit MOS chip was available and its bipolar counterpart was on the horizon. Obviously the cost of a memory *system* includes much more than the cost of its components; but component cost is obviously a large factor in the cost of an IC memory system, and the price level of one cent per bit is very important. (See the IC memory system cost estimate at the end of Section 4.13.)

Though we have concentrated our attention on cost, there are obviously other critical parameters affecting IC design—factors we don't have time to discuss here. Switching speed is one, and power dissipation is another. MOS circuits are inherently slower and dissipate less power than bipolar equivalents. The reductions which have taken place in component size (see Figure 4.12.5) have been accompanied by reductions in power dissipation. Furthermore, increases in components per chip (a consequence of larger chips and smaller components) reduce average component power by reducing the proportion of high-power output circuits necessary to transmit signals out of a chip.

A third critical problem has to do with package design. As the number of components per chip increases, the number of input-output leads per chip tends to increase as well. (This is an effect we ignored in the analysis leading to Figures 4.12.16 and 4.12.18, where we assumed, for each year, a package having a fixed number of pins independent of the number of gates per chip. We will discuss the relationship between pins and gates when we treat partitioning, below.) Unfortunately, technology for packaging and interconnecting chips lags behind semiconductor technology. Two general approaches are possible.

1. If we put one IC in a package, we must find a way to increase the number of pins available and still have a package which is efficient in terms of volume occupied in the finished system. The design of a package to be mounted on a printed circuit board is affected by constraints on the design of that board, and generally those constraints limit the distance between pins to no less than 0.1 inches. The popular dual-in-line package satisfies this requirement, but has the disadvantage that, as the number of pins increases beyond 16, the board space occupied per pin increases. The situation is graphically illustrated in Figure 4.12.20, which shows how the "standard" TO and DIP packages compare with one another and with a variety of 1971-vintage proprietary packages (black squares) having various pin arrangements. Note that the large DIP packages are actually less efficient in their use of printed-circuit board space than the very early TO-5 cases. The efficient proprietary packages generally employ more than two rows of pins on 0.1 inch centers, or else use a single row or pins on one edge of a flat package which mounts perpendicular to the board—an arrangement which reduces board space requirements but increases the spacing necessary between boards. No new standard has yet evolved (1976).

2. Instead of interconnecting chips at the printed-circuit-board level, we can connect several of them within a package, and use the resulting very-complex assembly as a component. Of course, the resulting component must, in general, have more pins than each individual chip would have had, so in a sense we are merely postponing, not eliminating, the packaging problem in using this "hybrid" approach. The advantage is that the chips can be interconnected using some batch processing technique, and that the resulting complex components will require fewer pins per chip than the individual chips require. One disadvantage is that the resulting hybrid components are so expensive that it is awkward to treat them as components (when one fails, do we discard it or try to repair it?). The principal problem, however, is that it has proven difficult to develop a batch interconnect technique which is low in cost and has a high yield. And most systems manufacturers therefore eschew hybrids and stick to monolithic technology.

**System Considerations.** Our IC cost model has indicated that there is an optimum IC size for minimum cost per gate (Figure 4.12.17). If we were to incorporate that model into our model for *system* costs, from Section 4.11, we would conclude that, because interconnect, packaging, and even power costs, tend to be proportional to the number of IC's (i.e. packages) in the system, the chip size for minimum system cost is even larger than that for minimum gate cost. Furthermore, we know that IC manufacturers offer a "computer-on-a-chip", and that a variety of increasingly sophisticated hand calculators are obviously making good use of large and complex chips.

However, if we examine computer and peripheral products of the various system manufacturers, and the popular IC's offered by semiconductor manufacturers, we discover that the chips commonly in use in the early and mid seventies are much smaller than the optimum. Chip areas of 2500 to 10,000 square mils are much more widely used than the optimum area in the range of 15,000 square mils.

There are two principal reasons for this apparent anomaly. The first is the packaging problem referred to earlier. As the complexity of a logical circuit increases, so do the number of input and output signals required to connect to it. The relationship between complexity and number of signal pins is obviously not a proper mathematical function. It depends on the particular combinations of gates and flip-flops in the circuit. At one extreme is the arrangement in which every input and output from every gate is connected to a pin, so the designer has complete flexibility in his use of the logical circuits. If the gates average three input pins and an output pin, the total number of signal pins on a G-gate IC is obviously $P = 4G$. At the other extreme is an array of memory bits. Here we need an input data pin, an output data pin, a control pin to specify whether we want to read or write, and a set of address pins. The total signal pins are thus $P = 3 + \log B$, where the log is to the base two and B is the number of bits stored.

Most practical logic layouts lie between these two extremes, and various authors have employed a variety of formulas to estimate the relationship between these critical parameters. Some of the estimates are plotted in Figure 4.12.21. Comparing this figure with the data in Figure 4.12.18, we see that the 40-gate chip which was optimum in

1968 would require 25-50 input pins, while the 585-gate 1970 chip would require 100-250 pins. These estimates assume random logic, and are on the high side if we partition our design so that a specific and regular function is performed on a chip. But they do emphasize the increasing disparity between chip complexity and the technology available for interconnecting chips.

The second reason for the difference between optimum and practical chip sizes has to do with what has been called the Part Number Problem. Suppose we examine the variety of alternatives we might choose from in designing a 10,000-gate system. At one extreme (as illustrated in Figure 4.12.22) we might design a single very large chip containing all the system logic. We then have one part number, used once per system. Or we could be more conservative and design ten 1000-gate special chips, so our system would require ten part numbers, each used once per system. At the other extreme, we could opt for very simple, standard parts. We might for example use just four part numbers each containing one simple logical element—perhaps an AND gate, an OR gate, an inverter-amplifier, and a flip-flop. Our system would then require four part numbers, each used an average of 2500 times per system. As the figure indicates, very complex parts tend to be special and are not likely to be usable more than once per system; but as average part complexity decreases, we begin to find multiple-use chips (counters, encoders, decoders, multiplexers, segments of arithmetic units) which limit the number of different parts we need to construct the system.

It is this difficulty in partitioning logic systems so as to identify large chips of wide general use which has limited the acceptance of complex IC's. Very large memory chips have wide use and are thus exceptions. The complex calculator chips are sold by the millions and are therefore exceptions, and the microcomputer chip seems also to be destined to find widespread use. But in general the biggest chips to find widespread standard usage have been the counters, encoders, etc., referred to above, whose complexity is measured in the tens of gates.

The reason system and IC manufacturers seek to use and to produce standard parts has to do with certain IC development and manufacturing problems. Noyce (NoycR68) estimated the layout cost of a complex IC at $10 per gate, and pointed out there are various costs associated with generating test sequences for a special IC and with starting up production for parts produced in small quantities. Other estimates put total IC development costs at $20,000 to $50,000 per part (ca. 1970-1972). That expense must be incurred with two or more IC manufacturers if a buyer is to have multiple sources for these critically important components. Thus if a part is only used once per system, a system manufacturer must sell 20,000 systems to reduce his amortised component development costs to $2 to $5 on a component whose base price may only be $1 to $2.

Of course there are some systems which do sell in quantities of 10,000 or more. IBM's System 3 is an example. Cash registers, calculators, terminals, and many such high-volume products do contain specially-designed, very large and complex IC's. But the majority of GP and minicomputer products do not sell in quantities which justify development costs measured in tens of thousands of dollars for one-per-system components. And therefore, the more widespread use of LSI hinges on the development of additional standard and widely-usable logic configurations, on the evolution of small systems which will sell in quantities of 100,000 or more, or on a very substantial reduction in IC development costs. The microprocessor, and the research being carried out on logic design using cellular arrays are attempts to develop new large logic partitions. And most semiconductor manufacturers are working on design automation and other techniques to reduce development time and cost.

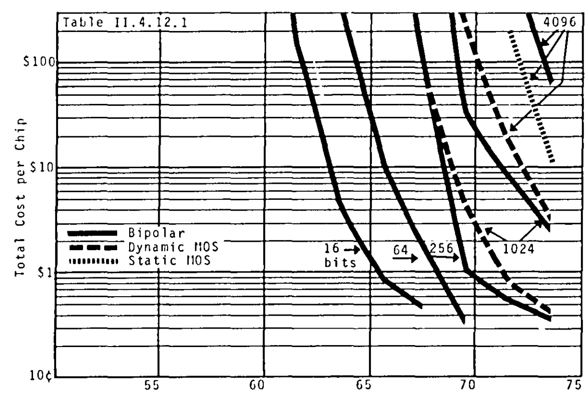



FIGURE 4.12.19 MANUFACTURING COSTS OF MEMORY IC's

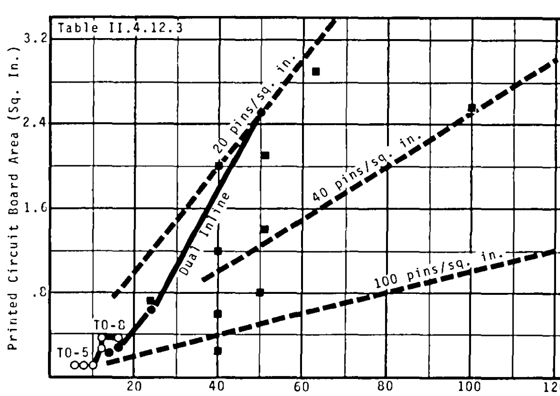



FIGURE 4.12.20 INTEGRATED CIRCUIT PACKAGES PRINTED CIRCUIT BOARD AREA REQUIREMENTS VS. NUMBER OF PINS

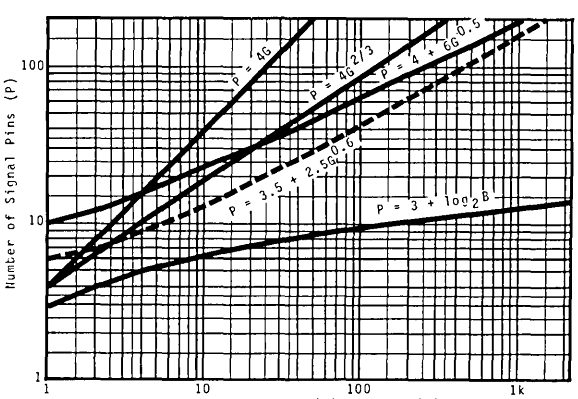



FIGURE 4.12.21 LOGICAL COMPLEXITY AND INPUT-OUTPUT SIGNALS

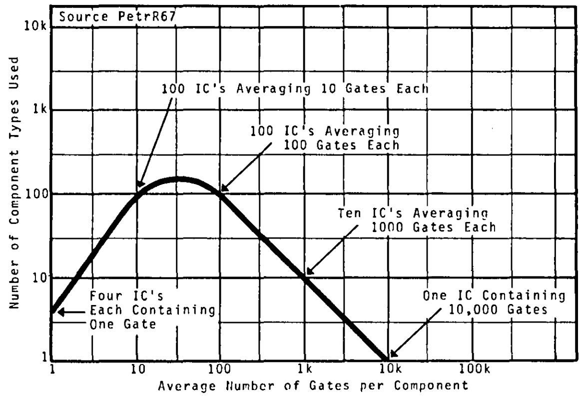



FIGURE 4.12.22 THE PART NUMBER PROBLEM ALTERNATIVES IN THE DESIGN OF A 10,000-GATE SYSTEM

## 4.13 MAGNETIC CORE MEMORY COSTS ●

### Introduction

When we were reviewing industry growth data in Section 1.2, we noted a striking increase in the sales of magnetic core internal memory, and observed that average internal memory size had increased continually, particularly since 1965 and the advent of the third generation of computers. When we reviewed unit and system performance in Chapter 2, we saw that core memory price and performance have both improved remarkably over the past 15 years, and our examination of the problems of improving system performance gave us some insight into the reasons for the increases in memory size.

The improvements in memory price and performance have come about as the result of a variety of changes in technology, and in this section we will attempt to understand what these changes were. Any dispassionate, objective observer looking at the minute magnetic core and the problems and costs obviously inherent in threading fine wires through thousands of small holes, would have to predict a very short life for the technology. It seems evident that a memory in which each bit must be individually created and assembled must soon be supplanted by one in which bits are somehow fabricated in batches. But despite the logic of these arguments, the core has lingered from triumph to triumph. The electrostatic storage tube, in which bits were stored as charges on the surface of a vacuum tube, was a batch storage technology used on many early computers. It was supplanted by the core memory principally because achievement of a storage density high enough to make the system economically attractive led to unfortunate decreases in reliability. In the intervening years, two batch magnetic technologies have seemed promising for high speed internal memory—the plated wire and the thin film. Both have reached commercial production, in UNIVAC and NCR systems, but neither has achieved the wide acceptance which is accorded a truly superior technology. The integrated circuit, another batch technology, is currently challenging the core, and toward the end of this section we will briefly look at IC memory costs.

One reason for King Core's long life is that his has been a very rich, complex technology, susceptible to improvement through changes in materials, procedures, tooling and test equipment, electronic technology, and system configuration. This complexity makes core technology difficult to describe, and in the pages which follow I have, as usual, had to neglect or simplify some things in the interest of providing as clear a picture as possible. I believe the result, while it lacks some depth, still accurately describes the principal factors which have helped the magnetic core prosper so famously. I will begin by showing how the core is used to store data, and will describe in some detail three configurations of cores and circuits which have been and are being used in memory systems. Then I shall describe five "typical" core memories representative of the years 1955, 1960, 1965, 1970, and 1972, will estimate the manufacturing costs of each, and will discuss the factors that influenced the various changes which have taken place.

A magnetic core is a doughnut-shaped object made of a special magnetic material. When sufficient electric current is passed through the hole in the doughnut, the core becomes magnetized in one direction; if the current is reversed, the core is magnetized in the other direction. When the magnetization changes direction, that change induces a current in any wire threading the core, and by sensing that current one can detect which direction the core had been magnetized and therefore whether a "zero" or "one" had been stored.

An individual core and its magnetization curve are shown in Figure 4.13.1. Look first at the curve, a plot of current, I, versus magnetic flux, F. Suppose the core starts in the state labelled "0" and that a current of magnitude 2I is passed through the hole. The state of magnetization goes from "0" through A to B, and as the flux changes suddenly (from -F to +F) a positive output current is induced in any wire threading the core, as for example in the "sense" wire of the figure. When the current is cut off, the magnetization state returns from B to "1" and we can say the core now is storing a "one". To store a "zero" we merely reverse the current, and the core state goes from "1" to D and E, and then back to "0". As the flux changes from +F to -F, a *negative* output current is induced in the "sense" wire.

In practice, the current 2I is supplied by *two* wires which thread the core and the pair of wires is used to select one core out of an array. If the two wires each are driven with current I the core switches as if one wire carried current 2I. If, however, only one of the drive wires is selected, and current I flows through the core, the core state moves from "0" to A (or from "1" to C) and then returns to state "0" (or state "1") when the current is removed. Such a half-selected core obviously doesn't change states.

In Figure 4.13.2 an array of cores is shown which makes use of this "coincident-current" selection process. Sixteen cores are arranged in a square, each linked by three wires: a horizontal X drive wire, a vertical Y drive wire, and a sense wire which links all cores in the plane. Let us suppose that core c is storing a "one" which we want to read. We supply current -I to the two wires, labelled Ix and Iy, which link core c. The core switches from "1" to E, a signal is induced in the sense winding, amplified by the sense amplifier (SA), and a "one" is stored in the flip-flop. If the core had contained a "zero", the -2I select current would have driven the core from "0" to E, no signal would have been induced, and the flip-flop would contain a "zero". The half selected cores a, b, d, e, f, g do not change state, being driven only to points D or G depending on whether they are storing "one's" or "zero's".

The selected core now contains a "zero" and its former content is stored in the flip-flop. The read operation is completed by rewriting the bit back into the core. To rewrite we must reverse the current in the X and Y drivers, and in addition turn on or leave off the inhibit driver depending on whether the flip-flop contains a "zero" or a "one". Since in the present example it contains a "one", the inhibit current is left off, and core c is driven from "0" to "1" via A and B. If it had contained a "zero", the inhibit driver would have added a third current -I linking all sixteen cores. As a result core c would have received only 2I - I = I units of current, and would not switch.

So far we have only discussed the sequence of events involved in reading a bit from a magnetic core. To store a new bit, we carry out exactly the same sequences of events, except that, after the read operation, when the selected core has been driven to "0", we transfer the new bit to be stored into the output flip-flop (overriding and therefore ignoring the bit which was just read out) and then carry out the rewrite cycle.

The number of X and Y drivers required to select a single bit in the plane of Figure 4.13.2 is proportional to the square root of number of bits in the plane (if the cores are arranged in a square array); and the plane thus makes use of the magnetic properties of a core to select a single bit economically as well as to store that bit. A memory *system* must of course store words, typically of eight to 64 bits, where all bits of a word are read and written simultaneously. There are basically three magnetic core system configurations for word storage and they are illustrated in Figures 4.13.3 to 4.13.5. All three are similar in that they provide a core plane for each bit in a word (all three systems shown have only two-bit words); a sense winding, sense amplifier, and flip-flop for each of these planes; and a selection system which makes use of the coincident-current effect described above to select a particular word during writing and/or reading. They differ in detail, as to precisely how this selection is done.

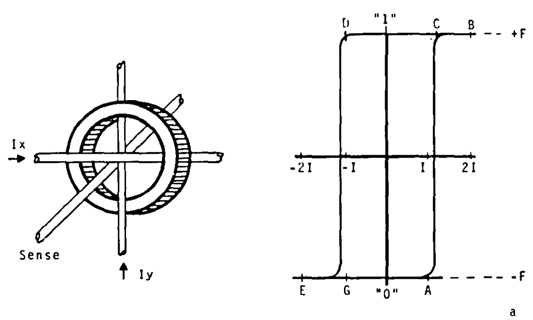



FIGURE 4.13.1 MAGNETIC CORE SWITCHING

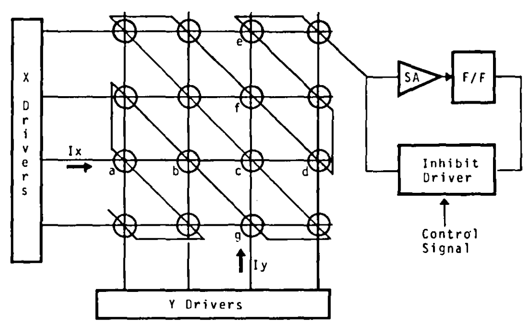



FIGURE 4.13.2 THREE-WIRE CORE PLANE WITH ELECTRONICS

The 3D system is the oldest and most widely used, and is shown in Figure 4.13.3. It provides one set of X and one set of Y drivers for the entire memory, and a given wire threading a row or column of cores in the X or Y direction in one plane threads the same row or column in all other planes, as is shown. The read selection process described by Figure 4.13.2 thus drives core c (for example) in each bit plane, and the word is read out into individual bit flip-flops. Writing is accomplished by use of an inhibit driver, again as described in connection with Figure 4.13.2. To write, we select X and Y currents so as to store "one" in the selected core in each plane, and in addition drive a third inhibit current in those bit planes in which a "zero" is to be stored.

A second memory configuration, called the 2D system, is shown in Figure 4.13.4. In this arrangement, the drive system is designed so that a Z driver supplies current to all bit cores in the desired word, and only that word. In addition, there is a sense-inhibit winding for each core plane. To read, we apply full current 2I with the Z driver and detect the resulting output signals on the sense lines. To write, we simply reverse current 2I to all bits in the selected word, and supply an additional cancelling half current I with the inhibit driver to those planes in which we want to write a "zero". Note that though the writing operation in a 2D system makes use of coincident-current selection, the read-out operation does not.

The third and final memory configuration to be described is known as the 2 1/2D system, and is shown in Figure 4.13.5. As with the 3D system, read selection is accomplished by adding currents from selected X and Y drivers. However, in the 2 1/2D system there is an X driver for each bit plane instead of one X driver for all planes. This makes it possible for us to eliminate the inhibit driver, and to write a "zero" or "one" by applying Y current to the column in which the selected core lies, but only supplying X current to the selected row in those planes where we want to write a "one".

The 2D and 3D systems have symmetric drive systems, so square arrays of cores are most economical. The 2 1/2D system, however, with an X drive for each bit in a word, is not symmetric, and a rectangular array which reduces the cost of the numerous X drivers results in lowest memory cost.

### Costs of Typical Systems

A magnetic core memory system includes the various elements we've discussed so far, and a few more. In our analysis of system costs, we will show how the cost of each of these elements has changed with time. The cost elements to be included, mostly shown in Figure 4.13.6, are:

**Magnetics.** The "stack", or assembly of wired cores suitably mounted. Includes the cores themselves, the labor for wiring them and attaching wire ends to terminals, the mechanical structure which supports and protects the cores, and testing and rework.

**Drivers.** The electronics which accepts a memory address as input and supplies current to the addressed set of cores for reading and writing data. Driver electronics includes: selection diodes, if necessary; components for address decoding and current switching; the printed circuit cards or other packages on which the electronics is mounted; test and rework. Inhibit drivers are included as well as X, Y, and/or Z drivers.

**Sense circuits.** The electronics required to separate signal from noise on the sense winding and to drive the flip-flop data register.

**Digital electronics.** The address and data registers and the control and timing circuits which accept data and address from an external source and control the sequence of internal operations which read and store information.

**Power.** Power supplies required for the drivers, sense circuitry, and digital electronics.

**Packaging.** The parts required to protect, support, and cool the assembled system.

**System assembly and test.** Each of the above elements itself requires assembly and unit test, whose cost is included in the cost of that element. The parts and labor required to assemble, interconnect, and test the elements in a complete system must of course be included in a discussion of total system costs.

We are now ready to review in detail the evolution of core system costs with time. In Table 4.13.1 I have listed the key characteristics of five core memory systems chosen as representative of typical production memories (not advanced or experimental systems) in the years shown. From the table we see that since 1955 system speed has improved by a factor of 20, memory sizes have increased by a factor of 20, smaller and smaller cores have been used, and core memory designers have made use of the various advances in electronic technology. We also see that 3D memory has dominated the scene, though the rapid reduction in electronic costs and a need for faster memories caused the 2 1/2D memory to be used starting in the mid-1960's. We will now examine each of the system elements of Figure 4.13.6 in turn, showing how its character and costs have changed and estimating the resulting total manufacturing cost for each of the five sample memories.

**Magnetics.** The principal cost elements of the magnetics are the costs of the cores themselves, and the labor costs of threading wires through the cores and of terminating them electrically and mechanically. Key parameters and costs for the magnetics portion of the five sample memories are shown in Table 4.13.2.

**TABLE 4.13.1 CHARACTERISTICS OF TYPICAL MEMORIES**

| | Units | 1955 | 1960 | 1965 | 1970 | 1972 |
|---|---|---|---|---|---|---|
| Cycle Time | ec. | 12 | 8 | 2 | 1 | 0.6 |
| Word Length | bits | 12 | 24 | 36 | 18 | 18 |
| Memory Capacity | words | 1024 | 4096 | 4096 | 16384 | 8192 |
| Total Capacity | bits | 12288 | 98304 | 147456 | 294912 | 147456 |
| Core Diameter | mils | 120 | 80 | 30 | 22 | 18 |
| Array Type | | 3D | 3D | 3D | 2 1/2D | 3D |
| Wires Per Core | | 4 | 4 | 4 | 3 | 3 |
| Array Dimensions | in. | 7.5x7.5x1 | 7.5x7.5x1 | 10x10x1 | 12x12x1 | 24x12x1 |
| Cores Per Array | | 32x32 | 64x64 | 128x128 | 288x256 | 384x384 |
| Arrays Per Memory | | 12 | 24 | 9 | 4 | 1 |
| Array Density | $bits/in^3$ | 18 | 72 | 164 | 512 | 512 |
| Electronic Technology | | Vacuum Tube | Ge | Si | IC | IC |

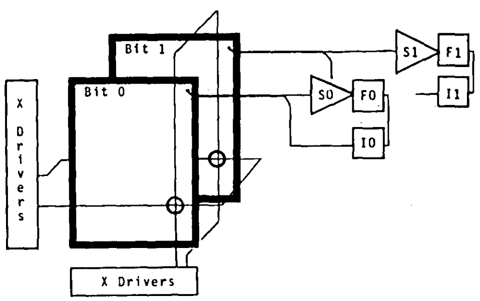



FIGURE 4.13.3 3D CORE MEMORY SYSTEM

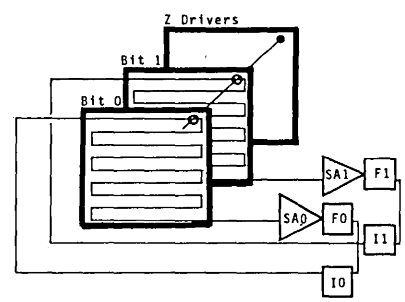



FIGURE 4.13.4 2D CORE MEMORY SYSTEM

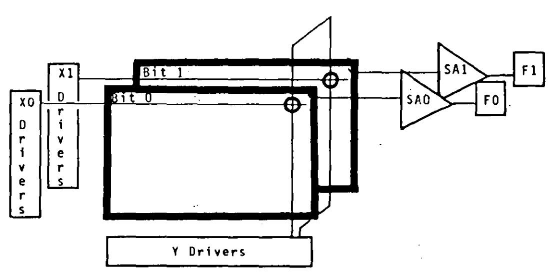



FIGURE 4.13.5 2 1/2D CORE MEMORY SYSTEM

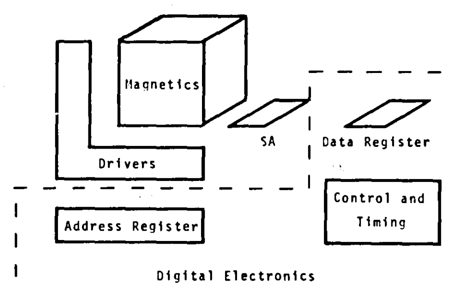



FIGURE 4.13.6 CORE MEMORY SYSTEM COMPONENTS

Let's first look at the cores themselves. Cores are typically manufactured by preparing the magnetic material as a powder, introducing it into a machine which compresses and forms it in a torus-shaped tool, sintering the formed doughnut in a furnace, and testing the result. The principal factors governing the large reduction in core costs from two and a half cents per bit to 0.04 cents per bit have been:

1. *Yield improvements.* In 1955 yield is shown at 20%. In fact there were often long periods, in those days, when a plant would "lose" the technology and be unable to produce *any* usable cores. The situation has improved steadily since then, and the current 80% yield at final test is achieved, in part, by using tests and inspections early in the manufacturing process to eliminate materials improperly prepared or formed. But the improvements have mostly come through better knowledge and understanding of the process and product.

2. *Production increases.* Volume production reduces unit costs by apportioning fixed costs over greater quantities. For example, labor costs include the expense of a substantial engineering and management staff which needn't grow much as output increases; depreciation cost is reduced as production rates justify multiple shift operations; and some of the "other" costs are similarly fixed—the cost of some utilities, and of maintenance materials, though not the cost of royalties. Large production rates also justify the development of better manufacturing tooling. For example, cores were originally pressed on a machine developed to manufacture aspirin tablets. Such machines cost about $5,000 each and produced one core per stroke at 100 strokes per minute. In 1969 a new machine was introduced which cost $20,000 but produced eight cores per stroke at 130 strokes per minute—a production rate increase of more than 10 times, at a cost increase of only four times. The new machine had the additional advantage that the pressing tool—the cavity and plunger which are filled with powder and actually form the core—lasted twice as long as did that of the old aspirin-machine tool.

3. *Reduction in core size.* Core diameter has changed from 120 mils to 18 mils, with the result that the number of cores which can be pressed from a cubic inch of material has increased from 4000 to 1.8 million. Since core density has changed but little, the weight of material required to manufacture a core has come down by a factor of over 400. Increasingly stringent material specifications have led to higher cost per pound, but the net result is that material cost continues to be a small proportion of total costs.

The other major magnetics cost is the labor cost of manufacturing an array of cores, and this cost is also summarized in Table 4.13.2. The cores must first be aligned in the proper configuration. Wires are next threaded through rows, columns, and (for the sense lines) diagonals of the array, and the ends of the wires are terminated (soldered) to terminals or printed-circuit connections. Finally the array is tested, repairs are made, and this test-repair sequence is repeated until the array is perfect. The principal factors which have led to the reduction in labor costs from 3.4 cents per bit to .04 cents per bit have been:

1. *Reduction in array size.* Figure 4.13.7 shows how the core arrays have evolved. In 1955 and 1960, each bit position in the memory was on its own array; by 1965 four bits were on an array; and by 1972 the number had been increased to 18. This improved density has been achieved in part simply because the cores themselves are smaller. In addition, it has been possible to reduce the spacing between cores from two diameters to one-half a diameter, partly because of the development of better alignment fixtures, but also because improved core and array uniformity have made it possible for designers to abandon a square layout of cores within the array (needed to help cancel readout noise) in favor of the much denser "herringbone" array (see Figure 4.13.8).

The increased core density has a favorable effect on circuit and packaging costs, as we will see later. Its effect on labor costs comes about because of the way wires are threaded through the array. A wire is first threaded on a needle slim enough and long enough to push through a row or column of cores. Wiring time basically depends upon the number of times the needle must be inserted, and the number of solder connections which must be made after threading. It is mostly independent of the number of cores threaded per insertion, simply because as that number has increased, the cores have been spaced closer to one another, forming a "channel" for the needle. Looking at the Y (vertical) wires in Figure 4.13.7, for example, we see the 1955 system requres 32x12 = 384 insertions, or about 31 insertions per thousand cores; and the 1972 system requires 3x128 = 384 insertions, or only 2.6 insertions per thousand cores. Terminations are reduced even more drastically. In the 1955 system, each Y wire, being on a separate subassembly, must be terminated at its two ends, and the subassemblies themselves must later be connected together. The total Y wire terminations are thus 2x32x12 for the individual mats plus 2x32x11 to connect the twelve mats together, for a total of 1472 or 120 terminations per thousand cores. In the 1972 system the Y wire threaded through bits 1, 4, 7, 10, 13, and 16 in the first column, then threaded back through bits 2-17 and finally again through bits 3-18 before being terminated. There are therefore only 2x128 = 256 Y terminations, or 1.7 per thousand cores.

2. *Configuration change from 4-wire to 3-wire.* The typical 1955-1965 memories were 3D, 4-wire systems. Performance requirements dictated, and circuit costs permitted competitive 2 1/2D systems in 1970, and the consequent elimination of the inhibit wire. As we shall see, the 1972 reduction in array size helped improve 3D system performance, and the invention of a practical circuit configuration made it possible to connect both sense and inhibit circuits to a common wire in the 3D system. Since each additional wire threaded through a core takes longer than the last (our calculations assume twenty-five seconds per insertion for the first wire and a 20% increase in insertion time for each additional wire, so that the second, for example, requires 30 seconds per insertion), a three-wire system has a substantial advantage over a 4-wire configuration.

3. *Reduced repairs per assembly.* In 1955 one bad core was found (and had to be replaced) for every 750 in an array. By 1972 the rate had gone down to 1 in 8,000, with a corresponding reduction in the cost of repairing and retesting. This improvement was a result of better core quality (arising from an improved understanding of core manufacture and from advances in core testing) and of improvements in core handling techniques.

4. *Overseas labor.* Table 4.13.2 shows that labor hours per thousand cores has dropped by a factor of 20 between 1955 and 1972 for the reasons described above. But we shall find that circuit costs per bit have fallen by a factor of 150 in that period, and meanwhile U.S. labor and overhead rates were increasing. The net result was that magnetics labor costs increased from less than 6% to more than 25% of core memory costs between 1955 and 1965, though labor hours

**TABLE 4.13.2 MAGNETICS COST OF TYPICAL MEMORIES**

| | Units | 1955 | 1960 | 1965 | 1970 | 1972 |
|---|---|---|---|---|---|---|
| **Cores** | | | | | | |
| Material | | MgMn | MgMn | Li | Li | Li |
| Material Cost | $/k | .20 | .20 | .10 | .05 | .03 |
| Depreciation Cost | $/k | 1.00 | .70 | .45 | .10 | .07 |
| Labor Cost | $/k | 3.40 | 2.40 | 1.72 | .41 | .19 |
| Tooling Cost | $/k | .10 | .10 | .10 | .05 | .05 |
| Other Costs | $/k | .30 | .20 | .15 | .10 | .05 |
| Subtotal | $/k | 5.00 | 3.60 | 2.52 | .71 | .39 |
| Yield | % | 20 | 30 | 40 | 50 | 80 |
| Total Cost | $/k | 25.00 | 12.00 | 6.30 | 1.42 | .49 |
| **Stringing** | | | | | | |
| Threading Time | hrs./k | 2.1 | 1.1 | .93 | .16 | .20 |
| Termination Time | hrs./k | 2.0 | 1.0 | .53 | .10 | .03 |
| Test/Repair Time | hrs./k | 2.0 | 1.5 | .80 | .38 | .09 |
| Total Time | hrs./k | 6.1 | 3.6 | 2.26 | .64 | .32 |
| Total Cost | $/k | 34.00 | 24.00 | 17.60 | .88 | .44 |
| **Frame** | $/k | 5.00 | 1.00 | .55 | .34 | .14 |
| **Summary** | | | | | | |
| Core Cost | $/k | 25.00 | 12.00 | 6.30 | 1.42 | .49 |
| Percent | % | 39 | 32 | 26 | 54 | 46 |
| Stringing Cost | $/k | 34.00 | 24.00 | 17.60 | .88 | .44 |
| Percent | % | 53 | 65 | 72 | 33 | 41 |
| Frame Cost | $/k | 5.00 | 1.00 | .55 | .34 | .14 |
| Percent | % | 8 | 3 | 2 | 13 | 13 |
| Grand Total | $/k | 64.00 | 37.00 | 24.45 | 2.64 | 1.07 |

See Table II.4.13.1 for explanations and for more detail. $/k signifies cost per thousand memory bits.

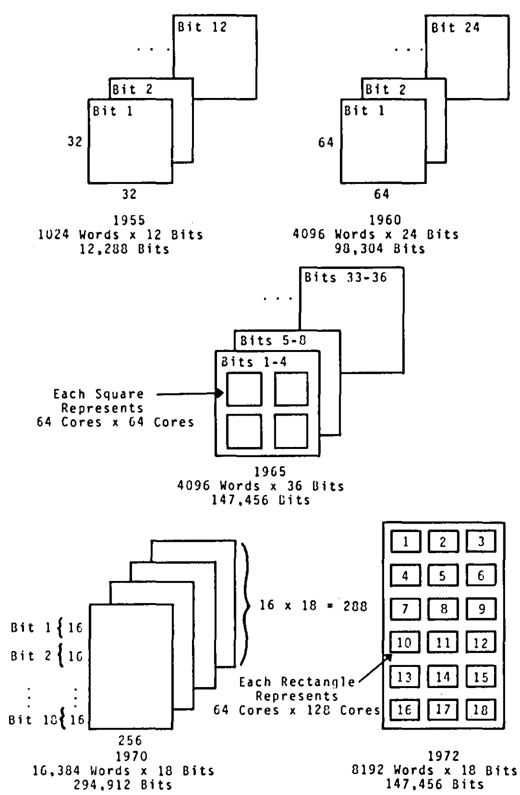



FIGURE 4.13.7 PHYSICAL LAYOUT OF BIT PLANES IN ARRAYS

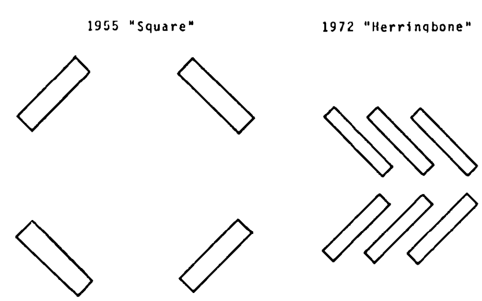



FIGURE 4.13.8 MAGNETIC CORE LAYOUT WITHIN ARRAY

per thousand cores was down by a factor of 3. To bring labor costs back in line, and to find workers able and willing to take on the tedious job of threading a rapidly increasing volume of core memories, much of the industry set up array manufacturing operations abroad—in Hong Kong, Singapore, Korea, etc. Although such operations had to be supported by smaller domestic groups which built prototypes and handled some repairs, the effective labor rate for array manufacture dropped from $7.80 per hour in 1965 to $1.38 in 1970 (both including overhead). Without that change, the cost per bit of the 1970 and 1972 systems would have been 2.7 and 0.70 cents, respectively, instead of the 2.1 cents and 0.38 cents shown in Table 4.13.4.

Another technique has for a long time been used by IBM to reduce array labor costs without taking production overseas. Under government contract IBM developed, and has since improved, a semi-automatic stringing tool. An early version of this machine enabled an operator to load cores and string 64 X and 64 Y wires in about five minutes—the threading being done 64 wires at a time. The use of such a machine in manufacturing the 64 x 64 array in 1960 would have reduced the stringing labor for X and Y lines by over 90% but (because the sense winding is the time-consuming wire) total stringing labor by only 20%, or $1.50 per thousand cores. Assuming present day machines still cannot handle the third wire, automatic stringing machines are even less effective in reducing total stringing labor for the large arrays of the 1970's.

The important aspects of magnetics costs are summarized at the bottom of Table 4.13.2. Note how the relative importance of the various elements has changed over the years, as magnetic costs per bit dropped from 6.4 cents to 0.11 cents.

**Drivers.** Two quite different techniques have been used to drive current through memory cores, and they are shown in simplified fashion in Figures 4.13.9 and 4.13.10. In each case we show the X drivers only, for a 4 x 4 array of cores—the same kind of driver circuits would of course be used for the Y dimension, and the same techniques are obviously applicable to larger arrays. The circuit shown in Figure 4.13.9 was used in memories of the 1950's and early 1960's, and makes use of the same coincident-current effect which selects the memory cores themselves. It requires a square-loop core for each of the lines to be driven—four in this case. Each of these driver cores is threaded with an X wire, a Y wire, and a third wire which is also threaded through a row of memory cores. When a row of memory cores is to be driven, one vertical and one horizontal driver core current source is switched on, and one of the four driver cores changes state. The resulting flux change induces a current in the third wire linking that core, and that current links the memory cores in one direction. A current in the opposite direction is produced by choosing the other pair of current sources linking the selected driver core. The cost of this driver was heavily dependant on the cost of the current switches and on the dimensions of the driver array.

The continuing push for improved performance and costs, and the development of suitable low-cost diodes led manufacturers to replace the coincident-current driver with the one shown in Figure 4.13.10. This circuit requires the same number of current sources as its predecessor, and uses two diodes on each driven line to prevent sneak circuits. But it eliminates a delay inherent in the switching cores; and in addition it reduces the number of wires connecting the memory array to the switch. This latter effect does not appear in the small 4 x 4 arrays of Figures 4.13.9 and 4.13.10. But in the 1960 64 x 64 array, for example, 128 wires must be run from the coincident-current core switches to the array; while if the electronics driver of Figure 4.13.10 were used, with diodes mounted on the memory core assembly, only 24 wires need be routed to the drivers.

Driver costs are detailed in Table 4.13.3. The remarkable reduction in costs is primarily attributable to:

1. The general drop in costs of electronics, already discussed in section 4.11. Various changes in technology—from vacuum tubes through transistors to different levels of IC's—account for the reduction in driver costs shown in the table.

2. The increase in array size. The number of driven lines in a square array of cores is equal to the square root of the number of cores. The number of drivers is proportional to the square root of the number of driven lines. The number of drivers therefore increases as the fourth root of array size, and large arrays reduce driver cost per bit.

3. The increase in the number of cores a driver can drive. Improvements in the switching speed and output power of transistors, and the reductions in drive impedance per core resulting from the more compact arrays, have made it possible to hold driver cost down as array sizes increased. Note, for example, an inhibit driver handled 1024 bits in 1955, and 8192 bits in 1972.

**Sense amplifiers.** The reduction in sense amplifier cost, from $175 each and $171 per thousand bits in 1955, to $1.50 each and $.18 per thousand bits in 1972, is shown in Table 4.13.3. In large part the reduction is simply a consequence of a general reduction in electronic manufacturing costs—the 1955 amplifier had 175 parts, the 1972 circuit is packaged two to an IC. However, while electronic technology was changing, sense amplifier specs were changing also. Increased memory speed led to requirements for greater amplifier bandwidths. Meanwhile improvements in core manufacturing technology resulted in cores having more and more uniform characteristics and less and less variability with temperature. And this, together with the increases we've seen in core packing density, simplified sense amplifier specifications by making the stack more and more uniform, so that the amplifiers didn't have to accomodate such a wide variation in output signal magnitude and timing. The improved uniformity also made it possible for a single amplifier to sense signals from longer and longer strings of cores, which of course further reduced the cost per bit of amplification.

**Digital electronics.** The cost of digital electronics is estimated by determining how many flip-flops are required and then by multiplying by the system cost per flip-flop (including gating) of components and interconnects as developed in section 4.11. For the 1965 system, for example, 36 flip-flops are required in the data register and 12 more in the address register to access 4096 36-bit words. Six additional flip-flops are required for timing and control—accepting addresses and data from and delivering data to the requested processor, and providing signals to turn on X, Y, and inhibit currents and to transfer the output of sense amplifiers into the data registers, all at the proper times. Using 1965 silicon transistor technology, these 54 flip-flops and their accompanying logic would each cost $30 for components and interconnects, for a total of $1620 or $11 per thousand bits.

**Power.** The drive, amplification, and digital circuits each of course must be supplied with power, and power requirements and costs are summarized in Table 4.13.3. Thinking first about drive circuit requirements, we realize that, for a 3D memory, only one X or Y driver is in operation at a time, but the inhibit drivers must operate in parallel so that drive power is mostly a function of the number inhibit drivers which must be "on" during writing, and of the power requirements and the duty cycle of those drivers. Drive current is dictated by core switching characteristics, and there has been little change in this parameter since 1960. Drive voltages have fallen, as the change was made from vacuum tubes to transistors, and as arrays have become more compact. Inhibit driver duty cycles are about 33% for 3D systems, but are nearer 100% for the 2 1/2D system, since the inhibit driver is the same as the X driver.

The move from vacuum tubes through discrete transistors to integrated circuits has reduced power requirements for digital electronics, as we saw in section 4.11. It has similarly affected sense amplifier power costs, as has the already discussed simplification in sense amplifier characteristics. Looking in general at the resulting power requirements summary in Table 4.13.3, we see that power costs per bit have fallen by a factor of over 100 since 1955, and that the reduction is due to reduced power requirements for sense and digital electronics, and reduced driver power per bit because of the increase in bits per inhibit driver.

**Packaging.** As we have seen, the volume occupied by magnetics, electronics, and power supplies all have been consistently decreasing since core memories were first shipped. (In Table 4.13.1, we see the number of bits per cubic inch in the magnetic array has risen from less than 20 in 1955 to over 500 in 1972.) As a result, packaging costs have dropped from $42 to $.38 for one thousand bits. Although the stack itself has been getting more and more compact as time has passed, the space per bit occupied by electronics has gone down even faster; and the stack, which occupied less than 10% of total space in 1955, occupied almost 40% in 1972.

**TABLE 4.13.3 ELECTRONICS AND OTHER COSTS OF TYPICAL MEMORIES**

| | Units | 1955 | 1960 | 1965 | 1970 | 1972 |
|---|---|---|---|---|---|---|
| **Drivers** | | | | | | |
| Driver Cost—each | $ | 20.00 | 15.00 | 10.00 | 3.00 | 1.00 |
| Transformer/Switch Cost | $/k | 13.00 | 2.50 | 4.30 | 6.83 | .43 |
| Diode Cost | $/k | | | .40 | 1.29 | .14 |
| Inhibit Driver Cost | $/k | 20.00 | 3.50 | 2.40 | | .12 |
| Total Cost | $/k | 33.00 | 6.00 | 7.10 | 8.12 | .69 |
| **Sense Amplifiers** | | | | | | |
| Sense Amplifier Cost—each | $ | 175.00 | 110.00 | 30.00 | 5.00 | 1.50 |
| Total Cost | $/k | 171.00 | 54.00 | 7.30 | .61 | .18 |
| **Digital Electronics** | | | | | | |
| Number of Flip-Flops | | 28 | 42 | 54 | 38 | 37 |
| Component & Interconnect Cost | $/FF | 82.00 | 40.00 | 30.00 | 11.20 | 2.90 |
| Total Cost | $/k | 187.00 | 17.10 | 11.00 | 1.44 | 0.73 |
| **Power** | | | | | | |
| Power Required—Total | mw/bit | 85 | 5.5 | 1.4 | 0.43 | 0.33 |
| Drivers | mw/bit | 20 | 1.6 | 0.8 | 0.37 | 0.24 |
| Sense Amplifiers | mw/bit | 39 | 2.4 | 0.3 | 0.02 | 0.03 |
| Digital Electronics | mw/bit | 27 | 1.4 | 0.3 | 0.04 | 0.05 |
| Total Cost | $/k | 29.00 | 2.00 | 0.94 | 0.50 | 0.23 |
| **Packaging** | | | | | | |
| Enclosed Space Required—Total | $ft^3$ | 22.2 | 21.5 | 10.1 | 10.1 | 1.72 |
| Memory Density | kby./$ft.^3$ | 0.09 | 0.74 | 2.38 | 3.17 | 9.30 |
| Total Cost | $/k | 42.00 | 7.00 | 2.35 | 1.84 | 0.38 |
| **System Assembly and Test** | | | | | | |
| System Test Time | man-wks. | 16 | 32 | 9 | 3 | 0.1 |
| Total Cost | $/k | 440.00 | 130.00 | 28.60 | 5.54 | .38 |

See Table II.4.13.2 for explanations and for more detail. $/k signifies cost per thousand memory bits.

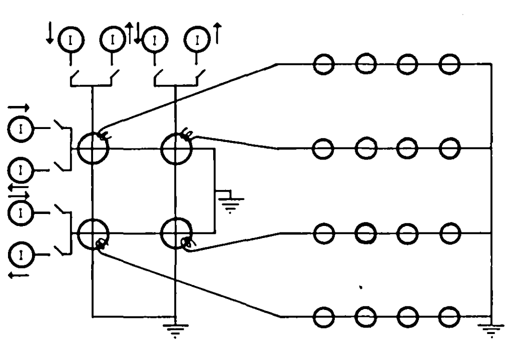


FIGURE 4.13.9 COINCIDENT-CURRENT DRIVERS

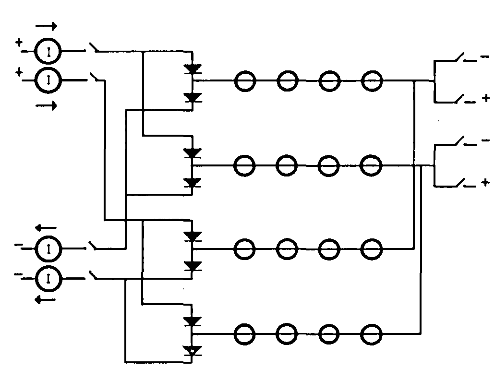


FIGURE 4.13.10 ELECTRONIC DRIVERS

**System Assembly and Test.** Until the early sixties, the assembly and the final test of completed core memory systems was a time-consuming and often frustrating job. Most difficulties arose from a basic design dilemma: the variability in magnetic cores, in array wiring, and in driver and sense amplifier circuits was not well understood, and engineers consequently were unable to predict worse case operating conditions, or to determine how circuit and magnetic parameters should be specified and tested at the subassembly level. The result was that early memories did not really have interchangable parts, and for each system a workable combination of drivers and sense amplifiers had to be chosen, by trial and error from a pool of circuits which themselves met their subassembly specifications, to match the magnetic "stack". The process was complicated by the fact that test equipment was primitive and required intervention by the test technicians; and by the occasional discovery of a stack or series of stacks which would not work with any combination of electronic parts, and which therefore had to be disassembled, modified, and retested.

As time passed, improvements were made in all areas. Better understanding of the problems led to better specifications and better test equipment for the key subassemblies and components. Higher production rates encouraged the development of faster, more automatic, and more comprehensive system test equipment. And of course the continuing improvement in core technology, and the increasing compactness of arrays, resulted in more uniform stacks, which, by 1972, were truly interchangable and would function with any combination of tested drivers and sense amplifiers.

**Summary.** In Table 4.13.4 and Figure 4.13.11 we summarize the cost data for the five memories, and can put the totals in perspective. Comments:

1. System Assembly and test costs have made the greatest changes, for reasons just mentioned. Until 1972, the test function was used to correct and compensate for design problems; and as those problems diminished the corresponding costs diminished from almost 50% of total system cost to less than 15%.

2. Of the hardware elements, sense amplifier costs have changed most precipitously. They represented nearly the largest single subassembly—almost one fifth of total cost—in 1955, and the smallest by 1972.

3. The cost of the magnetics and digital logic together account for about one half of hardware costs (excluding system assembly and test) in 3D systems. (In 2 1/2D systems, such as that shown for 1970, the large number of driver circuits required naturally lower the relative cost of magnetics and logic.) Since 1955, when the high cost of electronics and the small size of the memory inflated the digital portion, the high labor content of the magnetics has been a more and more important factor in system costs. As was mentioned earlier, this led to the overseas threading of cores as an expedient to keep magnetics costs a reasonable fraction of the total.

4. The costs of the driver circuits, of power, and of packaging have accounted for an increasing proportion of total costs as sense amplifier subassembly costs have fallen. These increases are generally attributable to the fact that the relative costs of driver circuits, including their power and packaging requirements, have increased over the years—today's require the same drive current that was needed in 1960 vintage memories.

5. In general, the continuing reduction in total costs, from 97 cents per bit to 0.4 cents per bit, is the result of a host of independent but interrelated changes and improvements—in materials, circuits, components, technique, tooling, and productivity to name a few. Probably the most important *single* factor has been the concurrent increase in bits per array and bits per square inch, which has led directly to reductions in the labor and material costs of magnetics, and indirectly to the reduction of test and electronic costs per bit and to improvements in performance.

**Integrated Circuit Memory**

We can make use of the data of Section 4.11 to estimate the cost of an integrated circuit memory. The calculations are indicated in Table 4.13.5 for the 1974 costs of a sixteen kilobyte memory (nine bits per byte), constructed from a 1024-bit chip and 4096-bit chip.

From Tables 4.11.8 and II.4.11.6 we find the system cost of a flip-flop in 1974 was \$2.04; and we can deduce that the support costs (i.e. all costs *except* those of the IC's themselves) for an integrated circuit were \$0.87. From Table 4.13.3 we know that a two-byte by 8 kword memory requires 37 flip-flops for addressing, data transfer, and control, and therefore that the control logic will cost about \$75 (\$2.04 x 37) in the system. The resulting cost *per memory IC* is \$0.52 for a memory constructed of 1024-bit IC's. Adding the \$0.87 required to provide power, interconnect, packing, and assembly/test to the IC, we find that these support costs plus the control unit costs amount to 0.14 and 0.07 cents per bit for the two memories.

We now must add the cost of the memory IC itself—a cost which has been falling rapidly, as we saw in Section 4.12. Estimating 1974 prices for static MOS IC's at \$2.00 and \$20.00, respectively, for the 1024-bit and 4096-bit versions, we compute a total memory cost at 0.33 or 0.56 cents per bit compared with the 0.375 cents for the same-size core memory of Table 4.13.4.

This analysis is surely subject to criticism. It assumes the IC memory is included with other electronics in a 24 cubic-foot cabinet. It assumes both the memory and address IC's can be mounted at a density of 90 IC's per 10-inch by 10-inch module. It assumes that the memory IC power level is comparable to average logic IC power. It assumes no special power system is necessary, and that system checkout is straightforward.

Errors in these assumptions are likely to add to the costs. However, the basic point is that support costs per bit are small compared with memory IC costs per bit, and the latter are falling rapidly (by March of 1976 the price of a 4096-bit MOS IC had fallen to \$6). With 16,384-bit chips on the horizon, will it be possible for magnetic core technology to keep up? It seems unlikely.

**Core Memory Performance**

As we saw in Section 2, the access time and cycle time of system internal memory is critically important to the raw speed of a processor. An organization planning a new family of machines generally starts by choosing a memory technology with some expected cycle time and access time, and then chooses a corresponding electronic technology compatible with that for the memory. The strategy for making this choice is very complex, but one key aspect of it might be mentioned here. Suppose first that we choose logic technology to match perfectly the currently available memory cycle time. Then we can design a system such that the limiting factor on speed is memory cycle time, and the logic is just fast enough to complete its processing in each cycle just before the memory is ready to accept another request. Such a balance of technologies would presumably be the most economical that could be chosen.

Next, suppose after shipping products of this kind for three years, we discover that rapid advances are being made in memory technology, and that we can buy a memory twice as fast as the previous one for less cost per bit. Because our electronic technology is presumed exactly to match the old memory technology, a faster memory would result in little gain in system speed; for as soon as we reduce memory cycle time, logic technology immediately becomes the limiting factor on system speed.

This story reminds us of two aspects of the system performance design problem. First, in designing a technology, it is always important to understand the various factors which limit or control system performance, and it is often desirable to pay a little extra to eliminate a secondary bottleneck in anticipation of later removal of the primary one. And second, internal memory performance is a critical factor in establishing system performance.

Magnetic core memory cycle time is the sum of a number of components: the time taken for logic circuits to decode the memory address and select a driver; the time for a driver to supply current to the array; the time for a selected core to change state; the time for the induced pulse to reach its peak in the sense amplifier; the time for the data register to settle down after receiving data from the sense amplifiers; and the time required for data regeneration, which involves a repetition of some of the above steps. Until about the mid 1960's, the high inductance and capacitance of the arrays and the relatively slow switching time of the cores themselves were large enough that they basically determined the memory cycle. However, as magnetics improved and arrays became smaller, memory cycle times reached one microsecond and more recently 0.5 microseconds, with the result that magnetics in a 1972-vintage memory typically contributed only about one fourth of the total cycle time—in other words, if the magnetics were infinitely fast, memory cycle time might go from 500 nanoseconds to 375 nanoseconds. And the memory designer, who in the late fifties and early sixties was pressed to squeeze every extra nanosecond out of the magnetics system, today finds himself trying to reduce electronic, wiring, and cabling delays.

### TABLE 4.13.4 CORE MEMORY SYSTEM COST SUMMARY

| | Units | 1955 | 1960 | 1965 | 1970 | 1972 |
|---|---|---|---|---|---|---|
| Magnetics Cost | $/k | 64 | 37 | 24.45 | 2.64 | 1.07 |
| Percent | % | 7 | 15 | 30 | 12 | 29 |
| Driver Costs | $/k | 33 | 6 | 7.10 | 8.12 | 0.69 |
| Percent | % | 3 | 2 | 9 | 38 | 18 |
| Sense Amplifier Cost | $/k | 171 | 54 | 7.30 | 0.61 | 0.18 |
| Percent | % | 18 | 21 | 9 | 3 | 5 |
| Digital Electronics Cost | $/k | 187 | 17 | 11.00 | 1.44 | 0.73 |
| Percent | % | 19 | 7 | 13 | 7 | 19 |
| Power Cost | $/k | 29 | 2 | 0.95 | 0.50 | 0.23 |
| Percent | % | 3 | 1 | 1 | 2 | 6 |
| Packaging Cost | $/k | 42 | 7 | 2.35 | 1.84 | 0.38 |
| Percent | % | 4 | 3 | 3 | 9 | 10 |
| System Assembly and Test | $/k | 440 | 130 | 28.60 | 6.29 | 0.47 |
| Percent | % | 46 | 51 | 35 | 29 | 13 |
| **Total Cost** | $/k | 966 | 253 | 81.75 | 21.44 | 3.75 |
| Without Overseas Labor | $/k | | | | 27.16 | 7.03 |

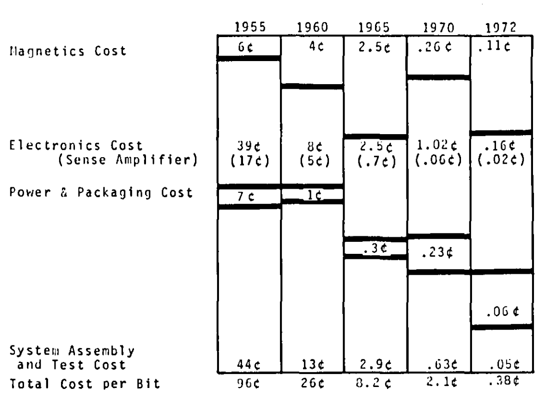



FIGURE 4.13.11 CORE MEMORY SYSTEM COST SUMMARY

### TABLE 4.13.5 INTEGRATED CIRCUIT MEMORY COSTS—16 KBYTES IN 1974

| | | IC Capacity 1024 bits | IC Capacity 4096 bits |
|---|---|---|---|
| **1974 Electronic Technology** | | | |
| System Cost per Flip-Flop | $2.04 | | |
| Cabinet Total Cost | $12,668 | | |
| IC Cost | $5,743 | | |
| Support Costs | $6,925 | | |
| Number of IC's | 7,954 | | |
| Support Costs per IC | $0.87 | | |
| **IC Memory System Cost** | | | |
| Number of Control Flip-Flops | 37 | | |
| System Cost of Control F/F's | $75 | | |
| Number of Memory IC's | | 144 | 36 |
| Control Cost per Memory IC | | $0.52 | $2.08 |
| Support Cost per Memory IC | | $0.87 | $0.87 |
| Control/Support Costs per Bit | | 0.14 cents | 0.07 cents |
| Memory IC Cost | | $2.00 | $20.00 |
| Total Cost per IC | | $3.39 | $22.95 |
| Total Cost per Bit | | 0.33 cents | 0.56 cents |

### 4.14 PERIPHERAL MANUFACTURING COSTS

The electronic portions of data processing equipment are fairly uniform in structure. Systems are constructed using sets of logical building blocks which can be designed and manufactured in a regular fashion, independent of the functions the equipment performs. Peripheral equipment, on the other hand, seemingly displays no such regularity, and it is correspondingly difficult to estimate peripheral manufacturing costs. We will in fact not attempt to present any estimate of absolute costs here, but instead will point out some of the similarities and differences which exist between the various peripherals.

A general model of a peripheral unit is shown in Figure 4.14.1, which attempts to identify a set of elements common to all peripheral equipment. We start with the media, on which data is somehow recorded. There must be a mechanism to hold and move the media, and transducers to convert signals derived from or required by the mechanism into signals required by or derived from the power converters, servos, and electronics. Because the performance of a peripheral unit is generally tied to rapid acceleration of the mechanism and/or the media, most peripherals require special power converters of some kind to supply bursts of energy to the transducers and thus to the mechanism. Special electronic circuits are also usually needed to amplify low-level signals from transducers, and to close servomechanism control loops between sensing and driving transducers. Finally, each peripheral or cluster of peripherals requires a set of conventional digital electronic logic circuits to interpret commands received from the processor, send appropriate control signals to the peripheral, and provide temporary buffer storage for in-transit data between peripheral and processor.

In Table 4.14.1 we see examples of the elements of peripheral technology, as applied to the most common peripherals. Many of the elements are obviously unique. The mechanisms in particular have very little or nothing in common with one another, and a manufacturing organization which masters the intricacies of assembling and testing a card reader/punch will not find that experience of much help in learning to manufacture, say, a magnetic tape unit. Even the elements which appear to be common between devices (solenoids, photocells, magnetic read/write heads, for example) often turn out, in practice, to be quite different from one another.

There have been no revolutionary changes in the electromechanical elements of peripheral technology comparable to the changes which have occurred in electronic technology as a result of the development of the integrated circuit. The card punch or magnetic tape drive or line printer which is marketed today is roughly as bulky, as heavy, and as costly as its predecessor twenty years earlier (see data in the tables of Part II, Chapter 2). In two general areas improvements have been striking: the performance of tape drives and moving-head files has improved markedly as a result of increases in magnetic storage density (see section 2.12); and electronics costs (of amplifiers, servos, controllers) are down as a result of IC and other solid-state circuit developments.

Peripheral equipment change is inhibited by the fact that peripherals handle media, and changes in media characteristics are constrained by the importance of compatibility (tomorrow's tape unit or card reader must be able to read today's tapes and cards), and by the difficulty involved in getting new standards accepted. Where really new media have been used, there have been striking changes in peripheral technology. The use of magnetic tape cartridges or cassettes has made it possible to devise a $200 tape unit, for example, and the use of heat-sensitive paper has permitted the development of extraordinarily simple character-at-a-time printers. But peripheral equipment technology as a whole has been and remains a set of fascinating and independent specialties.

## 4.2 Development Costs ●

### 4.20 INTRODUCTION ●

The growth of the computer industry has of course come about as a result of the development of a stream of new equipment, software, and services. In this section we will describe the development process, and will estimate development costs. We will primarily be interested in the cost of developing products, which are distinguished by the fact that each is distributed to and employed by a number of users. But we shall also examine the cost of developing applications, which include hardware or software systems or components assembled for a single specific user.

Before turning to a more detailed description of the Development function, it seems desirable to discuss the related subject of Research. *Basic research* is the investigation of fundamental properties of matter, energy, information, or organization. The mathematical analysis and experimental measurement of the motion of electric charges in solids, for example, was part of the basic research leading to the development of the transistor. Studies in semantics are part of the basic research behind new developments in computer languages. *Applied research*, on the other hand, is the exploitation of fundamental properties or techniques to the point where all the critical problems are solved and it is clear that the application of standard engineering or industrial practices, carried out in a development project, will lead to a product. Applied research is thus carried out with some product, or family of products, in mind. Studies of various specific semiconductor materials and impurities were part of the applied research leading to the development of the transistor. Note that the distinction between basic and applied research is blurred by the relative nature of the latter: today's basic research may turn out to be applied research for the product or application we invent tomorrow.

In the United States, most basic research is done under contract to the Federal Government, either in universities, or in government and industry laboratories, often in indirect support of applied research or development projects. Some basic research and a great deal of applied research is carried out in the very largest corporations, especially those in high-technology industries (electronics, communications, chemicals, etc.). Medium-sized and small companies, on the other hand—those with revenues less than $100M per year—are seldom able to afford any kind of research, basic or applied.

We will define *development* as an activity which identifies and documents the characteristics and component parts of some item (product or application) in sufficient detail that the item can be assembled and operated by others. We will assume the starting point for development is a detailed planning specification, defining the desired characteristics of the item to be developed. It can, however, be argued that the creation of the specification should be part of the development process too. Development is complete when a set of documents has been turned over to some other organization, and that organization has used them to assemble and operate at least one copy of the item developed. For a hardware product the development group supplies drawings and specifications to a manufacturing group whose responsibility it is to produce multiple copies. For a software product, the development group supplies program listings, operator instructions, and user documentation to a marketing group whose responsibility it is to sell and install multiple copies. For a software application program, the development group again supplies listings, instructions, and documentation, but this time to the operating group responsible for running the new program. In each case, we see it is the responsibility of development to produce documents, not products. Furthermore, to insure that responsibility for the product remains in one place, the development organization generally retains control over the documents it produces. That is to say, any changes in the documentation, at any time in the life of the product, whether made for the purpose of correcting design errors, or making the product cheaper or easier to produce or operate, must be approved by development; and manufacturing or operations is only permitted to use development-released documentation. A formal document control function, with change request forms, sign-off procedures, indexes identifying the latest approved version of each document, and a distribution system to insure that all interested parties get copies of the latest version, is generally an important adjunct to the development function.

For purposes of budgeting and control, development activities are generally organized in projects. Given a planning specification, a typical project will include the following activities:

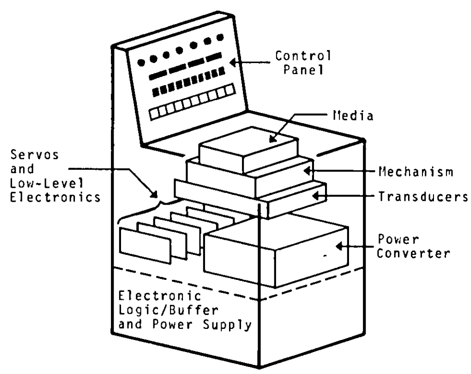



FIGURE 4.14.1 ELEMENTS OF PERIPHERAL TECHNOLOGY

**TABLE 4.14.1 PERIPHERAL EQUIPMENT TECHNOLOGY**

| Unit | Media | Mechanisms | Transducers | Power Converters | Servos | Low-Level Electronics |
|---|---|---|---|---|---|---|
| Punched-Paper Readers | Cards or Tape | Card bins, pickers, feed rollers, stackers. Tape guide and pinch roller. | Solenoids for paper drive. Photocells for detecting punched holes. | Electric, to drive solenoids. | None | Photocell amplifiers |
| Punched-Paper Punches | Cards or Tape | Card bin, pickers, feed rollers, stackers. Tape guide and pinch roller. Punch dies. | Solenoids for paper drive and punch dies. | Electric, to drive solenoids | None | None |
| Magnetic Tape Drives | Magnetic Tape | Tape reel spindle, bins, guides, pinch roller or capstan, take-up reel. | Magnetic, to read and write data. Photo-electric cells to detect tape position. Solenoid for pinch roller or pneumatic valve for capstan. | Electric, to drive solenoids. Pneumatic, for capstan and for tape bin control. | Control length of tape in bins between high-inertia reels and low-inertia tape drive. | Photocell, and magnetics read/write amplifiers. |
| Moving-Head Files | Disc Pack | Disc pack spindle, movable head assembly. | Magnetic, to read and write data. Optical, to locate head position accurately. Hydraulic piston or electric linear motor to move head assembly. | Hydraulic, for drive piston, or electric, for linear motor | Control position of head assembly. | Optical transducer and magnetic read/write amplifiers. |
| Line Printers | Continuous Forms. Format Control (punched) Tape. | Sprocket paper drive carriage. Embossed print type on drum or chain. Print hammers. Sprocket feed for format control tape. | Solenoids for drive carriage, print hammers, and format control tape feed. Photocells to read format control tape. | Electric, to drive solenoids. | None | Photocell amplifiers. |

1. Project plan. Provides a detailed plan showing how the development will proceed. Includes a schedule showing completion dates of critical sub-projects and documentation, a manpower plan, and a budget for labor and materials. The plan is used by development management to monitor project progress and to trigger corrective action if the project falls behind.

2. System Design. Describes in great detail exactly how the planning specification will be met. Distinguishes the principal components or parts in block diagrams and describes how the parts work together. Includes sequence or flow charts showing the timing of various functions. Describes the rules or algorithms to be used in the implementation. The various component parts identified in the system design document generally correspond (in large projects) to sub-assignments which are given to individual project members or groups, are identified in the project plan, and are often assembled and checked out separately before final system checkout.

3. Detailed Design. Implements the system design. Results in preliminary version of complete documentation describing how the product can be assembled or constructed.

4. Construction or Assembly. Provides a first complete version (prototype) of the product from the preliminary documentation.

5. Test. Compares operation of the product with operation as required by the planning specification. Includes correction of design errors or oversights, incorporation of indicated changes into the prototype, and re-test. Also includes revision of documentation.

6. Documentation Release. Supplies complete documentation to the organization(s) which will deliver, use, and/or maintain the product. Includes operating, technical, and maintenance manuals as well as basic drawings and listings.

7. Product Verification. Consists of an extensive and detailed test of the product, as constructed or assembled by the organization to which the documentation was released. Is conducted by an organization other than development (though with participation by the development organization), and includes actual or simulated user conditions. Generally results in detection of some design errors or oversights, not noticed in earlier tests, which require development to make changes in the released documentation.

These seven major development activities are listed roughly in the order they would be carried out in practice. However, the various tasks obviously overlap one another at various points. System design begins while the project plan is being drawn up, detailed design of some components starts before system design is complete, etc. Furthermore, a small organization may short-cut or even omit some of the functions, in the interest of economy and to speed up development. The project plan may be perfunctory, the planning specification may replace a formal system design specification (detailed system design residing in the designers' heads), documentation may be simplified, and the product verification eliminated altogether (on the grounds that system test is adequate). For small projects, in small organizations, with senior and experienced engineers in key positions, the resulting product might be little different from the product developed by an organization which followed the full development procedure as described. For the end user—the ultimate purchaser of the product—the difference might show up as a slightly higher error rate (because of the elimination of a comprehensive product verification test) and slightly reduced maintainability (because maintenance and technical documentation is minimal).

When the development project is complete, the development organization must continue to monitor the manufacturability and maintainability of the product, and must make modifications or corrections to solve problems identified by the manufacturing or customer service organizations—modifying drawings and releasing revised documentation as necessary. This sustaining activity peaks for a given product in the first few months after its release, and then falls off as the major problems are located and solved. It seems never to disappear completely, however. Computer hardware and programs are so complex that it would literally take centuries to exercise all combinations and sequences of data and functions; and the result is that design errors keep being discovered years after a product has been released.

Some minor product improvement is also carried out as part of the sustaining activity. However, major changes or improvements in product features, performance, or cost are generally treated as new development projects with their own specifications, budgets, schedules, and personnel.

Note that the sustaining function is generally a continually growing activity within a development organization. All products in use, or at least all those currently being distributed, must be sustained, and it doesn't take long for an organization to find itself sustaining ten or a hundred times as many products as it currently has under development. The cost and management of the sustaining function are thus formidable burdens.

All these introductory remarks apply equally well to hardware or software development projects, or to system projects which combine hardware and software development. We shall later comment in more detail on the very great similarity between projects which develop programs and those which develop (hardware) logical systems. However, there are differences as well as similarites, and it is therefore appropriate to treat hardware and software in different sections.

## 4.21 HARDWARE DEVELOPMENT COSTS ●

The development of a piece of data processing hardware—a processor or terminal or peripheral or controller or memory—includes two rather different activities: the development of a technology, and the development of one or more products based on that technology. By *technology*, I mean some combination of techniques, processes, materials, components, and assemblies whose specifications are well documented and which can realistically be manufactured and assembled in the non-scientific environment of a factory to produce reliable products, on schedule, meeting planned cost goals. A new material, an intricate mechanism, or a unique component, which an engineer or scientist can regularly produce, assemble, or process in his laboratory *cannot* be considered part of the technology available to a product design engineer until the manufacturing organization can reproduce it easily, in quantity, from drawings and other written documentation, using factory personnel.

A new organization must thus make a substantial investment in technology—an investment both in development and in manufacturing—to get its first product out of the factory. And an existing organization generally has to make a similar investment in technology if it is to introduce a new product substantially different (in cost, performance, or function) from its previous products. It follows that, in developing a technology, an organization should plan it with the idea in mind that it can form the basis for a family of products. The components, interconnects, power supplies, and packaging assemblies of an electronic technology should be chosen so they can be used to fashion a set of processors and controllers covering a wide performance range. The critical components in various peripheral products—print hammers for line printers, flying heads for discs and drums, linear actuators for moving-head files, optical hole-sensing sytems for card readers, etc.—should be designed and documented so they can be used with little or no change in a variety of printer, drum, disc, and card reader products.

The development tasks required to develop a hardware product are summarized in Figure 4.21.1. A planning organization of some kind works with management to provide technology and product specifications. The speed requirements in the technology plan are extremely important, for they determine what components may be used, and strongly influence the design of the interconnect system. Environmental specifications (temperature, humidity, elevation, electrical power voltages and frequencies) should be based on overseas as well as domestic conditions, if a product is to be used abroad. The expected production volume determines what can be spent on development or manufacturing for tooling or special parts. The product specifications included in the product plan state the functions required of the equipment to be designed. Reliability/Maintainability policy prescribes the worst-case failure rates and maintenance costs desired and expected, and expected product manufacturing costs are also indicated.

In the remainder of this section we will discuss support (overhead) costs, and then the costs of developing technology and products.

### Support Costs (Overhead)

We have previously pointed out that support functions vary from organization to organization, as do the accounting schemes employed to allocate the cost of these functions. So that we can provide some reasonable estimate of total development costs, we show in Table 4.21.1 a description of the possible level of activity required to support one development engineer. The technicians build and test rough models or breadboards and help test the prototype. The designers, draftsmen, clerks, and secretaries prepare and revise the documents which are development's output. The production workers fabricate and assemble the prototype. Materials are those required for breadboards and prototypes, and computer time is used for circuit design and for design automation—the name for a broad class of computer services which convert engineering designs into manufacturing and maintenance documentation. In estimating materials and computer time, I assumed they have remained a fixed proportion (25%) of the direct labor costs—the costs of enginering, designers, draftsmen, technicians, and production workers. That estimate is a very rough approach to a very complex situation. In 1955 there was virtually no design automation, and one required a dozen or more components to fabricate a flip-flop. By 1970, design automation had become critically important, eight or more flip-flops were included in a single component, and engineering productivity (as measured, say, by the number of flip-flops in a system divided by the number of weeks it took to design the system) had increased substantially. My man-week estimate shows materials and computer time costs per engineering man-week increasing by almost 90% (from $87 to $165) between 1955 and 1974 as a result of these various factors—but I can quote no study to validate those figures.

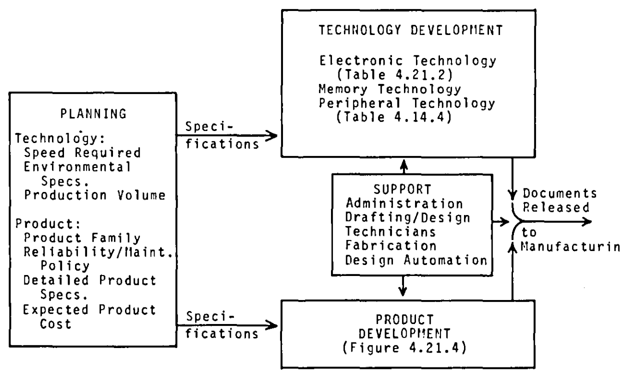



FIGURE 4.21.1 HARDWARE DEVELOPMENT TASKS

### TABLE 4.21.1 HARDWARE DEVELOPMENT OVERHEAD ●

| | Units | 1955 | 1960 | 1965 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|
| **Salaries and Wages** | | | | | | | |
| 1.0 Engineer | $/wk | 193 | 222 | 265 | 327 | 356 | 390 |
| 1.2 Designers, Draftsmen, Technicians | $/wk | 136 | 146 | 161 | 193 | 214 | 240 |
| 0.2 Secretaries, Clerks | $/wk | 14 | 18 | 21 | 26 | 28 | 34 |
| 0.2 Production Workers | $/wk | 20 | 22 | 24 | 30 | 34 | 36 |
| 0.4 Managers | $/wk | 116 | 133 | 159 | 196 | 214 | 234 |
| Subtotal salaries | | 479 | 541 | 630 | 772 | 846 | 934 |
| **Other Costs** | | | | | | | |
| Fringe Benefits—Rate | % | 8 | 10 | 12 | 14 | 15 | 16 |
| Cost | $/wk | 38 | 54 | 76 | 108 | 127 | 149 |
| Materials, Computer Time | $/wk | 87 | 98 | 113 | 138 | 151 | 165 |
| **Totals** | | | | | | | |
| Weekly | $/wk | 604 | 693 | 819 | 1018 | 1124 | 1248 |
| Monthly | $k/mo | 2.62 | 3.00 | 3.55 | 4.41 | 4.87 | 5.41 |
| Annual | $k/yr | 31.4 | 36.0 | 42.6 | 52.9 | 58.4 | 64.9 |
| Overhead Rate | % | 213 | 212 | 209 | 211 | 216 | 220 |

Source: Table II.1.4.3 for salary data. Personnel ratios are estimates.

**Technology Development**

In the introduction to this section, we mentioned the fact that two organizations developing the same product might employ two quite different project techniques, with one reducing development costs by short-cutting or omitting some functions, and the other following a fixed and elaborate procedure with great care. In technology development, the same alternatives exist and we shall discuss a range of costs for each development function. The minimum development choice will be made by an organization which is satisfied to operate well within the performance limits of existing technology, and has limited financial resources or expects to manufacture only one or a few units out of the new technology. The more elaborate policy will be used by a well-financed organization which expects a long, high-volume production run based on the technology, or by one which requires performance near the upper limits of that possible with current technology. A host of alternatives between the minimum and maximum give organization managers many fascinating and difficult decisions to make.

**Electronic Technology.** A summary statement of the tasks which must be completed in developing a technology, together with estimates of the engineering effort required to complete those tasks, is shown in Table 4.21.2. Note that the table is divided into two halves, and that the left-hand columns describe a bare-bones project, the right-hand columns a major engineering effort. Comments:

1. Wherever possible, engineers employ standard parts and assemblies, already developed and in production. A minimum effort, for a component part like a machine screw, resistor, or light bulb, requires simply that a vendor be selected and his part number listed. One disadvantage of that simple procedure is that the vendor may, for his own reasons, make a change in the part which affects the engineer's use of the part. For example, the engineer may choose a light bulb for a photoelectric system based on some measurements of light intensity from sample bulbs. For reasons of economy, the vendor may later change his bulb manufacturing process in such a way that initial light intensity is lower, or intensity drops very sharply during the first weeks of bulb life. If the bulb is bought by part pumber, the user has no advance warning that the bulb is unsatisfactory and no recourse to return the bulbs he can't use. If the bulb is purchased to an engineering specification (which for a photoelectic application, would include dimensions, light intensity, and wavelength requirements), then the vendor will reject an order received after he has changed the bulb, and if he doesn't the user can return the bulbs for credit if they fail to meet the specifications.

**TABLE 4.21.2 ENGINEERING TIME REQUIRED FOR ELECTRONIC TECHNOLOGY DEVELOPMENT ●**

| Technology Elements | Minimum Program | | | | Substantial Program | | | |
|---|---|---|---|---|---|---|---|---|
| | Tasks (Note 1) | No. of Elements | Time (Man-Months) Each | Time (Man-Months) Total | Tasks (Note 1) | No. of Elements | Time (Man-Months) Each | Time (Man-Months) Total |
| **Components** | | | | | | | | |
| Simple (Resistors, Capacitors, Relays, Light Bulbs, etc. Also Complex Parts —see below—whose specs are not critical.) | Select from units commercially available. List acceptable part numbers and manufacturers. | 50 | 0.02 | 1.0 | Select from units commercially available. Write purchase and test specs for each part type. Qualify two or more vendors for each part. | 200 | 0.5 | 100 |
| Complex (Vacuum Tubes, Transistors, Diodes, Integrated Circuits, whose specs are critical to product performance) | Select from units commercially available. Write simple purchase and test specs for each part. | 15 | 1 | 15 | Work with vendors to develop parts having special characteristics, either with new design or by adapting vendor's parts. Write specs and qualify two or more vendors for each part, as above. | 20 | 6 | 120 |
| **Interconnect** | | | | | | | | |
| Components (Connectors, Wire, Cables) | (Same as Simple components) | 20 | 0.02 | 0.4 | (Same as Simple components) | 40 | 0.5 | 20 |
| Techniques (Soldering, Wire-Wrap, Automatic Component Insertion, etc.) | Consult with Manufacturing | 1 | 0.5 | 0.5 | Evaluate and select equipment, write process procedures, insure that various component specs are consistent with interconnect techniques, work with manufacturing to debug initial production runs. | 1 | 20 | 20 |

**TABLE 4.21.2 ENGINEERING TIME REQUIRED FOR ELECTRONIC TECHNOLOGY DEVELOPMENT**

| Technology Elements | Minimum Program Tasks (Note 1) | No. of Elements | Time (Man-Months) Each | Total | Substantial Program Tasks (Note 1) | No. of Elements | Time (Man-Months) Each | Total |
|---|---|---|---|---|---|---|---|---|
| Printed Circuit Cards (General Specifications) | Select or adapt standard vendor cards. Make drawings and write specifications | 2 | 1 | 2 | Work with vendors to develop spec for high-density cards. Make drawings, and write procurement and inspection specs. Qualify two or more vendors. | 5 | 3 | 15 |
| Inter-Cabinet Cables | (Same as Simple Components) | 2 | .02 | .04 | Design cables to match technology impedance and bandwidth requirements. Provide assembly drawings | 5 | 3 | 15 |
| **Packaging** | | | | | | | | |
| Cabinet, Module Mounts and Cooling System. | Select or adapt standard vendor cabinet & chassis. Design necessary fittings for power supplies, cables, etc. Provide necessary procurement and assembly drawings. | 1 | 2 | 2 | Design cabinets, cooling system, and chassis for high component density, adaptability, volume production, and distinctive appearance. Provide necessary procurement and assembly drawings | 2 | 12 | 24 |
| **Power System** | | | | | | | | |
| Power Supplies | Select or adapt power supplies, from units commercially available, to match technology voltage and power requirements. Provide procurement and test specs. | 2 | 1.5 | 3 | Design power system to match technology voltage and power requirements, and for adaptability and volume production. Provide fabrication and assembly drawings and test specifications. | 7 | 12 | 84 |
| **Circuit Design** | | | | | | | | |
| (Design of the plug-in modules used as logic building-blocks) | Identify needed circuit assemblies. Design and breadboard circuits, lay them out on printed circuit cards, fabricate and test prototypes, and provide assembly drawings and test specs. Write logic rules for use by project. | 10 | 1 (Note 2) | 10 | (Same as for Minimum-program circuit design.) | 20 | 2 (Note 2) | 40 |
| **Totals (Note 3)** | | 103 | - | 34 | | 300 | - | 438 |

Notes:

1. In general, each task includes the procurement, examination, and test of sample parts and assemblies. For the minimum program, this will be done as part of a product project—the technology will be developed at the same time as a product is developed, and the procured parts will be incorporated into the first model. For a substantial program, technology development will precede the development of a first product by two years or more, several samples of each element will be procured (at least one from each vendor), a variety of tests and measurements will be made, and some sort of trial assembly will be fabricated, which makes it possible for the development group to test the performance of all the elements, working in a system.

2. The number of logic circuits required for a technology, and the design effort necessary per circuit, both changed markedly with the introduction of the integrated circuit. The figures shown are estimates for vacuum tube and transistor technology. Circuit design for IC technology is more properly project- rather than technology-associated. See text.

3. The totals include circuit design tasks and therefore are not applicable to IC technology development. See Note 2.

2. Another disadvantage to the simple procedure of choosing a vendor and his part number is that the user has no protection against vendor problems. Suppose some unique part is designed into an assembly, and suppose the assembly is critically dependent on the cost of the part. Now suppose the vendor has a fire, or goes bankrupt, or is purchased by a competitor, or simply has trouble manufacturing the part. The result may be that the part is no longer available, or that its price increases substantially. In either event, it may no longer be possible or economical to build the assembly which includes that part.

A small manufacturer generally may decide to live with this problem, figuring he will either redesign or discontinue the product if the critical part is no longer available at an attractive price. A high-volume manufacturer generally will opt to avoid unique parts, to locate multiple vendors for each part, and to write purchase specifications which several vendors can meet. This has the additional advantage that the purchasing organization can request bids from the various vendors, and can place purchase orders with the lowest bidder or bidders.

3. The purchase specification for a part or assembly is of course given to the vendors and becomes the basis of a purchase contract–the vendor agrees to supply parts which meet the specification, in return for being paid for the parts. The *test* specification, in the other hand, is a private document supplied to manufacturing for their use in testing and inspecting parts as they are received from the vendors. This specification identifies the critical parameters for each part and describes how they are to be measured. It may also specify or refer to test equipment or tools to be used in making the measurements.

4. In designing an assembly, the engineer must take into account not only the nominal value of the critical parameters for each part, but also the worst-case values. To take a very simple example, suppose an assembly must contain a hole into which a pin must fit. Suppose the engineer specifies that the hole is to be machined with a diameter of 0.25 inches, and the pin is to be machined with a diamerer of 0.24 inches. If all holes and pins had exactly those dimensions, there would be no problem. But in practice, there are limits to the tolerances which can be held on machined parts, and the engineer is likely to be faced with a choice. If he opts for "worst-case design", he designs hole and pin so that, in production, every part fits with every other part. If he chooses "statistical design", he acknowledges that some (small) fraction of parts will be incompatible, so that occasionally workers on the assembly line will find that two parts do not fit together, and will have to try another pair. The situation is illustrated in Figure 4.21.2, which shows the distribution of part dimensions under three possible design strategies.

In practice, of course, the situation is typically much more complicated. In designing an electronic circuit, the engineer may have to take into account the tolerances on a dozen component values. In putting together a logic system, he may have to allow for tolerances on the signal delay time of 100 circuits. In fitting a pin to a hole, he must worry not only about the diameter of hole and pin, but also about the tolerances on the various dimensions that determine the location of the centers of the hole and pin. In each case, the choices made are determined in part by the cost of holding various tolerance levels–of doing very precise machining, of buying precision parts, of inspecting and segregating (and perhaps discarding) out-of-tolerance parts.

5. The technology design task broadly known as circuit design has changed more than any other during the past twenty years. It includes the job of choosing a particular configuration of components able to perform some required function, and (for our purposes) the job of designing a subassembly of components and interconnect elements which can easily be replaced for maintenance purposes. The task has changed because components have changed so radically: where the designer of clock circuits, for example, once started with resitors, capacitors, and vacuum tubes, he now starts with an integrated circuit which may contain the equivalent of hundreds of interconnected resistors, diodes, and transistors. As a result, the emphasis in circuit design has turned from the problem of choosing a component configuration to that of designing the replaceable subassembly; and the most difficult part of the design job, which once was computing component values to assure a reliable configuration, is now computing the most economic partition of components on replaceable modules. With vacuum tube and transistor technology, the replaceable modules had quite general functions, useful in many products, and their design could readily be accomplished as part of a general technology design effort. As integrated circuits have grown in complexity, the replaceable modules have correspondingly grown more complex. And because designers have not usually been able to find general applications for complex modules, circuit design has had to become project-oriented and its functions and costs have been more properly charged to product than to technology development.

The cost of technology development and the distribution of those costs among the various tasks, are summarized in Table 4.21.3. There is, of course, an enormous difference in total cost, and a significant difference in the distribution of those costs, between the minimum and substantial development efforts. Note that for the minimum program, about three quarters of the total man-months required are used to select and specify complex components and to complete circuit design. For the larger program, the total effort is more uniformly spread among the various tasks, though the largest is still the critical job of choosing or designing complex components.

In both halves of the table, I have assumed the development effort is that which would be required for a new organization, having no previous technology. The development of a new technology by an organization which already has one in production would be simpler and less costly, primarily because of the fact that many of the simple components (e.g., resistors, light bulbs, screws, etc.) would be usable in the new technology.

**Peripheral and Memory Technology** As is indicated by Figure 4.14.1 and Table 4.14.1, peripheral equipment technology is extremely varied, and there is little in common between one type of device and another. The development of peripherals correspondingly is performed by designers working in specific product-oriented organizations. In other words, there is no "Peripheral Technology Group" which supplies mechanisms and servos and power converters and so on for product development groups. Instead, a Moving-Head-File Development Group (for example) will be formed to design a family of products, and will include engineers versed in file technology (magnetic recording, linear activator, and servo technologies in particular) along with product design engineers.

The time required to develop peripheral equipment technology and a product is very much a function of the skill, energy, and especially the directly applicable *experience* of the designers. A half-dozen bright engineers, motivated by their possession of a financial interest in a small new company, and qualified by virtue of their having designed similar devices for other employers, can and have shipped their first magnetic tape unit or moving-head file within twelve months of the time they started a design project. Thus six engineering man-years, or some $300,000 in 1970 development costs (including the various supporting functions) represents a minimum figure for technology *and product* development for a major peripheral. A more nearly typical project in a large organization would take twice as many engineers twice as long. The difference between the six- and twenty-four man-year projects reflects differences in the skill of the engineers, the degree to which the product will have been tested before shipment, the extent to which development will have to participate in the manufacture and check-out of early units, and (very important) the hours per week worked by engineers on the two projects.

The development of a magnetic core memory technology and resulting products obviously does not require expertise in mechanism design. But in other ways it is similar to peripheral equipment technology development: it requires a cadre of experienced engineers, and a project ranging from six to twenty-four man-months in size. Integrated circuit memory technology is treated much like any electronic technology.

Two final comments complete our discussion. The first has to do with our emphasis on the importance of "experienced" engineers. If a product cannot be developed except by someone who has already developed a similar product, how did the first product get developed? Where do the "experienced" engineers come from? The answer is that first products are usually developed under government contract (as for example the plotter and the more recent trillion-bit memories were), or in the R & D departments of very large organizations (as the moving-head file was developed by IBM). Engineers from these development projects migrate to other organizations, where they develop improved technologies and incidentally train other engineers, and over a period of time experienced engineering talent has spread to a number of organizations throughout the country.

The other comment has to do with the way small organizations often handle, or rather avoid, the complexities and cost of peripheral and memory development. Small companies setting out to develop system products have often concluded that their limited resources should first be aimed at developing processors, software, and a system, rather than peripherals and memory. They therefore buy these latter products, or at least buy the key elements (the magnetics portion of a core memory, or the mechanism-transducer portion of a peripheral, for example) from other firms. Their own development effort is thus limited to the work required to devise specifications for the items bought, and to incorporate those devices into a finished system product. At some later time, as the company grows and prospers, it may design its own replacements for this purchased technology.

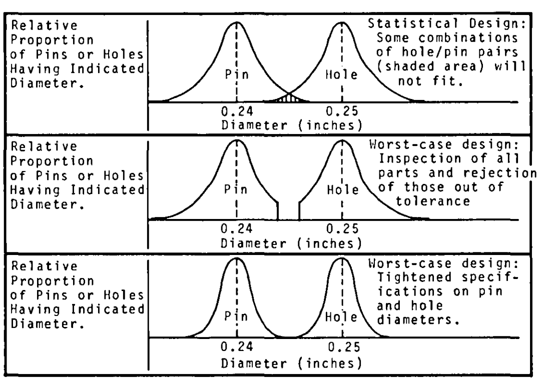



FIGURE 4.21.2 WORST-CASE VS. STATISTICAL DESIGN

**TABLE 4.21.3 TECHNOLOGY DEVELOPMENT COSTS**

| | Units | Minimum Program | Substantial Program |
|---|---|---|---|
| Total Effort | Man-Mo. | 34 | 438 |
| Percent Distribution | | | |
| Components-Simple | % | 3 | 23 |
| Complex | % | 44 | 27 |
| All Interconnect | % | 9 | 16 |
| Packaging | % | 6 | 5 |
| Power System | % | 9 | 19 |
| Circuit Design | % | 29 | 9 |
| Total Cost | | | |
| 1955 | $k | 89.1 | 1147.6 |
| 1960 | $k | 102.0 | 1314.0 |
| 1965 | $k | 120.7 | 1554.9 |
| 1970 | $k | 149.9 | 1931.6 |
| 1972 | $k | 165.6 | 2133.1 |
| 1974 | $k | 183.9 | 2369.6 |

The data is derived from Tables 4.21.1-2. For simplicity, I have assumed a uniform total effort during the entire time period, though the use of IC's since 1970 should move the circuit design task from technology development to product development—see Note 2 of Table 4.21.2.

**Product Development**

For reasons briefly mentioned in the above discussion of peripheral and memory development, we will confine this review of product development to the problem of developing digital electronic products—things like central processors, input-output processors, communication processors, or peripheral equipment controllers. We will begin by reviewing a schedule for the entire development process, and then shall concentrate on the tasks which must be performed to devise a specific product.

A very gross development schedule is provided in Figure 4.21.3, and a more detailed one in Figure 4.21.4. (The elapsed times shown are for a product of moderate complexity. We will discuss the relationship between product complexity, resource requirements, and elapsed time in a moment.) The gross schedule is drawn up based on the assumption that a family of products is to be produced, and shows details for development of the first member of the family. The process begins with a planning function which determines what markets the product line will aim at—that is, what classes of customers and/or applications the company wants to serve with its new products. From the market plan, technology and product specifications are derived and composed. (See Figure 4.21.1.)

Technology development begins as soon as technology specifications are firm. The plan as shown presumes a completely new technology is required, allowing eighteen months of technology work to be done before product development begins, and thus accommodating a good deal of analysis and experimentation on the part of the development organization. Product development can begin when technology basic design is firm, and when the product specification is complete. The production of first units from manufacturing commences during the development phase, and the first unit produced undergoes extensive tests as part of the development cycle. Active product marketing begins about a year before the first shipment of a system from manufacturing. Early in that year the engineering prototype is under test, and the company (and prospective customers) can compare its actual performance with the specifications.

The schedule and the above discussion describe these various activities as if they were independent functions carried out by separate agencies which work privately and simply communicate an end result to one another. In fact there must of course be a great deal of interaction between the organizations indicated in Figure 4.21.3. The marketing group obviously contributes to (and may in fact be responsible for developing) the market plan. Development people participate in production of the technology and product specifications. Manufacturing works closely with development to insure that the technology will be easy and cheap to produce, and that the manufacturing organization itself will be ready and able to produce products from it. And the maintenance organization (not shown) contributes to product specifications and runs final product test.

The detailed project portion of the schedule is shown in Figure 4.21.4. The seven activities described in the introduction to Section 4.2 are identified by numbers in parentheses. A development project of this kind is normally assigned to a manager whose first task is to prepare a plan and schedule which subsequently serves to help him coordinate all the tasks being performed, and to initiate corrective action if any portion is late or in trouble. Meanwhile system design begins and the planning specification, which describes the product in terms of the functions it is to perform, is converted to a structural concept defining hardware registers, describing their functions, showing data paths between them and listing the sequences of data transfers and manipulations which must be implemented to meet the product specifications.

The detailed design can begin when the system design is nearing completion. The designers implement the system design, distributing conceptual registers and data paths among real flip-flops and gates. The rules governing the use of these circuit elements—details like the time required for a signal at the input to a gate or flip-flop to have an effect on its output, the number of gates which can be driven by a flip-flop, and the physical size and power consumption of the circuit elements themselves—are supplied by the technology development organization in the form of a logic specification. As the work progresses, the designers reach a point where specific and unique combinations of circuit elements, not anticipated by the technology group, must be designed. The requirements for such circuits are handed back to technology, as shown, and in due course the necessary circuits are designed and returned.

During the latter half of design, drawings, layout, parts lists, wiring lists, and the other documents needed to specify the product so it can be built by manufacturing are created by the designers and processed by the documentation group—draftsmen, typists, and (increasingly in recent years) the design automation computer system. The technology development people also create drawings, of course, though that operation is not shown explicitly on the diagram. As the design nears completion, a prototype is constructed from these various released drawings. The design group then tests that prototype, starting with the simplest of functional tests and progressing through various stages to a complete system test, which attempts to create the heaviest workloads under the worst conditions using the most advanced and complex software that any user is likely to see. In the process of conducting these tests, the designers uncover a variety of errors, some in the basic design and some in documentation which improperly interprets or records the designer's plan. These errors must be corrected (both in the design and documentation, and in the prototype unit itself) and appropriate tests must be repeated to confirm that the "fixes" really work.

The manufacturing organization meanwhile prepares for a pilot run—the manufacture of five to fifty units (depending on the complexity of the product and the resources of the company) by factory people, on a special production line, overseen by manufacturing engineering. As soon as is feasible and reasonable, purchasing places orders for parts, especially those parts whose procurement requires a long lead-time, either because they are in short supply or because the vendor must make them especially for this product. At the end of product test, when all the documentation has been corrected and released, the pilot run begins. The first unit completed is used for a final series of extensive product verification tests, managed by the maintenance organization with development's participation. The tests carried out here are more stringent than those used in the earlier test, partly because there has been time to build on and improve the earlier tests, and partly because the maintenance organization has a different viewpoint from that of development and therefore will emphasize different things. For example, it may recreate situations customers have complained about regarding similar products, and will certainly have a critical look at the way maintenance and reliability features have been implemented. It will also conduct an environmental test to be sure the system operates properly within the tolerances, listed in the technology specification, on temperature, humidity, atmospheric pressure, and electrical power. Changes dictated by the results of these tests lead to further revisions in the design and documentation and of course require that modifications (identified as "rework") be carried out on the pilot units in manufacturing.

During the last months of the project, designers spend an increasing portion of their time on what might be called explanatory documentation—the technical manuals which describe precisely how the system works and which suggest how it is intended to be used and maintained. These documents are not needed for the pilot manufacturing run, but are employed by maintenance in the creation of training courses and manuals, and are useful to development later on, as new engineers take over the job of sustaining the product (i.e., making design changes dictated by subsequent problems which arise in actual use of the equipment).

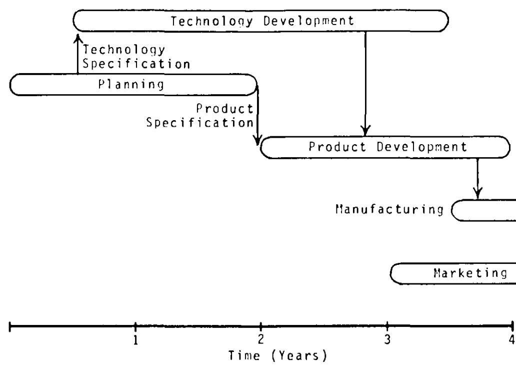



FIGURE 4.21.3 HARDWARE PRODUCT DEVELOPMENT SCHEDULE I
COMPREHENSIVE VIEW

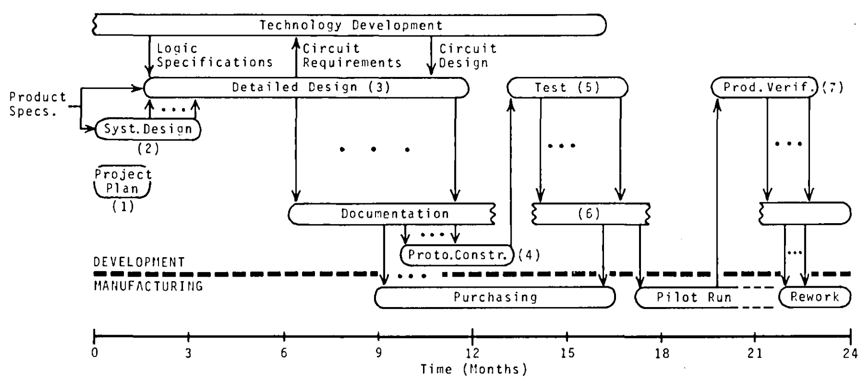



FIGURE 4.21.4 HARDWARE PRODUCT DEVELOPMENT SCHEDULE II
DEVELOPMENT ORGANIZATION DETAILS

**Product Complexity.** Development costs have changed during the past twenty years along with all the other costs associated with the production and use of data processing systems. Unfortunately, little has been published about the trends in hardware development costs, and in order to make a sensible estimate of the changes which have taken place it is useful to remind ourselves of the changes which have occurred in the products developed. Figures 4.21.5 and 4.21.6 are derived from the manufacturing cost data in Section 4.11, and give measures of the change in complexity of a processor selling for $100,000. The number of flip-flops has increased from about 200 to 9800, and the number of logic elements the designers must conceive of and interconnect has increased from 3,500 to 92,000. (Logic elements are the components or building-blocks used in detailed design. Until the advent of medium-scale integration, a logic element was simply a flip-flop or gate. But starting in the late sixties designers have made increasing use of complex IC's which provide the designer with registers, counters, adder segments, decoders, and finally arithmetic units and microprocessors. We regard each such component as a logic element, and thus find that they have increased less rapidly than have flip-flops—since complex MSI or LSI components typically contain many flip-flops.) Meanwhile, as shown in Figure 4.21.6, the physical size of the $100,000 system, as measured by the number of plug-in modules it includes and the amount of cabinet space it occupies, has been dropping as component and interconnect technology have progressed.

**Development Time and Cost.** A typical schedule showing how engineering manpower was deployed in a two-year-project to develop a $50,000 processor in 1974 is indicated in Figure 4.21.7. Generally speaking, a single group of engineers will of course handle the entire project: the system design people will continue with detailed design and diagnostic programming, will conduct test and product verification, and will write necessary documentation. A total of about 288 man-months were required to complete this 46,000-logic-element product, or about 160 logic elements per man-month. However, for development projects aimed at less complex products, the engineering resources required do not fall off proportionally, for there tends to be a minimum level of effort necessary to get the project started—to permit the various participants to become familiar with the product and with the technology being used.

Adopting that point of view, and estimating the engineering man-months required for a range of products in 1955 and 1972, I propose the very simple models shown in Figures 4.21.8 and 4.21.9 as approximations of the relationship between product complexity and development cost (in engineering man-months. Total man-months will of course be much higher, for as shown in Table 4.21.1, each engineer is supported by a total of two additional technicians, draftsmen, designers, clerks, secretaries, production workers, and managers.) Once again we present a range of costs, the lower "minimum" project being one carried out by a small organization operating with financial and elapsed-time constraints, and the "substantial" project characteristic of a larger organization planning a product which will go into large-scale production.

Note that we estimate the incremental development cost (of adding one logic element to a system to be designed) dropped by a factor of ten between 1955 and 1972. Some of the factors which contributed to that improvement are described as follows:

1. The development and improvement of design automation systems which automatically convert the designer's conceptual, shorthand description of the system into wiring diagrams (or into punched cards which drive automatic wiring machinery). Such systems often perform some combination of additional functions, such as: simulating system operation so that sample logic operations can be tested by the designer; combining and integrating the designs of several engineers; permitting the designers to use acronyms and symbolic notation for signals, wires, and circuit components; performing checks to determine whether design rules (governing such things as loading of signal drivers, delays through wiring and logic elements) have been followed; and constructing detailed documentation of the design, including indices and cross-references, for use by manufacturing and maintenance.

2. The increasing use of Boolean Algebra as a shorthand way of describing complex systems, and as an unambiguous input to design automation systems.

3. The trend toward parallel machine data paths and registers. Continuing reduction in electronic costs made it possible for designers to use parallel structures to improve performance. And wherever such parallelism exists, there is a great deal of commonality among the parallel elements—the logic describing the operation of one bit in a parallel adder, for example, will be identical to that describing the next bit.

4. The improvements which have taken place in interconnect technology. Improvements in printed circuits (along with reductions in component size) have permitted a reduction in the number of wires which must be installed per flip-flop; the replacement of soldered joints first by taper pins and then by wire wrap, has improved the reliability of wired connections; and the introduction of automatic wire wrap equipment has reduced elapsed wiring time and has greatly improved wiring accuracy. The results have been reductions in elapsed time and particularly in test time—the detection and location of wiring errors, a major factor in prototype checkout of early systems, has almost disappeared, and today's hardware checkout effort can be devoted to finding documentation and design errors.

Two other factors have arisen which tend to *increase* incremental development cost per flip-flop. The effect of the first is included in the model described by Figures 4.21.8 and 4.21.9; the effect of the second is not.

1. The necessity of improving reliability and maintainability. As processor complexity increases, the possible state combinations and sequences increase disproportionately. And as time passes, manufacturers have become more and more aware of the economic consequences of unreliability (see Sections 4.4 and 4.5). One result has been the addition of maintenance features to hardware. Another has been the provision of better diagnostic programs, designed to detect solid or intermittent failures and either to locate them or to provide some sort of clue as to what part of the system they inhabit. The addition of hardware features tends to add flip-flops and logic and is thus accommodated by the model. The substantial increase in diagnostic programming resource requirements is also included—in other words, the improvement shown between 1955 and 1972 is net of an increase in diagnostic programming.

2. The increasing use of microprogramming technigues. Manufacturers have employed microprogramming techniques in an attempt to reduce users' programming costs by supplying complex processor features (e.g., by emulating the instruction code of an existing processor on a new one). The

microprogram, in hardware, is a regular structure used to implement the control portion of a processor and composed principally of a high-speed, special (usually read-only) memory. The use of a microprogram structure permits the designer to implement a large number of very complex instructions in a relatively simple fashion—once the designer has completed the microprogram memory control and the arithmetic unit, along with any other special subsystems which the micro-control cannot handle, design of individual instructions becomes basically a program design problem and cannot be related directly to a count of logic elements. (The addition of one flip-flop in the register which addresses the microprogram memory, for example, makes it possible to double the size of that memory and thus double the amount of microprogram which can be provided.) The general result is that, for the complex systems where it is useful, microprogramming reduces the number of logic elements required for a given degree of complexity and as a result increases design time per (remaining) logic element. This effect is *not* included in the model described by Figures 4.21.8 and 4.21.9, which assumes the control system is designed in a conventional fashion.

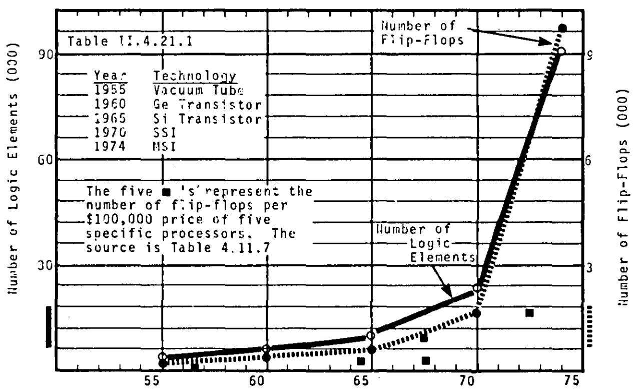



FIGURE 4.21.5 HARDWARE PRODUCT COMPLEXITIES I
LOGIC BUILDING BLOCKS IN A $100,000 PROCESSOR

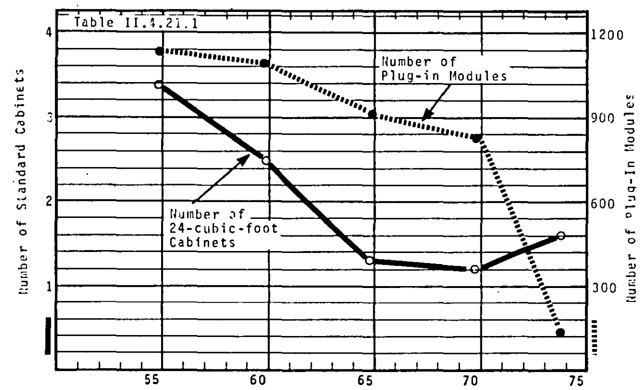



FIGURE 4.21.6 HARDWARE PRODUCT COMPLEXITY II
PHYSICAL BUILDING BLOCKS IN A $100,000 PROCESSOR

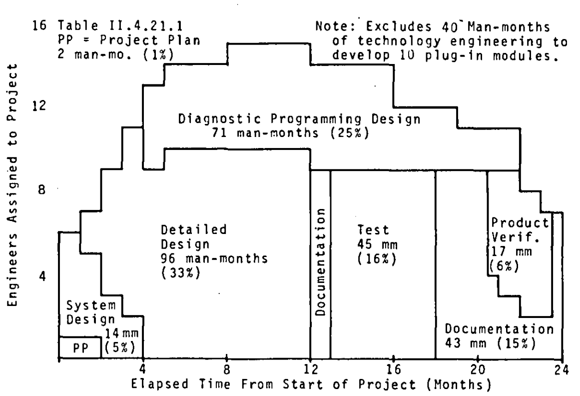



FIGURE 4.21.7 DEVELOPING A $50,000 PROCESSOR (1974)
ENGINEERS ASSIGNED VS. ELAPSED TIME

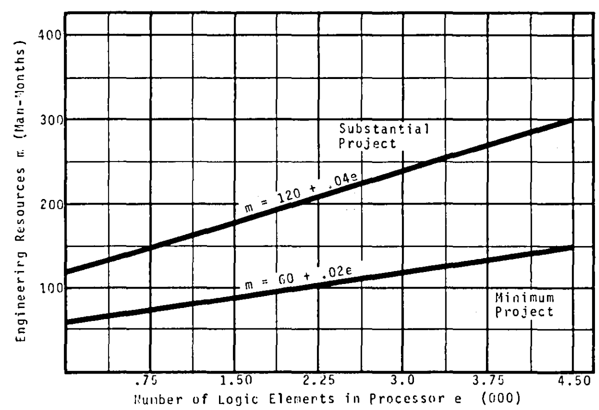



FIGURE 4.21.8 HARDWARE DEVELOPMENT COSTS (1955)
PROJECT MAN-MONTHS VS. LOGIC ELEMENTS IN PROCESSOR

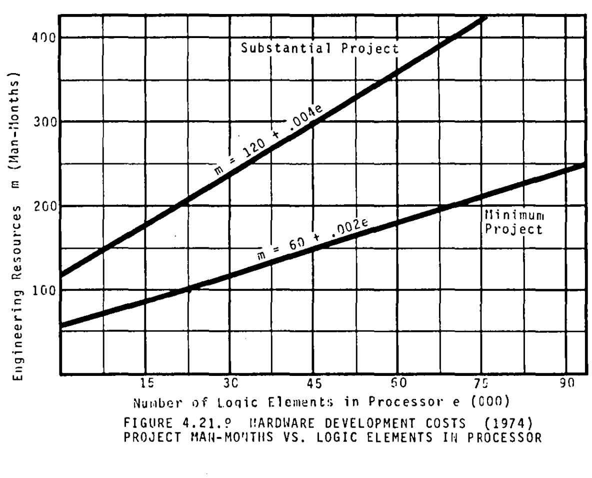



FIGURE 4.21.9 HARDWARE DEVELOPMENT COSTS (1974)
PROJECT MAN-MONTHS VS. LOGIC ELEMENTS IN PROCESSOR

Finally, total development costs, including the cost of designing both a new technology and a first product from that technology, are plotted in Figures 4.21.10 and 4.21.11 for the years 1955 and 1974. They are derived simply by multiplying man-months by the appropriate engineering cost per man-month, and adding the fixed technology development costs. In each figure the solid lines describe the costs of minimum projects, and the dashed lines the cost of substantial ones. Comments:

1. Technology development costs represent a very modest proportion of total development costs for a minimum project and a very major proportion of the costs for a substantial project. However, remember that these costs are those necessary to document a new technology, and that they therefore should be allocated over all the products built using that technology. If ten such products were developed over a period of five years, say, the technology development cost per product would of course be divided by ten and would not loom so large as a factor in total costs.

2. The incremental design cost of adding another logic element to a system decreased between 1955 and 1974—improvements in design productivity more than compensated for increases in salary and overhead.

## 4.22 SOFTWARE DEVELOPMENT COSTS ●

As was indicated in the introduction to this section, hardware and software development have much in common. In each, development activity is usually carried out in a project including the same seven activities: project plan, system design, assembly, detailed design, test, documentation, and product verification. For each, substantial effort and cost are required to sustain a completed product. Finally, and most important, each is fundamentally a logical synthesizing process which assembles a number of building blocks, each having a specific and clearly-defined function, into a system whose properties match those prescribed in a planning specification. For a hardware project, the building blocks are logic elements. For a software project they are the instructions implemented in the computer employed, or the statements compiled in the programming language.

There are obviously differences as well as similarities. The principal difference is that there is no software "technology" quite comparable to the hardware technology described by Table 4.21.2. The hardware technology effort is the engineering needed to develop hardware building blocks—flip-flops and gates along with the interconnects, packaging and power required to support those elements. Inasmuch as the software building blocks are the computer instructions, we could take the point of view that software technology development is the hardware project under which the CPU was designed. On the other hand, we shall see that the principal improvement in software development performance has come about as a result of the use of procedure-oriented-languages, which enable the designer to substitute a more complex set of building blocks (the compiler statements) for the basic computer instruction set. With this point of view, we might conclude that a compiler development project comprises software technology development. Whichever situation applies, software technology development is not a new *kind* of process, as hardware technology development was.

One might argue that a view of technology development as the design of the building-blocks used in product design is too narrow. In addition to building-blocks, the designer requires tools for use in the design process. For hardware development, the tools include electronic equipment like oscilloscopes or specially-designed component testers, and computer programs used for design automation, circuit design, or project control. For software development the tools again include electronic equipment in the form of hardware monitors (to measure various aspects of software performance by sampling, interpreting, and recording signals at selected hardware points) or load simulators (to supply a prerecorded set of jobs to the system in a controllable and repeatable way). Software tools would also obviously include computer programs—assemblers, debugging tools, documentation aids (e.g. a flow-chart generator), and the like. I will not defend too strongly my exclusion of tools from technology. Some tools (e.g. oscilloscopes, an assembler) are essential, and many others (e.g. basic design automation and debugging aids) are enormous time savers whose development and improvement have very materially increased development efficiency. However, the list of usable tools is very long, and it is difficult to draw the line between essential, important, and useful ones.

**Support Costs (Overhead)**

The overhead costs needed to support a programmer are substantially less than those required to support a hardware development engineer, as can be observed by comparing Tables 4.21.1 and 4.22.1. In the latter, two sets of development figures are shown, one referring to the development of application programs by a business data processing user, the other to the development of more complex software by suppliers—of digital systems or of program products. For the user, the base is taken to be a salary of a group of system analysts/programmers existing in the ratio 1 to 1.4, which is the average proportion of these functions in user groups (see Section 1.4). As usual managers' salaries are assumed to be 50% higher than the average systems analyst/programmer.

For the supplier of software, the more experienced development programmer replaces the systems analyst/programmer as the base. In addition, because software documentation is important and has grown more critical through the years, an increasing number of technical writers have been included as essential support. They assist the programmers in preparing descriptions, programmers' manuals, and operators' manuals for the operating systems, assemblers, compilers, utility routines, etc. which are produced and will be widely distributed by the supplier. Note that I have shown no comparable documentation activity for the user. Since users' programs are generally used only at the users' own installation, extensive documentation of application programs is generally not required. Whatever documentation is supplied (and it often is informal and inadequate, even for the purpose of supporting program maintenance) is generally written by the programmers and systems analysts themselves.

**Product Development**

Design of any particular software product or application program can begin as soon as a planning specification is complete. A typical detailed schedule for a moderate-sized project is shown in Figure 4.22.1, where again the seven basic development activities are identified by numbers in parentheses. (Compare with the hardware development schedule of Figure 4.21.4.) The project manager begins by laying out a plan and schedule. In the meanwhile system design begins, to convert the planning specification into a set of algorithms which will be used by the program, and thence to flow charts showing the sequences in which the algorithms are to be carried out.

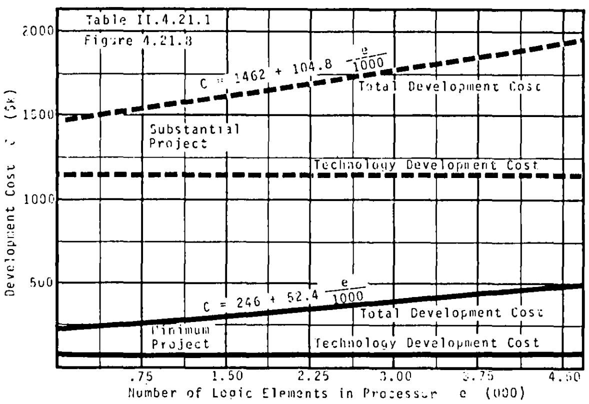



FIGURE 4.21.10 HARDWARE DEVELOPMENT COSTS (1955)
TECHNOLOGY PLUS PROJECT COSTS VS. LOGIC ELEMENTS IN PROCESSOR

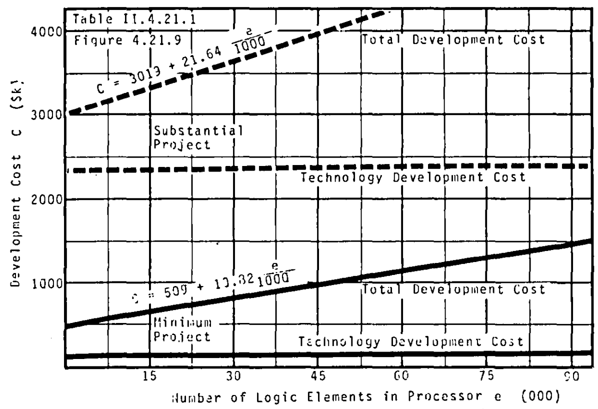



FIGURE 4.21.11 HARDWARE DEVELOPMENT COSTS (1974)
TECHNOLOGY PLUS PROJECT COSTS VS. LOGIC ELEMENTS IN PROCESSOR

**TABLE 4.22.1 SOFTWARE DEVELOPMENT OVERHEAD ●**

| | Units | 1955 | 1960 | 1965 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|
| **User Overhead** | | | | | | | |
| 0.58 Programmers | $/wk | 70 | 78 | 98 | 134 | 150 | 162 |
| 0.42 Systems Analysts | $/wk | 65 | 74 | 96 | 126 | 138 | 151 |
| Subtotal, P&SA | $/wk | 135 | 152 | 194 | 260 | 288 | 313 |
| 0.1 Secretaries, Clerks | $/wk | 6 | 8 | 9 | 12 | 13 | 17 |
| 0.2 Managers | $/wk | 41 | 46 | 58 | 78 | 86 | 94 |
| Subtotal Salaries | $/wk | 182 | 206 | 261 | 350 | 387 | 424 |
| Fringe Benefits—Rate | % | 8 | 10 | 12 | 14 | 15 | 16 |
| Cost | $/wk | 15 | 21 | 31 | 49 | 58 | 68 |
| Total Cost—Weekly | $/wk | 197 | 227 | 292 | 399 | 445 | 492 |
| Monthly | $k/mo | .85 | .98 | 1.27 | 1.73 | 1.93 | 2.13 |
| Annually | $k/yr | 10.2 | 11.8 | 15.2 | 20.7 | 23.1 | 25.6 |
| Overhead Rate | % | 46 | 49 | 51 | 53 | 55 | 57 |
| **Supplier Personnel** | | | | | | | |
| 1.0 Programmer | $/wk | 170 | 200 | 252 | 327 | 356 | 390 |
| 0.1 Secretaries, Clerks | $/wk | 6 | 8 | 9 | 12 | 13 | 17 |
| Technical Writers—Number | | .15 | .25 | .40 | .65 | .75 | .80 |
| Cost | $/wk | 17 | 31 | 56 | 109 | 133 | 160 |
| 0.2 Managers | $/wk | 51 | 60 | 76 | 98 | 107 | 117 |
| Subtotal Salaries | $/wk | 244 | 299 | 393 | 546 | 609 | 684 |
| Fringe Benefit Cost | $/wk | 20 | 30 | 47 | 76 | 91 | 109 |
| Total Cost—Weekly | $/wk | 264 | 329 | 440 | 622 | 700 | 793 |
| Monthly | $k/mo | 1.14 | 1.43 | 1.91 | 2.70 | 3.03 | 3.44 |
| Annually | $k/yr | 13.7 | 17.1 | 22.9 | 32.3 | 36.4 | 41.3 |
| Overhead Rate | % | 55 | 65 | 75 | 90 | 97 | 103 |

Source: M. Phister estimate.

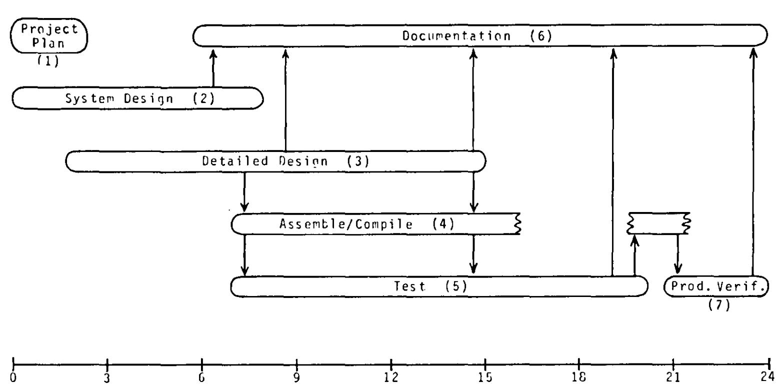



FIGURE 4.22.1 SOFTWARE DEVELOPMENT SCHEDULE
DEVELOPMENT ORGANIZATION DETAILS

The flow charts generally identify sub-programs having well-defined properties and simple interfaces or connections to other sub-programs, and the project manager uses this dissection to assign tasks to individual programmers. They in turn begin work on the detailed design—the translation of flow charts into lines of machine-language code or into sequences of compiler statements. As this work proceeds, the designers reach the point at which sections of code are complete enough that they can be assembled or compiled and checked out, in a limited fashion. As indicated in the figure, the detailed design generally can start before system design is complete, and test begins before detailed design is finished. When all sub-programs are complete and have undergone exhaustive individual checkout (to the extent that is possible or practical), the entire system is assembled and tested.

Software test is a difficult and time-consuming activity, and the checkout process itself has received increasing attention over the years. Generally some of the effort called detailed design will include the preparation of test cases and sample workloads to be used in test. As test proceeds and errors are discovered and corrected, the system is periodically reassembled or recompiled. When enough errors have been eliminated that the system performs its prescribed functions tolerably well, it will undergo tests to determine whether its performance (in terms of efficiency, response time, throughput, speed, capacity, etc.) meets specifications. At some point, when all major problems have been corrected, the product will be handed off to a separate organization where it will undergo further tests, here called product verification. These tests might be carried out by the customer engineering department of a system company, by the sales department of a software development company, or by the computer operations department of a service company. If the "product" is simply a user's new application program, the computer operations people are again the appropriate group to conduct product verification, which differs from final test only in that it is carried out by an organization separate from that which developed the product, and it attempts to evaluate operation and performance in the environment of the user, so that it includes an appraisal of documentation, and of the ease with which the product may be understood, operated, and used. The development group of course must monitor product verification, and correct any problems detected there.

Some recent analyses of software test and verification activities shed some light on the processes, but also make it clear that we have a lot to learn. Consider first the fundamental question: when coding is complete, how many errors exist, to be detected and corrected in test and product verification? An analysis of errors discovered during internal test of 86,000 new and revised lines of code in a new version of IBM's DOS/VS turned up 512 errors, or 6.0 per thousand assembly-language instructions (EndrA75). An apparently similar analysis of errors in four real-time interactive programs comprising a total of 46,700 new or revised assembly language instructions written at Bell Telephone Laboratories showed an errors rate of 5.88 errors per thousand instructions, and the same paper (MusaJ75) states that a range of 3.36 to 7.98 errors per thousand instructions has been noted.

On the other hand, an analysis of twelve missile-guidance program debugging projects by Rubey (RubeR75) showed that approximately one assembly-language error is made during the software development effort for every ten machine-language instructions in the final program—an error rate of 100 per thousand instructions. These are errors found in development debugging. The same paper contains a detailed analysis of errors found in "validation" (which appears to correspond to our product verification) of eleven programs containing about 600,000 instructions. Here the error ratio was only two per 1000 machine-language instructions. The reconciliation of these differences is not easy. Perhaps Rubey's "validation" corresponds to the IBM and Bell Labs internal tests, and those tests were preceded by debugging activities having a much higher rate of occurrence of errors.

Two analyses of the *kinds* of error found are shown in the top portions of Table 4.22.2, for the IBM internal tests and the Rubey validations. (In the IBM portion of the table, the boldface figures identify the three major error categories and add to 100%; and the normal-type, non-parenthetical figures show breakdowns of the major categories and also add to 100. In both the IBM and Rubey portions of the table, the parenthetical figures identify important sub-categories of error.) Comments:

1. Neither analysis relates testing cost to error types. If the cost of detecting and correcting an error is independent of error type, there would be no point in seeking more data. But if we took into account the man-hours and machine time spent on each error type, we might discover that twenty percent of the errors accounted for eighty percent of testing cost, and might as a result decide that some error categories are more important than others. For example, it seems likely that the 4% errors involving "registers not saved ... interrupts destroying information" were much more costly to detect, identify, and cure than the 4% "I/O command used incorrectly", and much much more costly than the 4% "spelling errors".

2. Incomplete and erroneous specifications are discussed as problems in both articles. However, Rubey points out that less than six percent of the specification errors were serious, and adds that the vast majority of such errors caused no program failures because the coding was correct even though the specification was in error. Had the programmers written code to conform to the specification, the number of serious errors would have increased by *38%*. As we carry on applied research to develop systems for creating code from specifications automatically, we must therefore be careful either to reduce the level of errors found in the primary specification, or to detect and correct, quickly and efficiently, the coding errors which result.

3. The errors discussed and described in these paragraphs were all in on-line programs written in machine language. The vast majority of programs in use are of course application programs written in higher-level languages—and it is difficult to find comparable analyses of errors in such programs.

One such analysis appears at the bottom of the table. It shows the proportion of programs compiled or assembled having errors detected by the compiler or assembler. The percentages were surprisingly low, and PL-I and Fortran seemed to have noticably more errors than machine-language programs. But the installation (an IBM TSS/360 system at an IBM research center) hardly represents a typical user, and the analysis gave no breakdown of error types, program size, or of the subsequent error history of the programs.

### TABLE 4.22.2
### ANALYSIS OF PROGRAMMING ERRORS I. ●

| Analysis of 512 Errors Discovered During Internal Tests of the Components of IBM's DOS/VS (Release 28) Error Classification | Percent |
|---|---|
| **Errors Specific to the Problem** | **46** |
| Dynamic Behavior and Communication Between Processes | 17 |
| (Registers and control blocks used repeatedly were not saved. Interupt destroys information which is still needed) | (4) |
| Functions Offered | 12 |
| Machine Configurations and Architecture | 10 |
| (I/O command used incorrectly, or simulated incompletely or incorrectly) | (4) |
| Others (Output Listings and Formats, Diagnostics, Performance) | 7 |
| **Errors Specific to the Implementation** | **38** |
| Initialization of Fields and Areas | 8 |
| (I/O area, buffer, etc. not cleared before usage) | (5) |
| Counting and Calculating | 8 |
| Addressability (in the sense of the assembler) | 7 |
| References to Names | 7 |
| Others (Placing of instructions within a module, bad fixes, masks and comparisons, estimation of range limits) | 8 |
| **Code Errors** | **16** |
| Missing Commentaries on Flowcharts | 5 |
| Incompatible Status of Macros or Modules --Integration Errors | 5 |
| Spelling Errors | 4 |
| Others | 2 |

Source: EndrA75

### TABLE 4.22.2
### ANALYSIS OF PROGRAMMING ERRORS II. ●

| Analysis of 1202 Errors Discovered during Program Validation of Eleven Missile Guidance Programs<br>Error Classification | Percent of Total Errors<br>All | <br>Serious |
|---|---|---|
| Incomplete or Erroneous Specifications | 28 | 1.6 |
| Intentional Deviation from Specifications | 12 | 0.7 |
| Erroneous Decision Logic or Sequencing | 12 | 3.4 |
| (Logic Sequence Incorrect) | (8.2) | (2.2) |
| (Branch Test Incorrect) | (2.3) | (0.8) |
| Erroneous Data Accessing | 10 | 3.0 |
| (Fetch or Store Wrong Data Word) | (6.6) | (1.4) |
| Violation of Programming Standards | 10 | 0.2 |
| Erroneous Arithmetic Computation | 9 | 1.8 |
| (Wrong Arithmetic Operation Performed) | (5.7) | (1.0) |
| Invalid Timing | 4 | 1.2 |
| Improper Interrupt Handling | 4 | 1.2 |
| Wrong Constants and Data Values | 3 | 1.2 |
| Inaccurate Documentation | 8 | 0 |
| Total | 100 | 14.3 |

Source: RubeR75. "Serious" errors are those which would cause the program to terminate, or would cause the program's outputs to differ significantly from the desired correct value.

### TABLE 4.22.2 ANALYSIS OF PROGRAMMING ERRORS III. ●

Analysis of Syntactic Errors in Programs Compiled on a Time-Sharing System

| Language Employed | Number of Programs | Percent Distribution Containing Errors | Error-Free | Terminated |
|---|---|---|---|---|
| Fortran | 113 | 16 | 78 | 6 |
| | 166 | 13 | 83 | 5 |
| PL-I | 139 | 17 | 73 | 10 |
| | 125 | 18 | 75 | 7 |
| Assembler | 66 | 12 | 62 | 26 |
| | 77 | 9 | 81 | 10 |

Source: BoieS74. Syntactic errors are those which prevent a program from compiling or assembling. "Terminated" refers to programs for which the programmer at his terminal voluntarily stopped the compilation or assembly before receiving feedback as to whether the program contained errors. The two sets of programs written in each language were written during two five-day periods.

**Product Complexity.** We have seen that the quantity of hardware one purchases for $100,000 has increased over the years (Figures 4.21.5-6 and Table 4.11.7). The increase came about because of cost reductions that have taken place in electronic technology; and improvements in hardware development efficiency have helped keep development costs in bounds, despite the increases in hardware complexity.

The lines of code available to support a $100,000 processor have also increased in number. As shown in Figure 1.25.5, for example, about 10,000 lines supported the IBM 650 in 1955. By the mid-sixties the IBM 1401 required 200,000 lines, and in the early seventies the IBM 360/30 needed 2,000,000 lines. A list of the program modules which comprised an early version of the IBM 360 operating system is presented in Table 4.22.3—even at that time OS/360 alone required almost 400,000 lines of code. There seem to be no comparable estimates of changes in user software complexity, although one might infer, from the fact that the *number* of user applications has remained fairly constant while computer speed has increased by several orders of magnitude, that each user application has become much more complex over the past twenty years (see Section 3.12).

**Development Time and Cost.** As software support requirements for computer products soared, and as computer users spent millions and then billions of dollars on applications programs (see Figures 1.25.1-2), various organizations attempted to study software development quantitatively, with the object of first understanding and then improving the process. The results of seven such studies, carried out between 1953 and 1972, are summarized in Table 4.22.4. Two cost factors are shown: programmer productivity, and computer time used in assembly and checkout. Each is given both in terms of source instructions or statements (which is what the programmer actually puts down on paper) and object instructions (which are the instructions actually stored in computer memory when the program is run). For procedure-oriented languages (POL), a statement generates several computer instructions; for machine-oriented languages (MOL) most statements correspond directly to comparable instructions.

We do not have exactly comparable data from the five studies, but there is enough to indicate an enormous variability from one experiment to another. Source instructions composed per man-month, for example, vary from less than 100 to almost 2400; and computer hours required per 1000 object instructions written range from 3.5 to over 30. There are many possible explanations for this enormous variability. One is the lack of a common definition of what the development process includes—a problem which helps account for differences between the five studies, but not the differences within a given study. Other explanations include the differences in programmer ability we have already noted (see Table 2.22.3), and differences in the complexity of the tasks the programs themselves accomplish.

In the mid-sixties the System Development Corporation collected data on 169 programs, written in various languages by various organizations and carrying out various types of computation on various machines. The results, summarized by Nelson (NelsE67) appear in the middle of Table 4.22.4 and comprise the best available collection of reliable data on program development. Even this data, collected and analyzed under conditions which should have eliminated inconsistencies in the definition of "programming", displays an enormous range of programming productivity, as indicated by Figures 4.22.2 and 4.22.3. Note that the mean programming rate is 4.87 man-months per 1000 object instructions, the median is 2.93 man-months per 1000 instructions, and the standard deviation 8.94. Seventy percent of the programs required less than five man-months per 1000 object instructions, but ten percent required more than nine and at least one required 100.

The SDC report attempted to derive formulas for development resources in terms of a great many parameters describing such things as the problem coded (e.g. "vagueness of design requirements definition"), the amount of documentation required, the power of the computer involved, the experience of the programmers, and the frequency with which various instruction types appear in the final code. From a practical point of view, these correlations did not prove useful: even when all these factors were taken into account, actual man-months required were often half or twice the man-months computed from the correlations.

One factor, however, did seem significant. Roughly speaking, it appeared that productivity in terms of man-months per 1000 *source* instructions was the same whether the programmer was working with machine-oriented or procedure-oriented languages. That is to say, he produces about the same number of compiler statements per month using a POL as he produces machine instructions per month using an MOL. Since the act of compilation generates three to five machine instructions for every compiler statement, the result is that a programmer is substantially more productive in generating object (i.e. machine) instructions when he uses a POL than he is when he uses a MOL.

**TABLE 4.22.3 SIZE OF PROGRAM MODULES IN AN EARLY (1966) RELEASE OF IBM'S OS/360**

| Component | Number of Statements |
|---|---|
| Data Management | 58.6k |
| Scheduler | 45.0k |
| Supervisor | 26.0k |
| Utilities | 53.0k |
| Linkage Editor | 12.3k |
| Testran | 20.4k |
| System Generator | 4.4k |
| Subtotal | 219.7k |
| Assembly E | 43.0k |
| COBOL E | 50.6k |
| FORTRAN E | 28.7k |
| Sort | 56.5k |
| Subtotal | 178.8k |
| Grand Total | 398.5k |

Source: J. Nash, of IBM, in NaurP69, page 67.

**TABLE 4.22.4 PROGRAMMING COST FACTORS—SUMMARY OF SEVEN STUDIES ●**

| Date | Program Language | Organi-zations | Number of Programs | Programmer Prod. Instruc./Man-Mo. Object | Programmer Prod. Instruc./Man-Mo. Source | Computer Use Hrs/1000 Instr. Object | Computer Use Hrs/1000 Instr. Source | Av. Length of Source Programs | Reference |
|---|---|---|---|---|---|---|---|---|---|
| 1953 | MOL | U. Toronto | 20 | 149 | | 31.8 | | 225 | GotlC54 |
| | MOL | IBM | 1 | 867 | | | | 4000 | |
| 1964 | MOL | S.D.C. | 60 | 322 | | 24. | | | ShawC66 |
| | Jovial | S.D.C. | 14 | 555 | | 12. | | | |
| '59-'65 | MOL | Various | 123 | 170 | 158 | 29.5 | 31.4 | | NelsE67 |
| | All POL | Various | 46 | 469 | 122 | 9.8 | 32.0 | | |
| | Fortran | Various | 8 | 364 | 78 | 10.3 | 43.8 | | |
| | Jovial | Various | 15 | 326 | 97 | 17.7 | 47.6 | | |
| | COBOL | Various | 12 | 800 | 207 | 5.2 | 18.1 | | |
| | Other POL | Various | 11 | 735 | 175 | 3.5 | 17.2 | | |
| 1965? | MOL | Bell Labs | 2 | | 48 | | | 51500 | BrooF74 |
| | MOL | Bell Labs | 2 | | 187 | | | 32000 | |
| | PL-I | MIT | 1 | 400 | 100 | | | 1.5M | |
| 1967 | PL-I | | 7 | | 1093 | | | 468 | RubeR68 |
| | COBOL | | 2 | | 930 | | | 429 | |
| | Fortran | | 3 | | 2392 | | | 724 | |
| | Jovial | | 2 | | 749 | | | 600 | |
| '61-'70 | MOL | Army-AF | 15 | 183 | | | | 58100 | ArmyMIS7I |
| | COBOL | Army-AF | 15 | 739 | 217 | | 29.0 | 29000 | |
| '71-'72 | MOL | Denmark | 1 | | 230 | | | 26000 | LaueS75 |

See also Table II.4.22.1

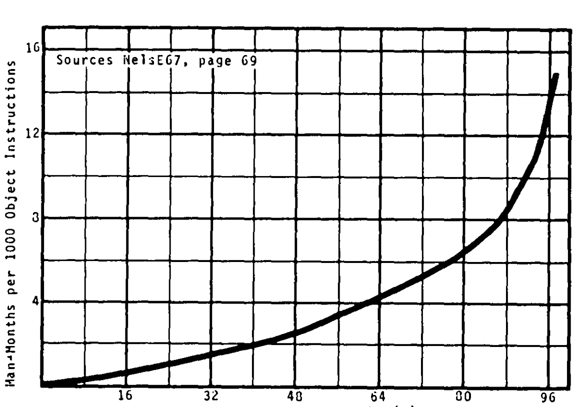



FIGURE 4.22.2 VARIABILITY IN PROGRAMMING PRODUCTIVITY I
CUMULATIVE PROGRAMMING MAN-MONTHS FOR 169-PROGRAM SAMPLE

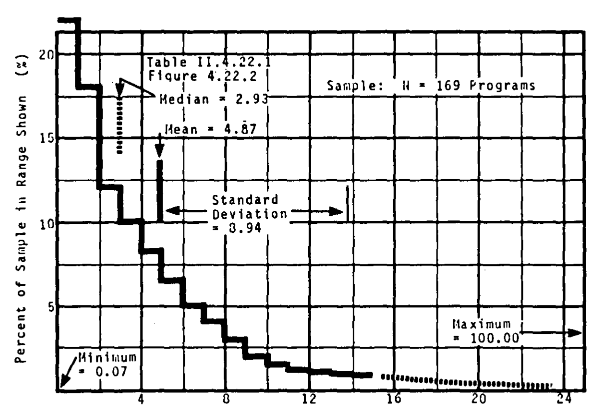



FIGURE 4.22.3 VARIABILITY IN PROGRAMMING PRODUCTIVITY II
DISTRIBUTION AND STATISTICS ON PROGRAMMING MAN-MONTHS

The data from the study is summarized in Figure 4.22.4, where medians, means, and standard deviations are indicated for programmer productivity (left side) and computer time required (right side), and in terms of source instructions (top half) and object instructions (bottom half). Looking first at the top left portion of the figure, observe that programmers working with MOL's achieve very nearly the same productivity, in man-months per 1000 source instructions, as do POL programmers: the mean for the POL user is greater than, but the median is less than that for the MOL user. However, when we look at productivity in terms of *object* instructions (bottom left) we find the POL programmer takes only 25% to 35% of the time required by the MOL user. Computer hours required per 1000 instructions is similarly reduced, as shown in the right-hand side of the figure.

A typical project schedule, for a 72,000-instruction program written in a machine-oriented language over a two-year period, is shown in Figure 4.22.5. (The relative proportion of project activity devoted to various tasks is consistent with the results of several published analyses described in Table II.4.22.2.) The schedule is based on the assumption that an explicit and detailed specification, giving functional and performance requirements for the required program, is available before the project starts. Note particularly that forty percent of project resources go into program checkout and verification; the actual coding of the program only occupies twenty-five percent of the programmer's time. The entire project is assumed to have required 300 man-months of effort, or about 4.2 man-months per 1000 instructions. If we assume the resources required are directly proportional to the number of object instructions in the program, and accept the results of the SDC study regarding the greater productivity possible though use of procedure-oriented languages, we must adopt a model for development cost similar to that shown in Figures 4.22.6 and 4.22.7.

The coefficients in the last two figures, intended to represent programming productivity in 1974, are derived from the SDC data with the help of two unsupported assumptions: that man-hour productivity has improved by a factor of two, and computer usage by a factor of four, over the twenty-year history of the industry. Some improvement seems likely simply because the programming task is better defined and organized year by year, and because the computer itself is being used more effectively to help the programmer—with debugging and documentation aids, for example. I argue that computer usage has improved faster than programmer man-months partly because the development of debugging tools has made it unnecessary for the programmer to spend time at the computer console "stepping through" his program, and partly because the improved speed and reliability of system hardware has cut computer time. In Figures 4.22.8 and 4.22.9 we see these productivity improvements plotted. In each figure, the shaded band shows the range of measurements reported in the SDC study. The means, minima, and maxima for POL and MOL programs are shown as circles and dots, respectively. The productivity trends, based on the growth rates given above and passing through the 1964 mean values, are shown as dashed lines. And the "average U.S." productivity, based on the ratios of machine (assembly) language to other language usage in the United States, from Figure 2.15.1, is shown as a solid line. It can be argued that recent improvements in software development have caused or will cause greater productivity improvements than are shown here. Baker, in describing a "Chief Programmer Team" concept (BakeF72-1) describes an 83,324-instruction program which required only 107 programmer man-months for a productivity of almost 780 lines per man-month. Later, in discussing the use of various techniques including structured coding, he reports a 50% improvement in productivity over non-structured methods (BakeF75). He also supplies data to show that structured programming reduces program errors (BakeF72-2). And Boehm, reporting on a conference which reviewed the subject, states that structured programming may give a 40% improvement in productivity (BoehB75-2).

It is of course at least rash, and very possibly foolhardy, for us to speak of averages and trends in the face of the enormous variability in programming productivity measured by the SDC study and by the other studies reviewed in Table 4.22.4. It seems likely that there are some factors we are not yet able to quantify which materially affect productivity. Two critical ones are the ability and experience of the individual programmer, and the complexity of the function to be performed by the program. I hope it is obvious that the use of this data in estimating programming costs is risky, and that it is extraordinarily easy to misjudge the programming man-months required for some specific job by a factor of two or three. One can have confidence in ones estimate only when one has programmed the same job before. And even then it is easy to underestimate. Table 4.22.5 records the history of a team which successively wrote three Fortran compilers. Note they missed their estimate by 100% the first time and 50% the second time. On the third try they underestimated by only 17%.

Using average programmer costs, including overhead, and average computer operating costs, including all expenses except those for programmers and system analysts, we can convert the man-months and computer hours from Figures 4.22.8 and 4.22.9 into costs per object instruction produced. The results are shown in Figures 4.22.10 and 4.22.11. Supplier costs are higher than user costs both because suppliers' programmer salaries are higher and because overhead includes technical writer support and is thus higher. If we note that suppliers' programs are generally written in machine language while users' are written in a procedure-oriented language, we conclude it may cost four times as much for the supplier to write a line of object code than it costs the user. The general trends in cost have been fairly flat: the increasing costs of salaries and overhead have been more or less balanced by improvements in productivity. However, we must remember that a great many estimates were used in deriving the curves, so that the actual trends may well be quite different from those shown.

**TABLE 4.22.5 A HISTORY OF THREE FORTRAN COMPILERS: ESTIMATED AND ACTUAL RESOURCES REQUIRED**

| | Project Size (Man-Months) | |
|---|---|---|
| | Estimated | Actual |
| First Project | 36 | 72 |
| Second Project | 24 | 36 |
| Third Project | 12 | 14 |

Note: Source is NaurP69, p. 74. The same team of programmers wrote all three compilers.

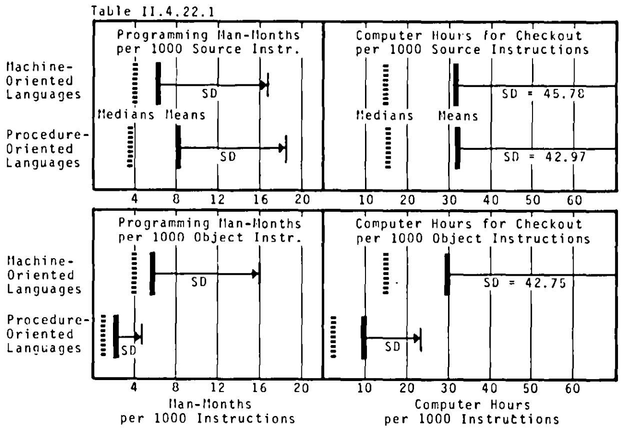



FIGURE 4.22.4 PROGRAMMING PRODUCTIVITY
MACHINE- VS. PROCEDURE-ORIENTED LANGUAGE

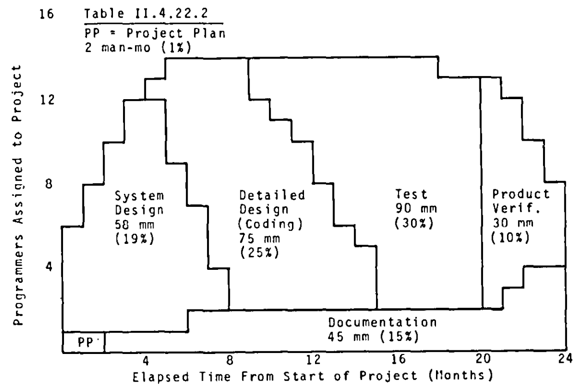



FIGURE 4.22.5 DEVELOPING A 72,000-INSTRUCTION PROGRAM
PROGRAMMERS VS. ELAPSED TIME (1974)

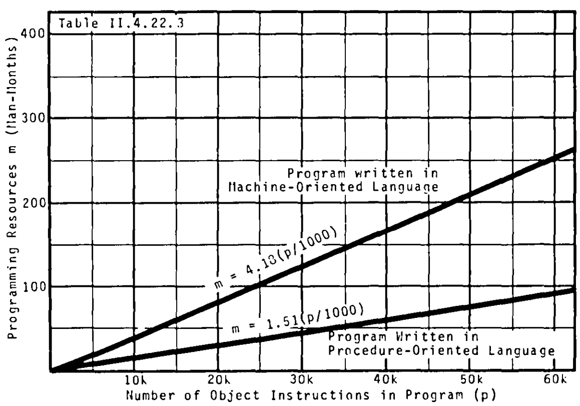



FIGURE 4.22.6 SOFTWARE DEVELOPMENT COSTS (1974)
PROJECT MAN-MONTHS VS. PROGRAM SIZE

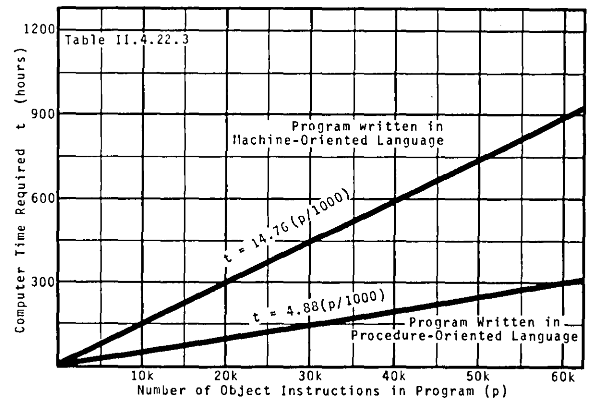



FIGURE 4.22.7 SOFTWARE DEVELOPMENT COSTS (1974)
COMPUTER HOURS VS. PROGRAM SIZE

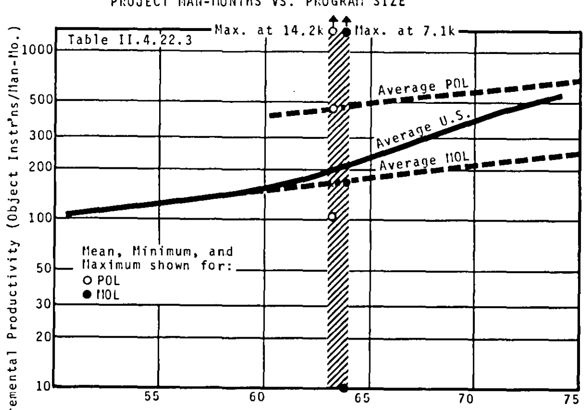



FIGURE 4.22.8 SOFTWARE DEVELOPMENT PRODUCTIVITY I
IMPROVEMENTS IN PROGRAMMER PRODUCTION RATE

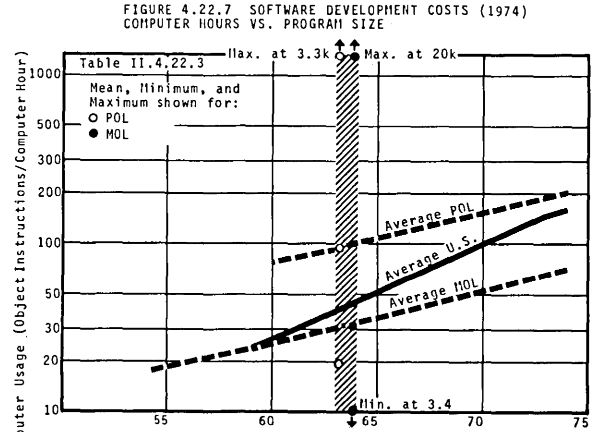



FIGURE 4.22.9 SOFTWARE DEVELOPMENT PRODUCTIVITY II
IMPROVEMENTS IN COMPUTER USE DURING DEVELOPMENT PROJECT

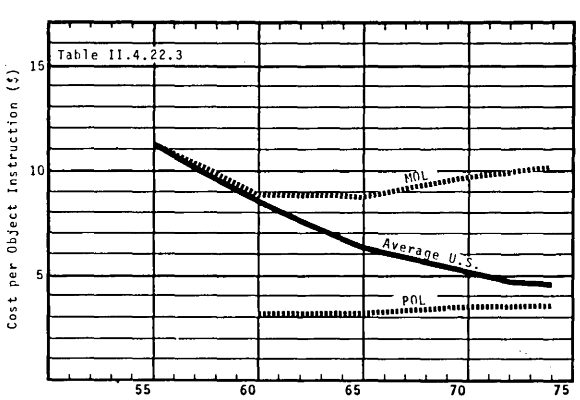



FIGURE 4.22.10 USER'S SOFTWARE DEVELOPMENT COST
COMPUTER TIME PLUS PROGRAMMER COST PER OBJECT INSTRUCTION

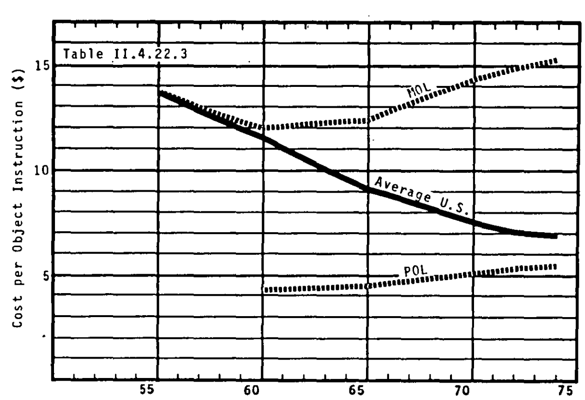



FIGURE 4.22.11 SUPPLIERS' SOFTWARE DEVELOPMENT COST
COMPUTER TIME PLUS PROGRAMMER COST PER OBJECT INSTRUCTION

We can also convert man-months and computer hours from Figures 4.22.6 and 4.22.7 into project costs, with the result shown in Figure 4.22.12. The two cost lines shown obviously represent the two extremes; cost curves for users employing MOL or suppliers using POL would lie between those shown.

There is some evidence (see for example BrooF75 and FarrL64) that programming effort is not proportional to program size, but increases faster than proportionally for very large programs—over 150,000 instructions, say. Putting it graphically, the curves of Figure 4.22.6 might in reality look like that in Figure 4.22.13. And an explanation for this non-linearity might be that design resources required are a function of the number of interconnections possible between program segments and between their designers, and that this number increases as the square of the number of segments or designers. There is not enough data available to permit us to quantify the non-linearity, or even to verify that it exists, though Brooks mentions a study reporting that effort increases with the 1.5 power of number of instructions, and the general history of difficulties in large programming projects (e.g. IBM's TSS and OS/360) suggests that there must be *some* problem.

**Program Maintenance**. When product verification is complete the development project terminates, the program is released to users, and a maintenance or sustaining activity begins—a state of affairs entirely analogous to that which exists when a hardware product is released. Users will encounter difficulties, and a sustaining group will be assigned the job of resolving the difficulties. Some will be the result of users' errors or misunderstandings, and will require no corrective action. Other difficulties will be caused by error, inadequacy, or awkwardness in the program itself or in its documentation, and the sustaining group will have to decide what to do about these problems. In addition, the maintenance or sustaining group is generally given the responsibility of adding minor improvements to the program, in response to requests from users or potential users.

A simple model proposing relationships between program size, initial error content, and the time the program is actually run on a system was suggested by Musa (MusaJ75) and is shown in Figure 4.22.14. Comments:

1. The model is based on the fundamental assumption that the program failure rate at any time is proportional to the number of errors existing in the program at that time, and to the frequency with which the program is executed—see comment 4 below.

2. Musa applied the model to the checkout phase of the development of the four real-time interactive programs mentioned earlier. He did not extend it to the program maintenance period, as we are here doing. He concluded that the constant of proportionality k was roughly equal to $1.3 \times 10^{-6}$.

3. We have seen that the initial error rate $\epsilon$ seems to lie in the range 0.005 to 0.1 (five to 100 errors per thousand instructions) at the beginning of checkout in the development phase. There seem to be no estimates of its value at the beginning of the maintenance phase. Incidentally, note that P is the number of *object* instructions in the program. If, as seems possible, the ratio of errors to *source* instructions is the same whether the programmer is using machine language or a procedure-oriented language, his $\epsilon$ in a POL program is reduced by the ratio of source to object instructions.

4. Program execution frequency is the rate at which the entire program would be executed on the given system, assuming all the instructions were executed in sequence. It is given by C'u/P, where C' is the *effective* system speed executing this program—the number of instructions actually executed in running the program for 100 seconds, divided by 100. The factor u converts program running time to calendar time and varies enormously from program to program. An operating system may be in use fourteen hours per day six days per week, giving u = 0.5. An application program that runs for twenty minutes once per month has u = 0.00046.

The model predicts that the various error factors will change exponentially, as shown in Figure 4.22.15, with a time constant given by P/kuC'. Applying the results to three specific programs, we get the curves shown in Figure 4.22.16 and 4.22.17. In these figures the solid and dashed lines represent error predictions for two applications programs, one of 2000 instructions with ten initial errors, and the other of 20,000 instructions with 100 initial errors. The dotted line represents a 100,000-instruction operating system with an initial 100 errors—its low initial error content reflects the assumption that, when it is first put in use, an operating system is better checked out than an application program. The first figure shows number of errors found versus time, the second the percent of instructions which must be rewritten per month, assuming the average error is corrected by rewriting five instructions. All programs are run on a computer averaging 100,000 instructions per second—something like an IBM 370/125 or 370/135. Comments:

1. The results are of course critically dependent on the various assumptions we have made. In particular, note our use of Musa's value for k, our assumptions about initial errors, and (for the second figure) our assumption that five instructions must be rewritten to correct an error. It would obviously be very desirable to have statistics from a variety of installations to determine representative values for these parameters.

2. The time constants (P/kuC') are different for these three programs. Since k and C' are constant, the time constants depend only on P and u. Note that, if the *ratio* of P to u were constant, the time constant would be constant. For many application programs, P/u may be nearly constant—we might expect that an application program's running time would increase with the program's length. But I have no data that might confirm or contradict that hypothesis.

3. In interpreting Figure 4.22.17, we might begin by determining what percentage of each program must be rewritten to correct *all* the errors. The 20,000-instruction program contains 100 errors, and this requires 500 rewritten instructions which is 2.5% of the total. The 2000-instruction program also requires 2.5% rewrites, and the large program only 0.5%. These percentages correspond to the areas under the three curves and help us understand the relation between them. It might seem strange that the small application program has a much higher initial percent rewrite rate than does the larger one; but if we realize that the total percent rewrites required is the same for both programs, and that the time constant is only fourteen months for the short program and over forty-five for the long one, we find it easier to accept the difference in initial rates. Of course, the *absolute* rewrite level is much smaller for the small program—3.7 instructions per month initially compared with eleven.

4. The application programs run so infrequently that it takes months for all the errors to be detected and corrected. The operating system, on the other hand, runs 50% of the time, with the result that errors show up quickly. Note that

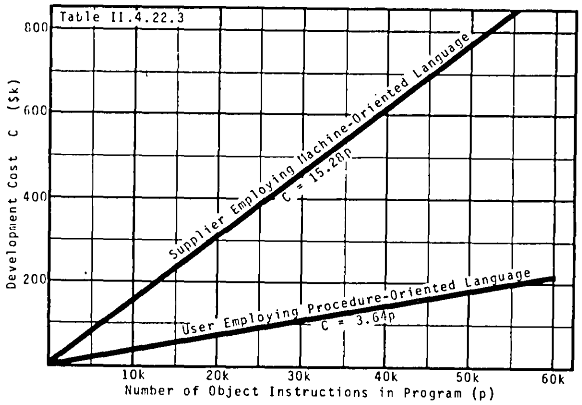



FIGURE 4.22.12 SOFTWARE DEVELOPMENT COSTS (1974)

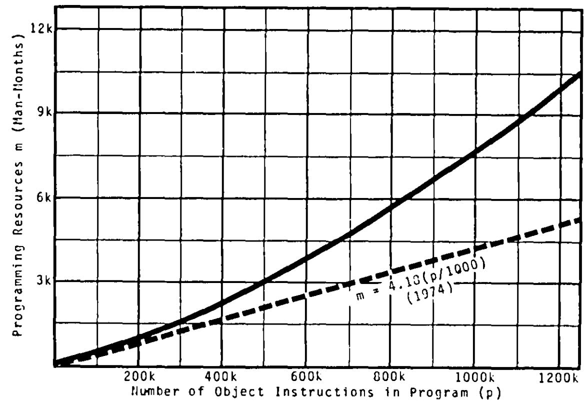



FIGURE 4.22.13 SOFTWARE DEVELOPMENT COSTS
EFFECT OF VERY LARGE PROGRAMS ON PROJECT MAN-MONTHS

Given a Program with:

$P$ = Number of Instructions in Program

$\epsilon P$ = Number of Errors in Program at Time Zero

$n$ = Number of Errors Cured by Time t

$N$ = Number of Errors Remaining at Time t

Then

$\epsilon P = n + N$

$\frac{dn}{dt}$ = Rate at Which Errors are being Cured
= Program Failure Rate
= 1/(Mean Time Between Program Failures)

Assume that

$\frac{dn}{dt} = k \times N \times$ (Program Execution Frequency)

If $C'$ = Effective Instruction Execution Rate

And $u = \frac{\text{CPU Hours per Week Spent on the Program}}{24 \times 7 \text{ Hours per Week}}$

Then

$$\frac{dn}{dt} = k N \frac{C'}{P} u = \frac{k C' u}{P} (\epsilon P - n)$$

Solving this Differential Equation, we find:

$$n = \epsilon P \left(1 - e^{\frac{-kuC'}{P}t}\right)$$

And

$$\frac{dn}{dt} = \epsilon k u C' e^{\frac{-kuC'}{P}t}$$

The number of Errors Found in a Short Time $\Delta t$ is

$$\frac{dn}{dt} \Delta t$$

If an Error is Cured by Rewriting w Instructions, then the Percentage of Instructions which must be Rewritten in time $\Delta t$ is

$$\frac{w \epsilon k u C'}{P} e^{\frac{-kuC't}{P}} \Delta t$$

FIGURE 4.22.14 PROGRAM ERROR RATE MODEL

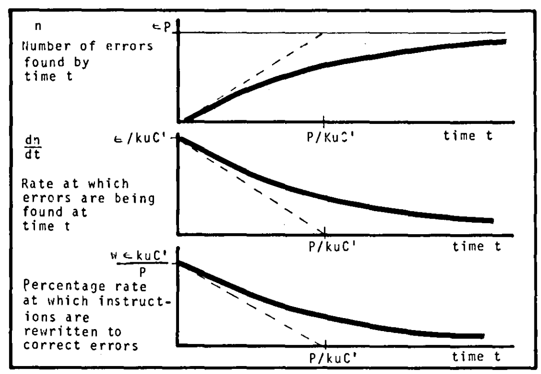



FIGURE 4.22.15 PROGRAM ERROR FACTORS VS. TIME

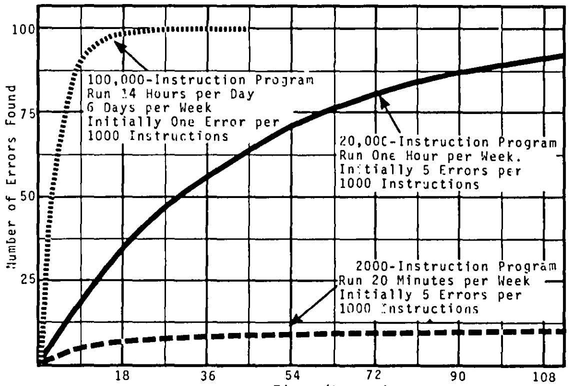



FIGURE 4.22.16 PROGRAM MAINTENANCE I
PROGRAM ERRORS FOUND VS. TIME FOR TWO APPLICATIONS PROGRAMS

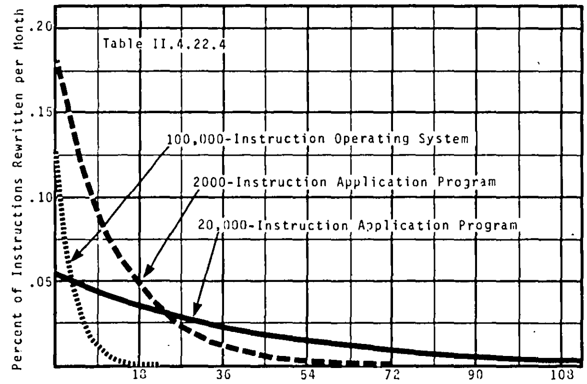



FIGURE 4.22.17 PROGRAM MAINTENANCE II
PERCENT OF INSTRUCTIONS REWRITTEN PER MONTH

the model predicts that 23 of the 100 errors will surface in the first month of operation.

We get an independent evaluation of the theory by applying it to the data collected during initial operation of a special operating system developed for the Univac 1108 (LyncW75). The dots shown in Figure 4.22.18 represent the cumulative number of software failures observed during the first thirteen months of operation of this system, and the solid line is an exponential which roughly fits the data. The eight-month time constant is comparable to that computed for the imaginary system of Figures 4.22.16 and 4.22.17, though the error incidence $\epsilon$ (156/40,000 or 0.0039) is almost four times the value we assumed in plotting those figures. The data brings to light a serious difficulty with our model, however. If we use Musa's value for the constant of proportionality k, and adopt what seem to be reasonable assumptions about the speed of the Univac 1108 and about the fraction of the time the system is executing the operating system programs, we compute a time constant of a little over 0.1 months compared to the eight months observed. As is indicated in Figure 4.22.18, the data given would predict a value for k of $0.018/10^6$, seventy times smaller than Musa's.

The reason for this very large difference is not clear. MusaJ75 does not provide the raw data from which the value for k was computed. One can infer from the data given that the computer used was substantially slower than the Univac 1108, and can speculate that our assumption that the rate of error detection is proportional to the execution frequency (and thus to the processor speed) may be false. But the assumption seems quite reasonable, and the difference between the two k's seems so large that it must be accounted for in some other way. Clearly we need more data.

But there is a bigger and much more serious difficulty with our model. If the primary task of program maintenance is to correct errors; and if a checked-out, released program has an average of five errors per 1000 instructions; and if five lines of code must be rewritten to correct an error; and if the maintenance programmer writes the same number of lines per code per month as the initial programmer—then twenty-five lines must be rewritten for every 1000 written, and one maintenance programmer can perform maintenance for *forty* initial programmers. In fact, what is called program maintenance requires much more work than is implied by the above analysis. For example, the Army-Air Force data summarized in Table II.2.21.1 includes figures on the number of programmers assigned to maintain various applications programs. For these systems, the number of programmers assigned to maintenance on a permanent basis often *exceeded* the number originally assigned to develop the programs.

There are several explanations for this substantial difference between theory and practice. Undoubtedly the most important is the fact, mentioned in the introduction to this section, that the maintenance or sustaining group is often given the responsibility for adding new features and generally improving the program, as well as correcting its errors. At the time a program is complete, the development group generally has several suggestions for improving its performance or for making it more efficient. As it is applied, users will suggest desirable new features; and over a period of time entirely new requirements will arise, imposed by changes in the organization or externally—e.g. by new government regulations. Sometimes proposed changes are so extensive that a completely new program is developed; but more often the changes are implemented as part of a sustaining activity.

There are other factors which contribute to high program maintenance costs. One is the practical problem of building and retaining a group of individuals who are familiar with all the organization's programs. Another is the certainty that the act of correcting errors begets other errors which in turn must be corrected. Belady and Lehman (BelaL71) show that, given the right circumstances (which they postulate may actually occur in the maintenance of very large programs), the maintenance function may actually become unstable, creating errors at a higher rate than errors are cured. Musa was concerned about this potential problem, but concluded it was not serious: for the programs he examined, the average ratio of the rate of reduction of errors to the rate of failure occurrence was 0.96.

The cost of program maintenance in practice is so high that we need a better understanding of the things which affect it.

**Comparing Hardware and Software Development.**

At the beginning of this section on development costs, we noted that there are striking similarities between hardware and software development projects. Specifically, if we compare the product design (not including technology developments) of a processor or controller with the design of a software product or application program, we note the following similarities: both start with a given planning specification; both include a system design phase where algorithms are specified, timing and sequence decisions are made, and the task is partitioned; and both include detailed design and test phases. Most important, the detailed design phases are remarkably alike. The designer's task is to implement the system design by assembling a set of well-defined and simple logic elements (instructions or statements for the programmer, flip-flops, gates, counters, and registers for the logic designer) which are connected in accordance with specified rules. The software "connections" are the lines drawn between blocks on a flow-chart; the hardware "connections" are the wires which tie components together. Once assembled, the logic elements carry out a sequence of operations whose effect is to perform the functions described in the planning specification.

Although hardware projects occasionally run into difficulty and are delivered late or with less-than-specified performance (e.g. IBM's Stretch, Burrough's ILLIAC IV, CDC's Star), it is evident that software projects run into difficulties much more frequently. It would therefore seem that a close comparison of the two processes might be fruitful—for example, that steps taken to improve one process might benefit the other, or that an understanding of the problems which beset one might warn us of potential or actual problems in the other.

The development resources required in 1974 for hardware and software projects are compared in Figure 4.22.19. Comments:

1. For the hardware projects, a logic element is a flip-flop, gate, or MSI logic component. For software projects, a logic element is an object instruction.

2. The constant factor (60 or 120 man-months for a product with no elements) in the hardware projects should be ignored—as stated above, there probably should be a similar factor associated with software projects.

3. Hardware and software projects are remarkably similar when looked at in these terms, especially when we remember

the variability which exists from project to project, and the fact that the curves themselves are the result of a variety of estimates and approximations.

Presumably development difficulty, and therefore resources required, is in part a function of the complexity of the design. For example, it must be dependent on the complexity of the logic elements (gates or commands), on the number of elements in the product, on the complexity of the products themselves for a given number of logic elements, on the interconnection flexibility available to the designer, and on the simultaneity (parallelism) of operation permitted in different parts of the product.

Presumably also development difficulty is dependent on the procedures followed and the disciplines enforced during the design process. For example, it will be affected by the completeness of the initial product specifications, by the availability of design automation tools, by the difficulty involved in product test, by project management techniques, by the experience and ability of the project team, and by the way design changes are implemented and controlled during the development process.

On the basis of this very cursory discussion, I offer the following tentative conclusions:

1. Probably the great interconnection flexibility possible in software use is a major cause of development problems. A program can itself change its own "connections" by modifying instructions; there is no analagous way for a processor to re-wire itself (though a microprogrammed computer having a writeable control store is perhaps equivalent). Steps taken to reduce the use of this interconnect flexibility, by designing re-entrant programs and by employing "structured programming" techniques, seem to reduce the incidence of software project troubles.

2. As was mentioned in connection with Figure 4.22.13, design resource requirements are probably a non-linear function of product size and complexity. It seems likely that modern software products are, more often than hardware products, complex enough to be materially affected by this non-linearity (compare, for example, Figure 1.25.5 and Table 4.22.2 with Table 4.11.6). The continuing reduction in the cost of logic elements encourages hardware designers to plan more complex products, and suggests there may come a point where hardware projects will more frequently encounter difficulties.

3. Qualitatively, it would seem that a hardware logic element is less complex than a software logic element—that a gate is simpler to understand and use than an addition command, for example. I know of no way to measure the relative complexity; but once again, the trend in hardware is towards using more complex elements (arithmetic unit "slices", or logic multiplexers and decoders, for example, implemented in IC components), and therefore perhaps toward project difficulty.

4. A more comprehensive study of the similarities and differences between hardware and software development might prove very useful in solving some software development problems or in heading off hardware problems.

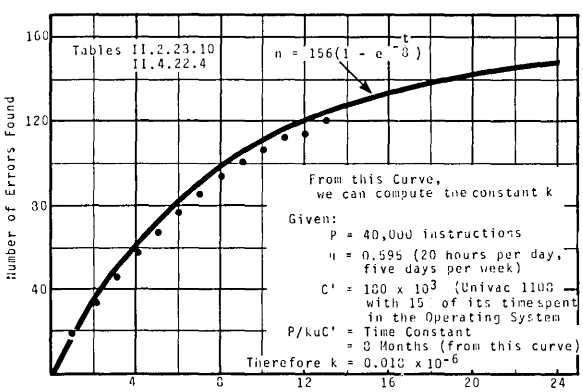



FIGURE 4.22.18 PROGRAM MAINTENANCE III
SOFTWARE FAILURES REPORTED FOR AN OPERATING SYSTEM

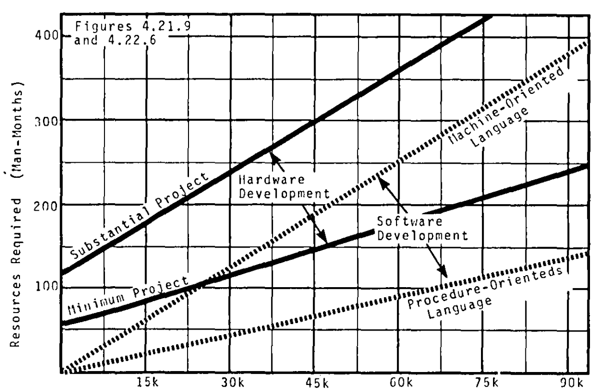



FIGURE 4.22.19 COMPARING HARDWARE AND SOFTWARE DEVELOPMENT
PROJECT RESOURCES VS. LOGIC ELEMENTS

## 4.3 Sales and Marketing Costs

The inventor is naive who believes the world will beat a path to his door to buy his new mousetrap. Even an infallible mousetrap will not sell itself, and the wise inventor establishes a sales division whose responsibility it is to distribute what the factory turns out.

The salesman is somehow regarded as an unnecessary nuisance by American intellectuals—he is society's low man. He is pictured as a purveyer of false dreams, who misrepresents an inadequate product, takes the money and is subsequently deaf to all complaints. Undoubtedly there are salesmen who fit this unhappy description. But the salesman has, in fact, an important and clearly-defined function: he must persuade potential customers to pay for a product. When the product is complex, or the potential customers unaware of its applicability to their problems, the effective salesman serves as educator in explaining what the product can do and as inventor in determining how it can serve the particular customer. Marketing, in contrast to sales, is a broader term which encompasses selling, but includes all the activities required to insure that an organization's products are distributed.

**Marketing Functions.** A brief listing of the functions of a marketing department would include the following:

1. Participate in market planning, which identifies the classes of customer to be served along with their potential purchase volumes, and product planning, which determines the general attributes of the products needed to serve those customers.
2. Establish prices for new products, and revise, when necessary, the prices of existing products, keeping in mind the profitability of the organization, the activities of competitors, and the elasticity of the market—the expected relationship between price and number sold.
3. Attract the attention of potential customers with advertising, press releases, mailings, and calls by salesmen.
4. Make the sale. This is the salesman's primary function. It requires first that he "qualify" the potential customer—i.e. determine whether the customer has in fact decided to make a purchase, whether he has funds now available to pay for it, and whether he has an open mind about a supplier (or has already decided to buy from a competitor). Next the salesman must identify the potential buyer's decision-makers—the individual or group which has been authorized to make the buying decision. These preliminary steps lead to the chief selling job: explaining the merits of the product and showing how it may be used. And finally it is the salesman's job to close the sale—to persuade the decision-maker to sign an order authorizing the delivery of a specific item or set of items.
5. Support the customer, after the closing, with help on planning the installation, training his personnel, implementing new functions and procedures, and (ultimately) adding new equipment to perform additional functions or to handle heavier loads.
6. Support the salesman by educating him about the product and its uses, training him to be an effective salesman, and providing him with various sales aids, brochures, and manuals.

**Marketing Costs.** The cost of marketing a product depends on the type of product being sold, the kind of customer being approached, and the nature of the sales force. With regard to product, we might distinguish the selling of hardware, software, systems (hardware plus software), services, and supplies, each of which presents unique selling problems and costs. And in each of these categories the sales problems may vary widely: a time-sharing company and a computer system maintenance company both sell services, for example, but their products and sales problems are obviously quite different.

Selling costs also depend on the kind of customers approached. Most organizations with data processing products sell directly to the end user, which itself is usually a company, or a government agency or university. However, products can also be sold to organizations which in turn sell them to the end user. In such situations, inasmuch as the buying organization takes a number of units and itself performs the ultimate selling function, the supplier offers his products at a substantial discount. The buying organization may for example be a retailer who sells punch cards or pocket calculators; or it may be an original equipment manufacturer (OEM) who incorporates the product into a product of his own—as a key-to-disk system manufacturer may incorporate another manufacturer's minicomputer into his own system, for ultimate sale to an end user.

Finally, selling costs depend on the type of sales force employed. One can sell directly using one's own employees; or one can sell using a sales representative, which is an independent organization whose sole function is selling technical products throughout a specified geographic region. The sales representatives' functions are to make the sale and to support the customer after the closing: the other marketing functions, including market/product planning, pricing, advertising, and sales support remain with the primary organization. The sales representative receives a commission (computed as an agreed-to percentage of the sales price) on the sales he makes, and does *not* maintain an inventory of the items he sells—he forwards orders to the supplier who fills them from his own inventory. Sales representatives are typically used when an organization is small and cannot afford its own sales force, or where it wants to promote sales in geographic regions its own sales force can't cover.

To understand better some of the ramifications of marketing costs, let us examine typical costs for a system company selling GP computers to end users. A simplified model describing such costs is shown in Figure 4.3.1. Total costs are the sum of home office and field costs. Field costs are dependent on the number and kind of people doing the selling, and typically GP systems are sold by a salesman who receives a base salary and a commission, supported by systems analysts who help the salesman by developing proposals and by assisting the customer to prepare for and manage the system. The systems analysts may or may not receive a fraction of the commission. The field sales force must be supported by managers and secretaries, working in offices, and their travelling and entertainment expenses must be reimbursed by the company. These various costs are covered by an overhead factor applied to their base salaries. It is useful to divide total costs by total sales to get a percent-cost figure, and to examine that percentage from the point of view of an individual salesman, whose average sales responsibility is obviously the quotient of total product sales and the number of salesmen—that is, $S/n$.

In practice, a company plans its annual sales strategy and expenses a year in advance. The marketing organization is then given an expense budget based on this plan, and it hires people and establishes salaries and other costs so that the total cost will be within the budgeted figure. In accepting the expense budget, it agrees to sell a specified dollar value of systems during the budget period. Typically the budgeted expenses are 15% of the expected sales.

With its budget in hand, the marketing department must apportion expenses and expected sales to the sales force. Each salesman is assigned a territory—sometimes geographical, sometimes a list of customers and potential customers—and is given a specific sales goal for that territory. The goal will differ from territory to territory depending on the salesman's experience and ability and on the sales prospects in the territory. The sum of all the individual sales goals equals or exceeds the expected sales the department agreed to in accepting the budget.

A variety of sales strategies are possible in the framework of this simple model, and Figures 4.3.2 and 4.3.3 illustrate two possibilities, one designated by a solid, the other by a dashed, line. The first of these figures plots the last equation of Figure 4.3.1, showing total costs as a function of the average sales per salesman for the two strategies. The dashed-line strategy requires that the salesmen sell an average of $750,000 worth of systems in the year, provides each salesman with two systems analysts for support, and backs him with $26,500 in home-office marketing expense. The solid-line strategy in contrast increases the sales goal to $1 million, but also increases the support to three systems analysts and $41,000 in home-office expense. Comments:

1. If each organization achieves its sales goal, it ends the year operating at that point on the curve represented by the black dot, where total costs are 15% of sales.

2. If an organization exceeds, or fails to meet, its sales goal, the result will be sales costs which are less than or greater than 15%, as shown by the curves. Missing either goal by 10% changes costs by roughly 10%—increasing them to 16.6% of sales if the goals are not met, and reducing them to 13.7% if the goals are exceeded.

3. An organization which fails to meet its sales goals is thus immediately penalized by having sales expenses a greater-than-expected proportion of sales and therefore ultimately of revenue—"ultimately" because some sales made this year won't be delivered and paid for until next year or even the year after. But in addition, the company's other plans were based on a higher level of sales than were actually achieved. In particular, the manufacturing organization presumably bought materials and started building systems in anticipation of the planned sales level, and the development budget was set at a level consistent with planned sales. Thus a failure to meet sales goals leads to an unexpected increase in inventory of parts and unsold equipment as well as a reduction in shipments and thus a drop in profits. Obviously sales is the key to company success, and neither innovations in hardware or software development, nor manufacturing efficiencies will be of use if the marketing organization fails to meet its goals.

4. Note that both strategies employ four field sales personnel for every $1 million in annual sales. To achieve $100 million in sales, for example, the dotted line strategy would deploy 133 salesmen ($100M/$750k) and 267 systems analysts, while the solid-line strategy would use 100 salesmen and 300 analysts—a total of 400 in either case.

Marketing Costs = Home Office Costs + Field Sales Costs

Assume H = Annual Home Office Costs

Field Sales Costs = Field Salaries, with Overhead + Commissions

- $n$ = Number of Salesmen
- $x$ = Number of System Analysts per Salesman
- $w_1$ = Salesman's Base Annual Salary
- $w_2$ = System Analyst's Annual Salary
- $b$ = Overhead Rate (ratio)
- $c$ = Commission Rate (ratio)
- $S$ = Annual Product Sales

Total Annual Marketing Costs

$$= H + (nw_1 + nxw_2)(1+b) + cS$$

Annual Cost as Fraction of Total Annual Sales

$$= \frac{H + n(w_1 + xw_2)(1+b)}{S} + c$$

$$= \frac{\frac{H}{n} + (w_1 + xw_2)(1+b)}{S/n} + c$$

Where

- $H/n$ = Annual Home Office Cost per Salesman
- $S/n$ = Amerage Annual Sales per Salesman

FIGURE 4.3.1 MARKETING COST MODEL
COSTS FOR A SYSTEM COMPANY SELLING DIRECTLY TO END USERS

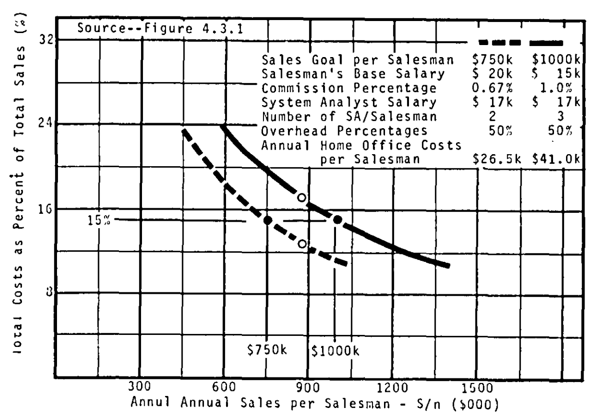



FIGURE 4.3.2 MARKETING COSTS
COSTS AS A FUNCTION OF AVERAGE SALES PER SALESMAN

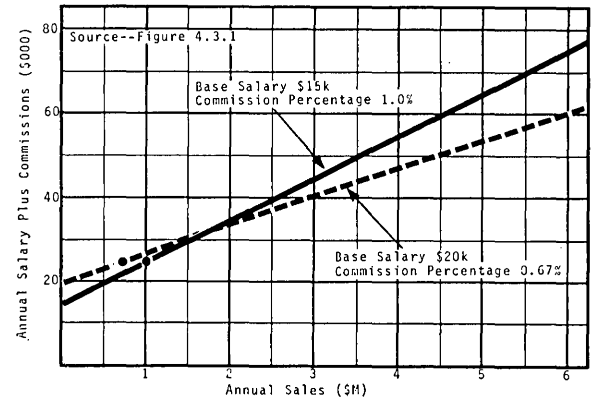



FIGURE 4.3.3 SALESMAN'S INCENTIVE
SALARY PLUS COMMISSION AS A FUNCTION OF ANNUAL SALES

5. The curves of Figure 4.3.2 can represent slightly different strategies if we change the sales goals. For example, a large, wealthy, and successful organization with very low manufacturing costs might be able to afford a sales cost 17% of sales, while a small, young, and struggling company, might be forced to hold those costs at 13%. These two results could be achieved by setting sales goals at $875,000 (as shown by the open dots in the figure), without changing any other portions of the strategy. The large organization would then be using almost 4.6 field sales people per $1 million of sales, while the smaller one would be using less than 3.5. And these could be quite reasonable differences if the bigger company is selling in a crowded, competitive, and near-saturated marketplace while the smaller is selling in a newer and more specialized one.

The salesman, who is the key to the marketing organization's and thus to the company's success, has typically been given strong financial incentives to meet sales goals. As is shown in the model, he receives a base salary plus a commission which is some percentage of the sales he closes during the year. In fact, the commission may be shared with the systems analysts, and the commission plan may not be the linear one depicted here. But given those simplifying assumptions, Figure 4.3.3 shows how the salesman's total pay varies as a function of his annual orders taken. Note the plans were chosen so that a salesman meeting his goal under either strategy earns $25,000 per year. But an individual who is particularly effective will consistently exceed his goal. And there will be occasional years when the effective salesman is also lucky—when, for example, a large company with headquarters in his territory signs a purchase order for several systems to be delivered to various regional plants—and earns three to five times his base salary. Such incentives attract and hold able people, and encourage them to investigate all potential customers in their territory and to provide helpful advice and effective proposals to those who purchase systems.

**A look at IBM Marketing.** IBM sells and services a variety of products besides computers—notably typewriters, punched-card equipment, and more recently dictating machines and copiers. On two occasions IBM has reported the total number of sales and service personnel in its employ, and these figures are shown in line 1 of Table 4.3.1. For the nine-year period shown (1956-1965), when IBM's business changed from largely punched-card-oriented and electromechanical systems to electronic computers, and when its worldwide revenues almost trebled (line 6), sales and service personnel remained a relatively constant 30% of total employees (lines 1-3).

While total revenue was growing, what IBM classifies as "Data Processing System" revenues grew even faster, annual orders for computers grew faster still, and the value of computer systems in use grew fastest of all (lines 6-13). Since the number of computer sales people is related to the value of orders taken, and the number of service engineers to the value of computer systems in use, we can infer that these categories of personnel grew faster than most other categories. Using the estimated productivity figures of lines 14 and 16, in terms of people required per million dollars worth of orders or of systems being maintained, we can compute the number of sales and service people required from the other data in the table. The resulting totals, on line 18, have indeed increased dramatically as a percentage of all sales and service people (line 19) and of all employees (line 20). But note that, in 1965, when nearly 80% of revenues were from data processing, only 27% of the sales and service employees were selling and servicing computers. If our analysis is valid, the majority were presumably selling and servicing relatively low-priced products such as typewriters, where high productivity per dollar sold or maintained is difficult to achieve.

**TABLE 4.3.1 THE GROWTH IN IBM SALES AND SERVICE**

| | | Units | 1956 WW | 1956 US | 1965 WW | 1965 US |
|---|---|---|---|---|---|---|
| 1. | Number of Salesmen, Systems Engineers, and Customer Engineers (Servicemen) | k | - | 15.8 | 55.0 | 32.0 |
| 2. | Total Number of Employees | k | 72.5 | 51.2 | 172.4 | 111.1 |
| 3. | Percent of total in Sales and Service | % | - | 30.9 | 31.9 | 28.8 |
| 4. | Percent Increase—In Total Employees | % | - | - | 136.5 | 111.9 |
| 5. | In Sales and Service Employees | % | - | - | - | 102.5 |
| 6. | Total Revenue | $B | .892 | .734 | 3.573 | 2.487 |
| 7. | Data Processing System Revenue | $B | .52 | - | 2.75 | - |
| 8. | Total GP and Mini System Value Ordered | $B | .174 | .143 | 2.725 | 1.897 |
| 9. | Total Value of Computer Systems In Use | $B | .244 | .227 | 8.020 | 5.852 |
| 10. | Percent Increase—In Total Revenue | % | - | - | 300.6 | 238.8 |
| 11. | In Data Processing System Revenue | % | - | - | 429 | - |
| 12. | In Computer System Value Ordered | % | - | - | 1466 | 1227 |
| 13. | In Value of Computer Systems in Use | % | - | - | 3187 | 2478 |
| 14. | Estimated Number of Salesmen and Systems Engineers—per $1M Ordered | | 4 | 4 | 4 | 4 |
| 15. | Total | k | .7 | .6 | 10.9 | 7.6 |
| 16. | Estimated Number of Customer Engineers per $1M in Use | | 1.25 | 1.25 | 0.5 | 0.5 |
| 17. | Total | k | .3 | .3 | 4.0 | 2.9 |
| 18. | Total Estimated Data Processing Salesmen, Systems Engineers, and Customer Engineers | k | 1.0 | .9 | 14.9 | 10.5 |
| 19. | As Percent of All Such Employees | % | - | 6 | 27 | 33 |
| 20. | As Percent of All Employees | % | 1 | 2 | 9 | 9 |

Source: See Notes in Part II

## 4.4 Maintenance Costs ●

We have seen some evidence which indicates that computers today are substantially more reliable than they were in the early fifties, when the first machines were made to work and there was, in some quarters, serious doubt as to whether such large collections of vacuum tubes would ever operate longer than five minutes without failure (see Figures 2.23.21-23). Despite the very great improvements which have been made, computer system reliability is still deplorable. We saw in Section 2.23 that large systems like the IBM 370/165, the BGH 5500, and the Univac 1108 may typically suffer one to five failures per day. And anyone who works very long at a computer terminal—whether he's writing BASIC programs, or confirming airline reservations, or subscribing to a text-editing service, or handling bank deposits and withdrawals—becomes accustomed to failures somethere in the range of several per week to several per month.

It has been argued, rather cogently, that computer users have too readily accepted unreliable service as inescapable, and that system manufacturers have too complacently devoted their engineering money to improvements—first in speed and then in functions performed—with nothing but a certain amount of lip-service attention paid to reliablity. Robert A. Worsing, who operated one of the world's biggest IBM installations at Boeing in the mid-sixties, put it very succinctly in a speech to a group of IBM maintenance managers. "How many of you," he asked rhetorically, "would board a Boeing 707 jet which, despite two hours of PM every day had a probability amounting to certainty that it would require airborne maintenance at least once between midnight on succeeding Sundays? ... Why do you expect so much more reliability with an airplane than with a computer? They aren't any more expensive. They are much more difficult to pilot. They are not kept in a special environment. I say the only reason is that airplane customers regard degrees of reliability as unthinkable, while computer customers do not." (WorsR67) The fact that reliability data is difficult to locate substantiates Worsing's claim. If users were really determined to get some action taken regarding reliability, their first step should be to establish reliability measures, and then regularly to collect and publish data based on the measures. A mass of data which gave statistically significant comparisons of the reliability of different systems and of the equipment of different manufacturers would provide a real incentive to system manufacturers to concentrate on reliability improvements, and would at the same time help them by identifying more accurately the kinds of trouble users have.

In this section we will explore the cost of unreliability from the manufacturers', not the users', point of view. We will begin by reviewing maintenance prices, which bear some relationship to costs, and will then establish and discuss a simplified model of the maintenance activity, connecting system failure rates and repair times with the dollars spent to keep equipment in working order.

## MAINTENANCE PRICES ●

Trends in IBM maintenance prices are given in Figures 4.4.1 to 4.4.4. To make it possible to compare prices of units of various degrees of complexity, the data is expressed as monthly maintenance price per $100,000 in sales price—so a $200,000 processor which cost the user $400 per month to maintain and a $50,000 controller which cost the user $100 per month would both be plotted as $200 per month per $100,000 purchase price.

Each of the four figures traces the history of two equipment categories between 1960 and 1973. Figure 4.4.1, for example, describes processors along with the average of all units. And for each of those two categores, two curves are shown. The solid curve plots the maintenance price of the then current generation of equipment; the dotted curve, the maintenance price of all equipment, new and old, still shown in the GSA price catalog. (The data represents a moderate-sized sample of all IBM units, but it is not weighted—the maintenance price per $100K of the 360/65 and the 360/30 are averaged together with no regard to the relative numbers of the two units installed. See notes on Table II.2.11.3 for more information.)

Looking at the curves, we observe that there has been a fairly consistent upward trend in the maintenance prices of processors, internal memory, controllers, and punched card equipment; and that tape units, moving-head files, and line printers exhibited a sharp drop in maintenance price with the introduction of the second-generation systems. The net result, as shown in the "All Units" curves of Figure 4.4.1, was a reduction in average maintenance price from 1960 to 1963 and a subsequent substantial rise. Note that in absolute terms the electromechanical units (tape units, moving-head files, line printers, and card equipment) cost the user two to four times as much to maintain as do the electronic units (processors, controllers, internal memory).

The trends shown are the resultants of a great variety of forces. In setting maintenance prices for a new unit, IBM estimates costs (based on expected reliability and maintainability) and adds a modest profit to establish a minimum price; depending on various factors (and especially the maintenance prices then existing for comparable IBM units), an initial price is set equal to or higher than the minimum. Then after some months of field experience with production units, the maintenance price may be adjusted to reflect actual operating experience. Subsequent changes to the purchase price also affect the maintenance ratio plotted here. And since (as we shall see) labor costs are the largest component of the cost of maintenance, the continuing upward trend in salaries and wages would lead to increased costs and prices even if nothing else changed. If the maintenance price for "All Units" in Figure 4.4.1 is expressed in 1958 dollars (using the GNP deflator of Table II.1.1.1), we should find it was highest in 1960, lowest in 1963, and has since 1964 been relatively stable. (See the last line of Table II.2.11.3.)

All these graphs refer to IBM prices and products. I do not have corresponding data available for the other manufacturers. However, Table II.4.4.2 compares maintenance costs for all major system manufacturers as of 1967. Though the samples are small, the prices seem to confirm the conclusion implied by the reliability data in Figures 2.23.21 to 23: that IBM equipment by 1967 was substantially more reliable than that of other manufacturers. In 1967 only RCA had an average maintenance price per $100K sales price as low as IBM's. Honeywell and NCR were about 50% higher, Burroughs and CDC 80% higher, Univac 115% higher, and XDS almost 200% higher. These figures do not, of course, *prove* anything about relative reliability. The relationship between maintenance costs and reliability is fairly direct, as we shall see. But maintenance costs are influenced by other things (especially by the geographical concentration of equipment installations), and in any event there is not necessarily a direct relationship between costs (to the maintenance supplier) and price (to the system user). Furthermore, it can be argued that part of the maintenance price differential, as measured in monthly payments per $100,000 purchase price, stems from the fact that IBM's purchase prices *for a given function* tend to be higher than those of her competitors. Nevertheless, the very large differences in maintenance price per $100K system price between IBM and the other manufacturers is at least consistent with observed differences in equipment reliability.

## A MAINTENANCE COST MODEL ●

Once a product line is engineered and in production, little can be done about the intrinsic reliability (best characterized as Mean Time between Failures or MTBF) and maintainability (best characterized as Mean Time to Repair, or MTTR) of the hardware. In the first place, the design philosophy and approach is established and committed and cannot easily be changed. One can't add special self-checking features, or change from a statistical to a worst-case approach to tolerances without a very major redesign. In the second place, even the most minor change is very costly once a unit is in production. Any change must be retrofitted onto every unit so far produced, and onto units partly complete in the factory. New parts must be ordered and obsolete ones scrapped. New test procedures and tooling must be designed and put in use, and old tooling modified or scrapped. Documentation must be changed, and training manuals revised. Manufacturing and maintenance personnel must be retrained.

Despite the difficulty and expense, a typical product undergoes many reliability and maintainability changes during its life. The changes are generally introduced to correct design errors or oversights (e.g., a function performed incorrectly, or a dimensional tolerance improperly allowed for), or to solve problems which arose after the product was first shipped (e.g., a purchased component which could not quite meet its specifications, or a preventive maintenance procedure too difficult to follow in practice). The various changes can however only eliminate the grossest and most obvious kinds of failures. There remains a hardware failure rate inherent in the design. And to repair equipment when these inescapable failures occur, to prevent their occurrence with preventive inspections, replacements, or adjustments—and to deal with software failures—a manufacturer must employ a maintenance organization.

The responsibilities of the maintenance organization give it a schizophrenic personality. One responsibility is to keep the customer satisfied with the operation of the system, and that responsibility would best be fulfilled by stationing an experienced Customer Engineer (CE) knowledgeable about every product and expert in software problems, at each site and by providing him with a complete set of spare parts. The other responsibility is to minimize the cost of maintenance. And that responsibility might best be fulfilled by having a maintenance man call on a site once a month to do PM and to repair any equipment which failed since his last call. For very large, multi-million-dollar installations, the first approach is practical and economic, and one or more CE's, with spare parts, are assigned to work at the customer site. For very small installations (e.g., a group of terminals at a remote site), it may be quite practical to use the second scheme. In either of these instances, the user's requirement for good service and the supplier's for low cost may coincide. But for the majority of moderate-sized installations the maintenance organizations must adopt a policy and strategy which best balances user and supplier objectives.

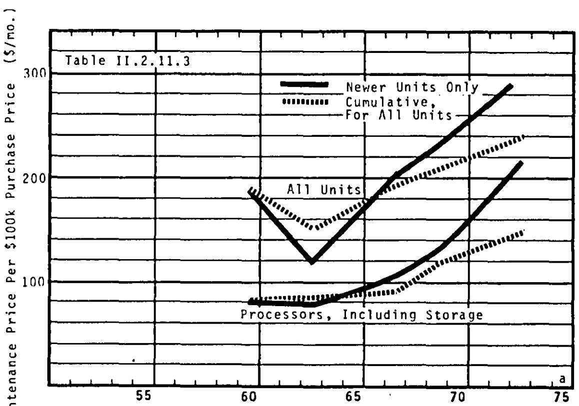



FIGURE 4.4.1 IBM MAINTENANCE PRICES I
AVERAGE FOR ALL UNITS, AND PROCESSORS

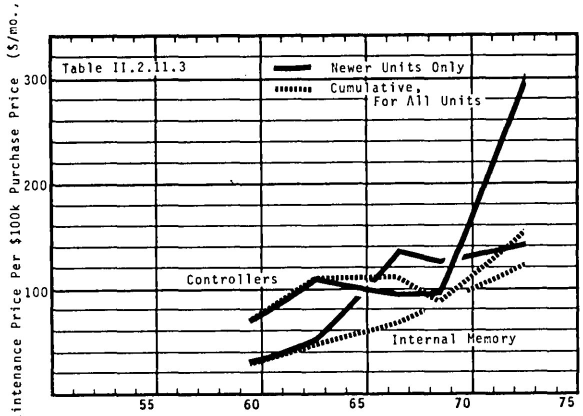



FIGURE 4.4.2 IBM MAINTENANCE PRICES II
INTERNAL MEMORY, AND CONTROLLERS

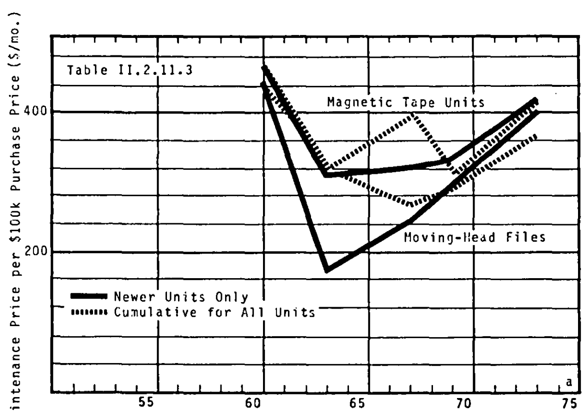



FIGURE 4.4.3 IBM MAINTENANCE PRICES III
MAGNETIC TAPE UNITS, AND MOVING-HEAD FILES

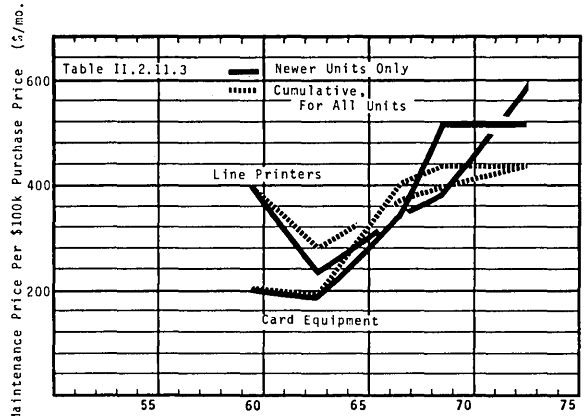



FIGURE 4.4.4 IBM MAINTENANCE PRICES IV
CARD EQUIPMENT, AND LINE PRINTERS

To provide some insight into the way these objectives interact, and to understand better the factors which affect maintenance costs in general, let us examine the very simple maintenance cost model described by Figure 4.4.5. It assumes there are three principal components to maintenance costs: the cost of corrective maintenance (CM), of preventive maintenance (PM), and of providing a spare parts inventory. The cost of the first two components is proportional to the hourly cost of the customer engineer and to the number of hours per month he must spend on CM and PM. The cost of spares is proportional to the investment in spares and to the cost of maintaining that inventory. Comments:

1. We assume the CE overhead rate includes the cost of his travel, supervision, tools, technical support, and facilities. We also note that the CE cannot spend all of his time directly on maintenance activities. Some of his time is spent on training, some on paperwork, some on equipment installations or removals and some on making engineering changes. Some of his time must be spent idle, waiting for a maintenance call, for if the CE is busy all the time, a customer having problems will have to wait until he is available. We assume all these non-maintenance activities are accounted for by dividing the CE's hourly rate by the fraction of the time he is available for maintenance.

2. When the CE has diagnosed a system's problem he usually cures it by replacing a subassembly of some kind. (Software errors, intermittent failures, and maladjustments are examples of troubles not cured by part replacement.) The replacement part comes from an inventory of parts held for that purpose. The cost of replenishing that inventory—of repairing the failed subassembly or of replacing it if it cannot be repaired—is a cost proportional to the number of failures which occur. Since preventive maintenance activities also frequently result in parts usage, and since the usage is roughly proportional to the time spent on PM and CM , we have approximated it by using an equivalent hourly parts cost which is added to the CE salary rate.

3. We assume that the frequency with which failures occur is proportional to the total time the equipment is operated per month. In other words if one system is operated 10 hours per day and another identical system 20 hours per day, I assume the latter will have twice as many failures per month as the former. Because the causes of failures are not well understood, this assumption is a bit suspect. Some failure mechanisms are a function of power-on time, whether or not the equipment is attended and "operating", and some users leave power on 24 hours a day. Some failures are accelerated by the temperature changes which occur when power and/or air conditioning is turned on and off. (The failure rate of an integrated circuit may double when ambient temperature goes from 20 to 40 degrees Centigrade—68 to 104 degrees Fahrenheit). The situation is not well-understood, and our assumptions should correspondingly be viewed with suspicion.

4. The maintenance organization must either be able to repair failed parts, or to supply them quickly from an inventory created for that purpose. Since many parts cannot be repaired (e.g., a broken gear or a bad bearing) and others require special tools or error-locating aids (e.g., a bad component in an electronic plug-in module) field repair is generally not feasible. The best spare parts strategy will be based on the expected populations and failure rates of individual parts, on repair or replacement time from the factory, and on transportation times between parts depots and user sites. The only factor we include is the total value of parts stocked, independent of their location. The cost of stocking those parts is assumed proportional to their manufactured cost, and includes depreciation, interest charges for the money tied up in inventory, and handling costs including loss, breakage, inventory control, etc.

5. Down time is time the system is out of service due to unexpected failures. It is assumed to start when the user detects the failure, and to end when the failure has been identified and eliminated. It includes the time it takes to report the failure to the maintenance organization, the time it takes that organization to locate and assign a CE, the travel time for the CE to reach the site, the time it takes to reprocuce and thus to locate the problem, the time required to correct the problem (including the time necessary to request and deliver a spare part from some other location, if necessary), and the time necessary to verify that the problem has been corrected. We lump all these factors into two times: the average time it takes the CE to reach the site (travel time) and the average time required to repair the failure (the MTTR).

6. Percent Down Time is found by dividing the average down time by the average interval between down times. That interval is the Mean Time Between Failures, or MTBF. The proportion of time the system is available to the user or for scheduled PM is found by subtracting percent down time from unity. For example, if a processor has an MTBF of 250 hours, a mean time to repair of 2 hours, and an average travel time of 1 hour, the percent down time is 3/250 or .012 (1.2%) and it is available for use or for PM 98.8% of the time.

7. Percent down time per \$100K of equipment price is found by dividing percent down time by the unit sales price expressed in units of \$100K. For example, if the processor whose MTBF is 250 Hours had a price of \$150,000, its percent down time per \$100K would be .012/1.5 = .008 (0.8% per \$100K).

8. PM time is the time required for a CE to do scheduled preventive maintenance on a unit. It is found by adding his travel time to reach the site to time actually required to perform the PM. PM travel time is less than CM travel time for several reasons: the CE can schedule his trip to visit sites in a sequence that shortens average time; he can perform PM on several units at once, reducing the travel time per unit; and he may be able to perform some PM during an emergency maintenance visit, with a resulting PM travel time of zero. Percent PM time is the quotient of PM time and the scheduled PM interval, and percent PM time per \$100K of equipment price is computed in the obvious way.

9. The percent total time lost to the user is the sum of percent down time and that portion of percent PM time which excludes PM travel time.

10. In the interest of simplicity, we assume that percent down times and PM times add together. In fact even with a single unit there will occasionally be a second failure while a first is being repaired, or the CE may be able to perform PM during CM time—while waiting for a spare part to be delivered, for example. For single units with large MTBF's, and low MTTR's, the probability of concurrent failures is small and it is reasonable to add percentages. As we combine several units into a large system and look at the maintenance costs of the entire system, we will have to take into account the higher probability of concurrent failures.

One useful way of regarding the maintenance activity is to think of it as a process whose costs are dependent directly on down time—on that portion of operating time the system is out of service due to failures. Figure 4.4.6 illustrates this print of view. The three dotted lines show how the cost of maintaining typical terminals, CPU's, memories, and peripherals vary with percent down time. (These curves are based on 1970 CE salaries, on 350 operating hours per month, and on a CE availability fraction of 0.65. See the discussion in connection with Table II.4.4.3 for more details.) Comments:

1. The incremental cost of maintaining a peripheral, based on the CE's salary and the parts cost of repairing the unit, is the same as the incremental cost of maintenance for processors and memory. In other words, if the percent down time for a peripheral increases by 0.5%, say, it will cost an extra $40 per month for every $100K in peripheral value; and an increase in 0.5% in CPU down time will also cost $40 per month. Terminals, on the other hand, have a higher incremental maintenance cost ($53 per 0.5% compared with $40) and this higher ratio comes about because the parts cost of repairing a terminal is high—the terminals are relatively simple and easy to diagnose and failures are usually cured by parts replacement, so the cost per CE hour of replacement parts is high.

2. The differences between fixed maintenance costs for the three types of unit—the maintenance cost for zero percent down time—are explained by the facts that we assume a substantial (and costly) PM program for the peripherals, but not for processor, memory, or terminals; and we assume that there are a large number of identical installed terminals, so the spares complement per terminal can be comparatively speaking quite low.

The solid line in Figure 4.4.6 is derived from the three dotted ones on the assumption that a system includes units as shown in the lower right-hand corner of the figure. And the black circles lying on the four lines represent operating points for a particular system in which processor, peripherals, and terminals have MTBF's of 1000, 750, and 2000 hours, respectively, and MTTR's of 3, 1.5, and 0.5 hours. (Travel time is assumed to be 1 hour.) The resulting system MTBF and MTTR are 58.8 and 1.5 hours—assuming the failure of *any* component creates a system failure. Comments:

1. Remembering (Figure 4.4.5) that percent down time is found by dividing the sum of MTTR and travel time by MTBF, we can get a feeling for the effects of changes in these basic maintenance parameters. If inexperienced maintenance personnel or a series of hard-to-diagnose hardware or software problems caused the CPU and Memory MTTR's to increase from 3 to 5 hours, the black circle would move to the right on the CPU/Memory dotted line from 0.4% down time to 0.6% down time and maintenance cost for the $200k processor and memory would increase by $32 (12.7%) per month. If an engineering change improved terminal reliability so that the MTBF increased from 2000 to 2500 hours, the terminal operating point would move to the left from 1.5% down time to 1.2%, and maintenance cost for the six $5000 terminals would drop by $9.50 (16.4%) per month.

2. System down time is 0.85% per $100K, or 0.85x5 = 4.25% for the $500K system. System availability is thus (100-4.25) = 95.75%, not counting time lost to PM—which of course can be scheduled. PM lost time is 0.5% per peripheral or 4.5% total.

3. If we stopped performing PM on the peripherals, the peripheral dotted line would slide down on the figure until it coincided with the CPU/Memory line. However, the peripherals would then be susceptible to the various short-term failures which PM anticipates and prevents; and peripheral MTBF would drop to perhaps 200 hours, so that peripheral down time would be 4.2% per $100K. The peripheral black circle operating point would thus move to the right completely off the graph, and peripheral maintenance costs would increase from $323 per $100K to $437 (see the discussion below regarding Figures 4.4.9 and 4.4.10).

4. If we exchanged a peripheral for six more terminals (as we might do if we were using terminals for an increasing share of data entry), the "system" line in the figure would slide down and the operating point would move to the right. The result would be an increase in system percent down time (from 0.85% per $100K to 0.87%) and a decrease in maintenance cost (from $1190.6 per month for the entire system to $1151.7).

Monthly Maintenance Cost =
Corrective Maintenance Cost
+ Preventive Maintenance Cost
+ Inventory Cost

Corrective or Preventive Maintenance Cost =
(Hourly Customer Engineer and Spares Usage Rate)
x (Equipment Operating Hours per Month)
x (Percent Corrective or Preventive Maintenance Time)/100
= R x H x Percent Maintenance Time/100

Inventory Cost =
(Maintenance Parts Inventory Value) x (Inventory Monthly Cost Rate)
= I x C

Let R = Hourly Customer Engineer and Spares Usage Rate

$$= \frac{(\text{C.E. Hourly Rate}) \times (1 + \text{Overhead Rate})}{\text{Fraction of the Time the C.E. Spends on Maintenance}}$$

+ Hourly Parts Cost

$$= \frac{S\,(1 + r)}{f} + P$$

Let T(p) = Scheduled P.M. Interval
T(rp) = Scheduled C.E. P.M. Time
T(tp) = C.E. Travel Time for P.M.
T(f) = Mean Time Between Failures (MTBF)
T(rf) = Mean Time to Repair (MTTR)
T(tf) = C.E. Travel Time for Corrective Maintenance

Then Percent Preventive Maintenance Time

$$= \frac{T(rp) + T(tp)}{T(p)} \times 100$$

Percent Corrective Maintenance Time
= Percent Down Time

$$= \frac{T(rf) + T(tf)}{T(f)} \times 100$$

Summarizing:
Monthly Maintenance Cost

$$= \left(\frac{S\,(1 + r)}{f} + P\right) H \left(\frac{T(rp) + T(tp)}{T(p)} + \frac{T(rf) + T(tf)}{T(f)}\right) + I \times C$$

And Maintenance Cost per $100k Equipment Price is Found, if Percent Maintenance Times and Maintenance Parts Inventory are Given per $100k Equipment Price

FIGURE 4.4.5 MAINTENANCE COST MODEL

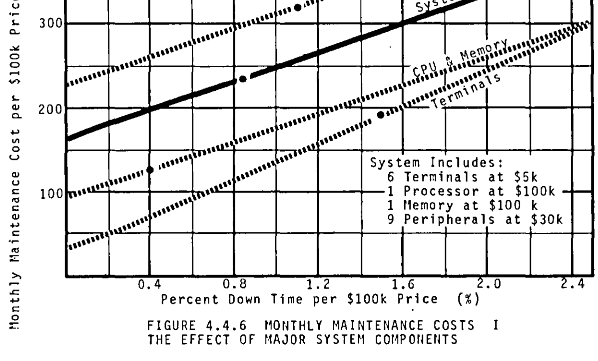



FIGURE 4.4.6 MONTHLY MAINTENANCE COSTS I
THE EFFECT OF MAJOR SYSTEM COMPONENTS

The next three figures show the sensitivity of the results to some of the assumptions made in setting up the model. Figure 4.4.7 shows what happens to system costs when a change is made in the fraction of his time the average CE can spend on maintenance. We assumed 0.65 (the black circle) with a resulting maintenance cost of $238 per month per $100K at 0.85% per month per $100K down time. A new company with relatively few units installed over a wide geographical area might have to distribute CE's so that each CE handles only a few units, and the average idle time is higher. Or a company might spend a disproportionate amount of CE time on paperwork and expediting. In either case, the fraction f might drop to 0.5, and maintenance costs would increase to $282 per month per $100K. Conversely in a big well-run company f might be 0.8 and maintenance cost would drop to $211.

The effect of changing operating hours per month is shown in Figure 4.4.8. Roughly speaking, the four lines shown represent system maintenance costs for one-, two-, three-, and four-shift operations. The effect on cost is very great—our model shows a cost increase from $238 per month per $100K to $311 when we increase operating time from 350 to 525 hours. The increased costs arise from an assumption that the number of failures is proportional to *operating* time, not calendar time, and this assumption is open to question as was discussed above. At one time most manufacturers charged for maintenance in proportion to equipment hours operated. The fact that today most manufacterers charge a flat maintenance price independent of operating hours is perhaps an indication that failures are more nearly related to calendar time.

Figure 4.4.9 shows the effect of changes in PM policy on peripheral maintenance costs. Here p is the percentage of operating time spent in performing preventive maintenance on a $30K peripheral unit. As that percentage increases and decreases the fixed cost of peripheral maintenance increases and decreases proportionally. The dotted line indicates the minimum improvements PM must provide to be worthwhile. For example, with no PM (p=0) we could have a peripheral down time as high as 2.8% per $100K and at the same maintenance cost we have with 0.5% PM. In other words, if the 0.5% PM didn't reduce down time at least from 2.8% to 1.1% it would not pay for itself—though it might be very worthwhile from the point of view of the user.

The function of preventive maintenance, of course, is to reduce the incidence of preventable failures. Peripheral units in particular are subject to such failures, which are normally caused by the accumulation of dirt at or near the read-write mechanism. Magnetic oxide accumulations on a tape unit read/write head, paper fibres in the punched-card or line printer mechanisms, and dust or dirt particles on the moving-head file floating heads will all cause failures if not removed periodically. Of course, if PM is done too frequently, its cost will obviate its benefits; if it isn't done frequently enough the down time from preventable failures will increase maintenance costs. There is, then, an optimum PM interval, and the curves of Figure 4.4.10 illustrate the point. Here we assume that the $30K peripheral is subject to preventable failures occurring, on the average, every 160 hours. And we plot percent lost time (the sum of PM and CM time) per $100K as a function of the PM interval, assuming a normal distribution of failures around the 160-hour mean. For the solid curve, the assumed standard deviation of the failure distribution is only 16 hours—the preventable failures are "bunched" close around the 160 average point. The PM interval for minimum lost time can therefore be relatively high. As the standard deviation increases, the other curves show that the optimum PM interval gets shorter and the minimum percent lost time increases.

**Another Look at Maintenance Prices.** With our model in mind, let us have another look at some IBM maintenance prices. Figure 4.4.11 illustrates the effect of combining units having different intrinsic reliabilities—namely, processors and memories. For each system shown, the lowest-purchase-price unit has the smallest memory, and other units, represented by dots connected to the first, differ only in having larger memories. As we add memory to a unit, its total memory down time tends to increase in proportion to the amount of memory added. The down time cost per $100k of memory thus tends to stay the same. However, in adding memory we don't have to add a proportional amount of spare parts because the memory is composed of many identical subassemblies and one spare subassembly can serve many units. Since processors and memories do not generally require preventive maintenance, the spares costs are the only fixed costs and their cost per $100k of memory tends to drop. Thus if we for the moment ignore the processor, whose cost and reliability are presumably independent of the amount of memory attached, we'd expect maintenance costs per $100k or memory to fall as memory is added, asymptotically reaching a value which corresponds to the cost of corrective maintenance of a unit of memory.

The maintenance prices for the System/3 and for most of the IBM 360 and 370 family *do* fall off with increasing memory size, as shown in Figure 4.4.11. However, the maintenance prices for the 360/65 and for the larger 370 systems *increase* as memory size increases. One possible explanation for this phenomena, consistent with our model, is that the memory is less reliable than the processor alone. If its down time is large enough, the effect of adding memory will be to raise total maintenance costs per $100k price even though the fixed-cost component of total cost is dropping. Of course, price at any time presumably reflects IBM's maintenance experience at that time. By November, 1975, for example, the maintenance price per $100k sales price of the 360/65 and 370/165 still increased slightly with increasing memory size; but the 370/155 maintenance price *decreased* with increasing memory size. Perhaps between 1973 and 1975 IBM's experience with the 370/155 led them to conclude that the processor was less reliable than memory rather than more reliable as was believed in 1973.

Of course there are matters completely independent of maintenance costs which influence pricing and therefore influence the factor we are examining here. For example, it has been alleged that IBM set processor prices unrealistically high and incremental memory prices unrealistically low in introducing the 370 systems (see Figures 2.11.10 and 2.11.11 and the accompanying discussions). If that were true, the result would be that maintenance prices per $100k sales price would be lower for systems with small memories and higher for systems with large memories than would be the case if purchase prices were more nearly related to manufacturing costs.

The data of Figure 4.4.11 also suggests something about the relative intrinsic reliability of IBM systems. Note that the System/360 family generally costs less and less to maintain, per $100k price, as we go from the smallest 360/20 to the largest 360/50. That is what we would expect for a family of systems whose down time per $100k price is constant, and whose fixed maintenance costs are relatively large for small systems and relatively small for large ones. But what are we to conclude from the fact that maintenance prices for the System/370 generally increased from the smallest 370/125 to the largest 370/165? One possible explanation is that IBM expected each processor to have a larger down time per $100k of price than did the smaller predecessor. Incidentally, by November, 1975, the maintenance price per $100k sales price of all System/370 systems were much more nearly the same than was the case in 1973; but those prices were roughly 50% to 100% higher than corresponding prices for System/360 processors in 1975.

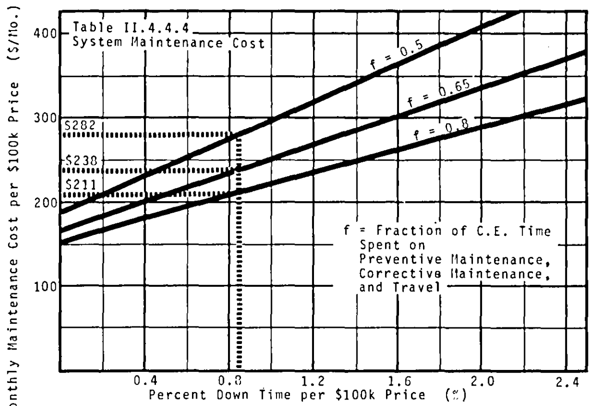



FIGURE 4.4.7 MONTHLY MAINTENANCE COST II
THE EFFECT OF CUSTOMER ENGINEER AVAILABILITY

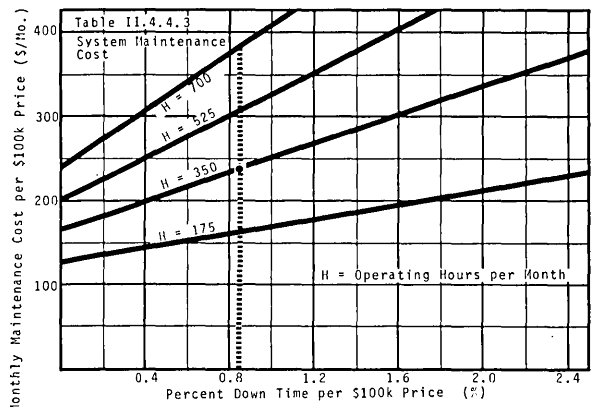



FIGURE 4.4.8 MONTHLY MAINTENANCE COSTS III
THE EFFECT OF TOTAL OPERATING HOURS

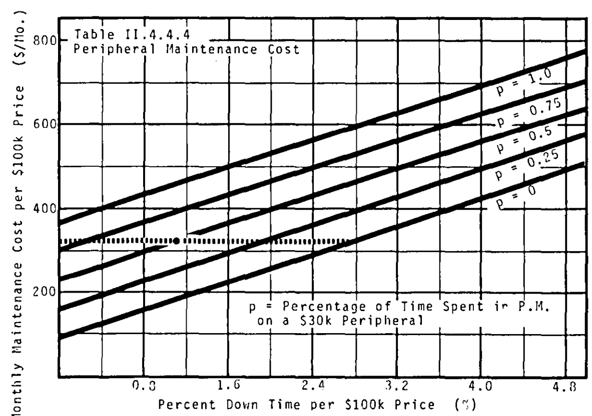



FIGURE 4.4.9 MONTHLY MAINTENANCE COSTS IV
THE EFFECT OF PREVENTIVE MAINTENANCE COSTS

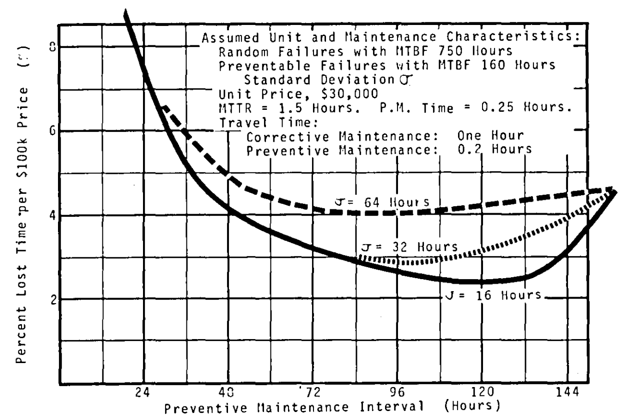



FIGURE 4.4.10 MONTHLY MAINTENANCE COSTS V
THE EFFECT OF PREVENTIVE MAINTENANCE ON LOST TIME

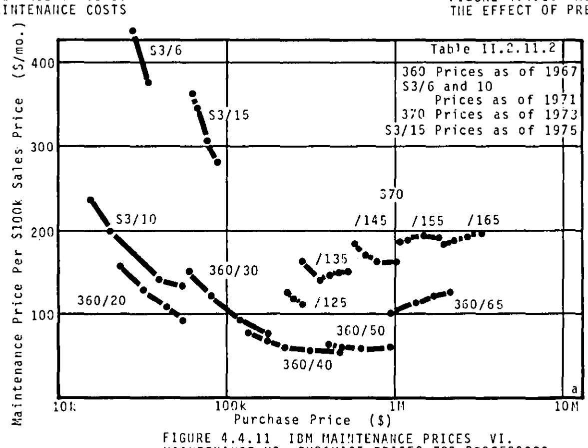



FIGURE 4.4.11 IBM MAINTENANCE PRICES VI.
MAINTENANCE VS. PURCHASE PRICES FOR PROCESSORS

So far we have looked only at processors and internal memory. If we examine the maintenance prices of IBM peripherals, shown in Figures 4.4.12 and 4.4.13, we find other phenomenon apparent. First, we observe that controllers, like processors, are relatively cheap to maintain. The 2803 (controller for the 2401 and 2402 tape units) and the 2821 (controller for punched card equipment and line printers) are cheaper than the System/3/10, which is shown for reference purposes. Except for the 2821-6, whose very high maintenance price is inexplicable, these specific controller prices are consistent with the averages shown in Figures 4.4.1 through 4.4.4.

Next look at the 3410's and 3420's. The six models, shown as dots connected by dashed lines, represent two quite different technologies and a range of performance within each technology. The high-performance 3420's have automatic threading, tape cartridge loading, the ability to read data backwards, and other features not found in the 3410's. The six units, all capable of recording and reading data at 1600 bits per inch, provide a series of tape speeds and therefore of data rates, from 12.5 inches per second for the cheapest 3410 to 320 ips for the most costly 3420. Inasmuch as each unit is more complex than its lower-performance neighbors, one might reasonably speculate that each has a higher percent down-time than its lower-performance neighbors. But apparently the fixed costs of inventory and of preventive maintenance are dominant for these units and added complexity adds little to down time. In fact (see Figure 4.4.13) the lowest-performance 3420 actually costs less to maintain than does the highest-performance 3410, despite the performance advantages of the former. Probably the 50 inch-per-second 3410-3 has a higher percentage down-time than does the 75 inch-per-second 3420-3. As we push a technology towards its performance limit, its reliability drops off; if we employ a technology very conservatively (running a tape system at 75 i.p.s. when it was engineered to run at 320 i.p.s.) we can expect it to provide high reliability.

The 3410's and 3420's whose prices are shown were first shipped in the late sixties or early seventies. The 2401's and 2402's, also shown in the figures, are third-generation units first shipped in the early- to mid-sixties. The twelve model numbers shown—six 2401's and six 2402's—actually provide only three different tape speeds: 37.5, 75, and 112.5 inches per second. For each model number the lower three dots represent units with a recording density of 800 b.p.i., and the adjacent three dots represent 1600 b.p.i. units. The 2402 differs from the 2401 only in that two tape drives are packaged in a single unit. Comments:

1. The maintenance costs of the 2401's were substantially higher than those of the newer 3420's, though the older units provided fewer features and lower performance. The implication is that the newer units probably have lower down-time percentages and require less preventive maintenance than their predecessors.

2. For a given 2401 model number, an increase in recording density from 800 to 1600 b.p.i. adds little to purchase price but adds considerably to maintenance price; on the other hand, an increase in read-write speed adds considerably to purchase price but little to maintenance. One result of this is that a doubling of recording density actually leads to an *increase*, while an increase in tape speed results in a decrease, of maintenance cost per $100k sales price.

3. The first increase in 2401 read-write speed, from 37.5 to 75 inches per second, results in a modest increase in maintenance price; the next increase, to 112.5 i.p.s., leads to a large increase—presumably the 112.5 i.p.s. system is beginning to push the practical limits achievable by the mechanism, with the result that CM costs rise sharply and (perhaps) that more frequent PM actions must be scheduled.

4. The two-drive 2402 costs almost exactly twice as much to maintain as the corresponding single-drive 2401. One would think that the maintenance price of a double drive would be substantially discounted from twice that of a single, on the grounds that the fixed costs of spares and PM are shared by the two units—one should not need double the available spares for a 2402 compared to a 2401, and the travel time for PM for a 2402 should be half of that for a 2401. Perhaps the 2401 maintenance price was established under the assumption that few installations have only a single drive, so the economics of multiple-unit sites are taken into account in the 2401 price.

So far we have only looked at the total cost of maintaining data processing equipment. The bar graphs in the next two figures give us some insight into how those costs are apportioned for a presumed "typical" system. In Figure 4.4.14 we can see, for each type of unit and for the system as a whole, how costs are distributed in five categories: CE direct labor (the cost of the hours the CE puts in doing PM and CM and travelling to the site); CE "indirect labor" (the cost of the hours the CE spends in training, paperwork, etc.); labor overhead (the cost of the CE's fringe benefits, supervision, facilities, technical support, etc.); parts cost (the cost of replacing parts used in effecting repairs); and inventory costs (the cost of having a spare part inventory). Looking first at the bar chart on the right, for the system as a whole, we can see that only about 12% of total maintenance costs goes to cover the CE's salary while he is on the site, though 18% pay his total salary and over 50% is used to pay all labor-related costs. Inventory costs amount to about 40% of the total, and the remainder is required for parts repair and replacement. The other bars in the figure point out how different the distribution is within the three types of unit. Peripheral unit costs are distributed much like system costs, but inventory costs predominate in the CPU/Memory and parts costs are prominent for the terminals.

The next figure gives us a different perspective on the same data, showing what proportion of labor, parts, inventory, and total costs are spent in maintaining the three types of unit. The striking thing here, of course, is the predominance of the peripherals. Peripherals represent 54% of what the user pays for this system; but according to our model their maintenance costs are almost 75% of total system maintenance costs. And over 85% of all system labor costs (left-hand graph) are spent doing PM and CM on card equipment, magnetic tape units, and files.

Finally, let us use the maintenance cost model to see how maintenance costs have changed since the mid-1950's. The five solid lines in Figure 4.4.16 represent cost/down time curves for five $500,000 systems, each typical of the time. The 1970 curve is the same as the system line in Figure 4.4.6.) The five black circles represent typical operating points in each of the years. Comments:

1. The fixed costs have increased over the years primarily because of increased use of PM to reduce peripheral equipment down time.

2. The incremental costs decreased between 1956 and 1960 because of the increased concentration of computers, and consequent decrease in travel time and increase in the proportion of the CE's time spent on maintenance. They

have increased since then because of increases in CE salaries, maintenance overhead, and monthly operating hours.

3. Between 1956 and 1965, down time per $100k dropped from almost 3% to less than 3/4% despite an increasing proportion of inherently unreliable peripherals, and despite the improvements which took place in system performance. As a result, maintenance costs fell by a third, from over $300 to almost $200 per month per $100k. Since 1965, however, we speculate that system and software complexity have led to reduced time between failures and increased repair time, and that the result has been those increases in down time and maintenance cost shown. Note that, even if down time continued to decrease in 1970 and reached 0.25% in 1974, the model predicts that maintenance costs would have increased. The picture presented is thus consistent with the U-shaped curve of maintenance *price* pictured in Figure 4.4.1.

**Conclusion.** The model developed in this section, and the numerical values assigned to its various variables, are unlikely to represent or parallel any specific organization's maintenance costs. The point is not how "accurately" the model portrays what has happened and is happening. The point is that any specific organization designing or maintaining systems should have an understanding of these costs and of the way costs are interrelated. Such an understanding can best be promoted and improved through the use of a model, and a well-conceived, realistic model can and should be used to help evaluate maintenance features, plan maintenance strategies, and set maintenance prices for new products.

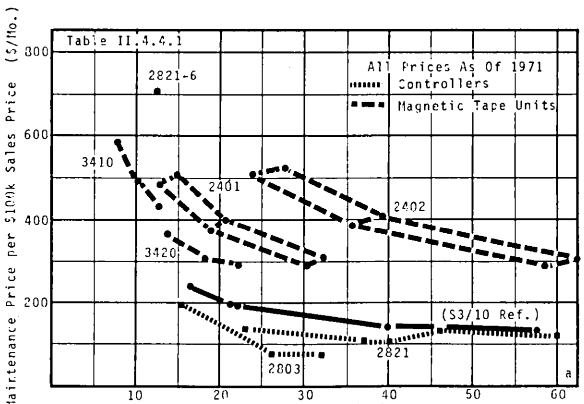



FIGURE 4.4.12 IBM MAINTENANCE PRICES VII. MAINTENANCE VS. PURCHASE PRICES FOR PERIPHERALS

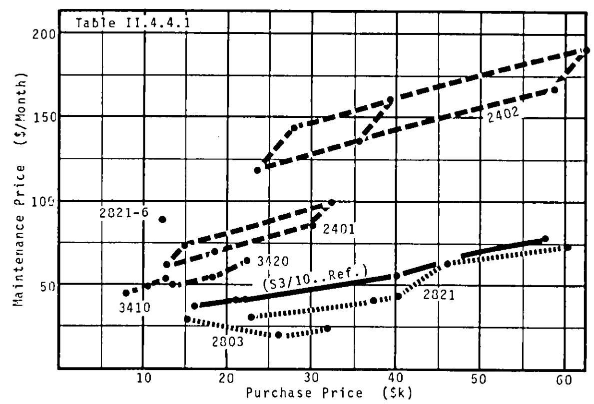



FIGURE 4.4.13 IBM MAINTENANCE PRICES VIII ABSOLUTE MAINTENANCE PRICES FOR PERIPHERALS

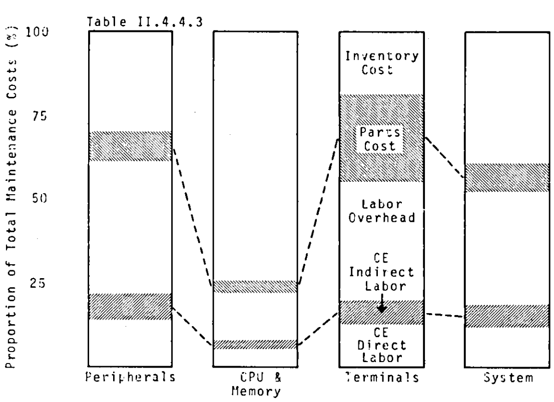



FIGURE 4.4.14 DISTRIBUTION OF SYSTEM MAINTENANCE COSTS I PROPORTION OF COSTS SPENT IN DIFFERENT COST CATEGORIES

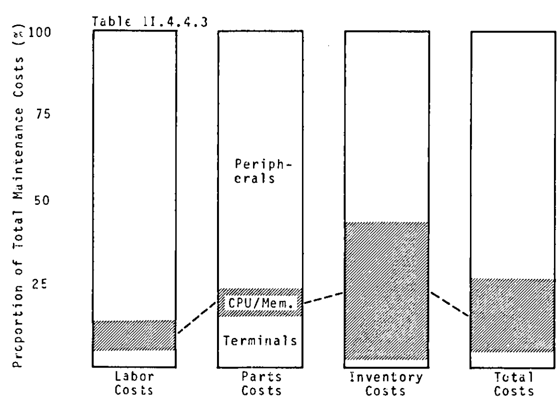



FIGURE 4.4.15 DISTRIBUTION OF SYSTEM MAINTENANCE COSTS II PROPORTION OF COSTS SPENT ON DIFFERENT UNITS

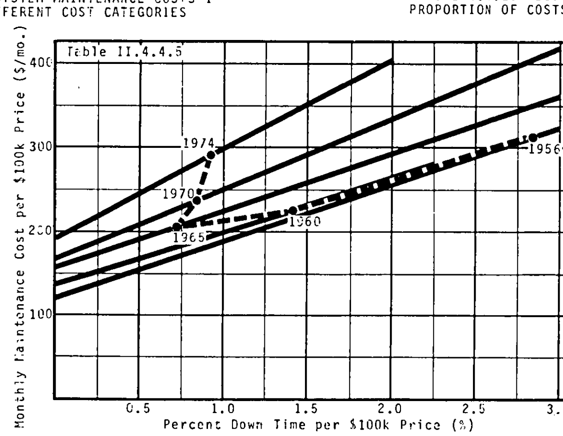



FIGURE 4.4.16 CHRONOLOGY OF SYSTEM MAINTENANCE COSTS

## 4.5 Life Cycle Costs

It is often enlightening to examine the total cost of an item over its entire life, taking into account not only its obvious initial costs, but also the expenses of various kinds which are incurred as time goes by. Thus the "Life Cycle" costs of ones automobile, for example, would include the costs of gasoline, lubrication, repairs, insurance, and parking as well as the initial cost of the car itself.

It is particularly helpful to contemplate potential life cycle costs when one is evaluating alternatives and making plans, for such an analysis calls attention to the truly important factors. Thus a user considering a change in his data entry system might look at the life cycle costs of keypunching, a key-to-disk system, an OCR system, and an on-line terminal system before making a decision.

System manufacturers look at life cycle costs when they prepare plans for new products, and it will be instructive for us to create a cost history of an imaginary product, using the cost models developed in this last chapter, and to compare the results with some confidential IBM data released in connection with the IBM-Telex trial.

The product to be examined is the $100,000 processor whose development costs were outlined in Section 4.21. We assume a development project was initiated in 1974, and that the product was first shipped four years later. We assume a total of 1000 units were shipped, with a shipment and installation history as shown in Figure 4.5.1. Assuming that 30% of the processors were sold and the other 70% leased, the revenues received for the product are indicated by the dashed and dotted lines in Figure 4.5.2.

We assume this processor is the first of a family of five processors built using a new electronic technology, and that the family is supported by 600,000 lines of new software. One-fifth the cost of the technology and of the software is apportioned to this processor, along with the development cost of the processor itself. Other costs included are those for manufacturing, marketing, maintaining, and sustaining the product. The total of all these costs and expenses is shown as a solid line in Figure 4.5.2 (see Table II.4.5.2 for details of the calculations employed).

The major expenses are incurred during the first years of product life, and in Figure 4.5.3 we break down the total-expense curve of Figure 4.5.2, showing the various categories of cost during the first twelve years of product life. Development costs lead all the rest, of course, followed by marketing costs, which are assumed to be spent as orders come in, and which therefore precede manufacturing costs. Sustaining costs are comparatively small, start in the year the product (and its software) are first shipped, and trail off thereafter. Maintenance costs, proportional to the number of processors in use, lag all the rest and represent 100% of costs after the tenth year.

The net result of costs and expenses is a "cumulative gross profit" history which starts negative, when there are many expenses and no revenue, and turns positive when enough revenue has been received to pay off the accrued expenses. The dotted line in Figure 4.5.4 shows the result under our assumption that 70% of the processors are leased, and the other two lines show comparable results under the assumptions that all systems are sold and all systems are leased. If all systems are sold, a situation which perhaps approximates that of a minicomputer manufacturer, the breakeven point occurs early in the sixth year; if all are leased, it doesn't occur until late in the eighth year. But the ultimate gross profit when all systems are leased is about 50% higher than when all are sold. (An available interest rate of 10% per year is assumed in the calculations leading to Figure 4.5.4, and we make the results strictly comparable by charging interest at that rate while the cumulative gross profit is negative, and including interest income as part of the profit when that profit turns positive. It is principally for that reason that the "all processors sold" profit continues to rise after the last purchase income has been received in year 9.)

We can add total expenditures and total revenues together over the nineteen-year period, and determine what proportion each bears to total revenue or to total expenses. The result is shown in the first column of Table 4.5.1: a total of $180.2M in revenues is received, and a total of $56.6M in expenses and costs is paid out. However, these figures ignore an important consideration—the time value of money. If we can earn interest on our money, a dollar spent in year one on development, for example, is worth more than a dollar of purchase-price income received in year seven, which in turn is worth more than a dollar of lease income received in year fourteen. Putting it another way, we'd rather have a dollar now than a year from now, because we could invest it now at 10% and have $1.10 a year from now. Inasmuch as the data plotted in the figures and appearing in column one of the table represent revenues and expenditures taking place at different times, they are not comparable until we compute the present value of each, taking the interest rate into account. The result is shown in the second column of the table. Note that the revenue, much of which is from leases and is therefore received relatively late in the processor's life, drops by 57% when the time value of money is taken into account; but expenses, many of which are spent early in the processor's life, only fall by 43%.

Before commenting on the significance of this distribution of life cycle costs, let us compare them with some available industry figures. The last two columns of Table 4.5.1 show IBM's expected life cycle costs for their 370/135 and /145 processors. The data comes from two confidential IBM reports issued in 1971 forecasting revenues and expenses over the entire product life (year by year through 1977 and with a "balance" to cover the remaining years). Unfortunately, the terms used are not defined, so it has been necessary to make various assumptions about cost categories. Comments:

1. Revenue from the maintenance of purchased systems is not itemized, and it is not clear whether it is omitted, or is included with the other revenue items.

2. What I have called Manufacturing Engineering is called "SDD" in the reports. It includes items labelled Development, Prog. Eng., Programming, SCR (Scrap and Rework?), and Prod. Test. It is clearly not what we have labelled development, for it doesn't start for the 135 until the product is shipped.

3. It is not clear whether the IBM figures have been discounted to take the time value of money into account. If they have been, the IBM percentages agree well with our theoretical example. If they have not been discounted, they should be compared with column one rather than column two of Table 4.5.1, and the agreement is not good.

4. IBM did not specifically break out marketing, development, and sustaining costs. Instead, the reports included a general category labelled "apportionments", which apparently covers these items and other general and administrative expenses. The IBM data on the "total costs" line is thus not comparable with ours. We can get some insight into the question of the relationship between revenues

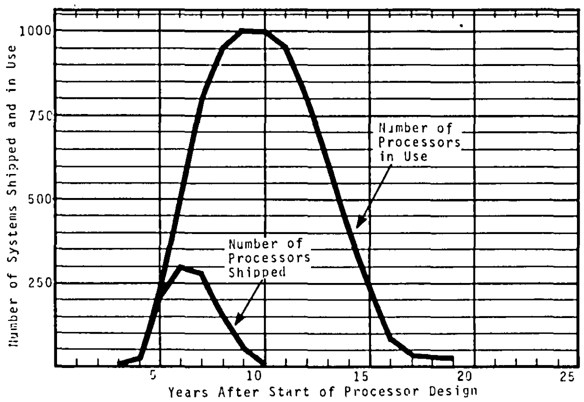



FIGURE 4.5.1 SHIPMENT HISTORY OF A $100,000 PROCESSOR

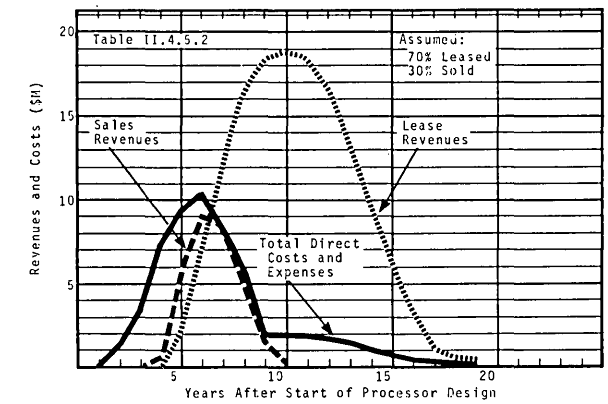



FIGURE 4.5.2 REVENUES AND TOTAL COSTS FOR A $100,000 PROCESSOR

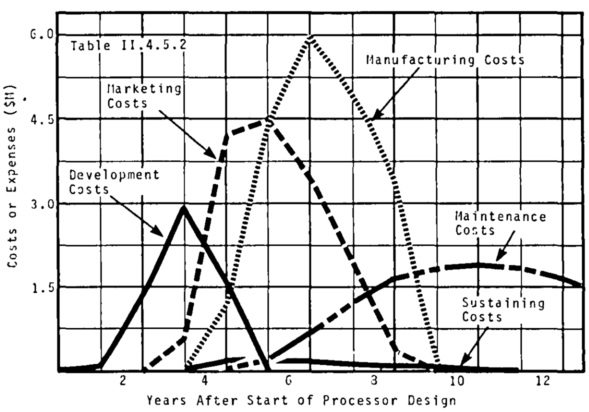



FIGURE 4.5.3 COSTS AND EXPENSES FOR THE $100,000 PROCESSOR COST BREAKDOWN FOR THE FIRST TWELVE YEARS

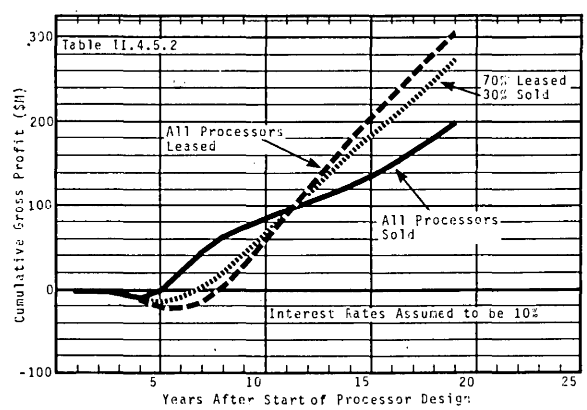



FIGURE 4.5.4 CUMULATIVE GROSS PROFIT FOR THE $100,000 PROCESSOR WITH THREE DIFFERENT ASSUMPTIONS ABOUT SALES AND LEASES

## TABLE 4.5.1 LIFE CYCLE COSTS

| | | $100k Processor | | IBM 370/ | |
|---|---|---|---|---|---|
| | | Actual | PV | 135 | 145 |
| Revenues | $M | 180.2 | 77.2 | 1568 | 2293 |
| Percent—Lease | % | 80.0 | 74.8 | 84.5 | 75.7 |
| Purchase | % | 16.7 | 22.1 | 15.5 | 24.3 |
| Maintenance | % | 3.3 | 3.1 | | |
| Total Expenses | $M | 56.6 | 32.5 | | |
| Expenses as Percent of Revenues | | | | | |
| Manufacturing | % | 11.1 | 15.0 | 14.1 | 15.5 |
| Manu. Engineering | % | | | 1.4 | 1.7 |
| Maintenance | % | 8.0 | 7.5 | 7.1 | 10.1 |
| Other | % | | | 0.3 | 0.5 |
| Total Direct Costs | % | 19.1 | 22.5 | 22.9 | 27.8 |
| Development | % | 3.4 | 6.2 | | |
| Marketing | % | 8.3 | 12.5 | | |
| Sustaining | % | 0.5 | 0.7 | | |
| Apportionment | % | | | 43.1 | 32.3 |
| Contingencies | % | | | 0 | 4.8 |
| Total Costs | % | 31.3 | 41.9 | 66.0 | 64.9 |
| Expenses as Percent of Total Costs | | | | | |
| Manufacturing | % | 35.3 | 35.8 | 21.3 | 23.9 |
| Manu. Engineering | % | | | 2.1 | 2.6 |
| Maintenance | % | 25.6 | 17.9 | 10.8 | 15.6 |
| Development | % | 10.8 | 14.9 | | |
| Marketing | % | 26.5 | 29.7 | | |
| Sustaining | % | 1.7 | 1.8 | | |

Sources: Tables II.4.5.1 and II.4.5.2. Revenue from $100k processor assumes 70% are leased, the remainder purchased. "PV" is the present value with interest at 10%. IBM 370/135 and /145 data is from private IBM forecasts, but terms used are not defined.

and marketing or development costs by looking at company annual reports. In Table 4.5.2 revenue and cost figures are shown for IBM and three other systems manufacturers. Note that research and development costs are in the range six to eleven percent, quite compatible with our theoretical processor, and that selling and administrative costs range from sixteen to twenty-five percent—though there is no indication as to the distribution between "selling" and "administrative". Note also that the IBM and CDC figures in particular include revenues and expenses for non-data processing activities, like the sale and maintenance of typewriters, and the operation of a service business.

Let us conclude with some general remarks about the life-cycle costs shown in Table 4.5.1.

1. While the figures in column two do allow for the time value of money, they do *not* allow for the effects of inflation. All costs shown are 1974 costs. In manufacturing it is possible that improvements in productivity will counteract the effects of inflation, so that our estimate of constant cost per unit may be reasonable. However, productivity is not so likely to improve in the sustaining and especially the maintenance activities, with the result that those functions will probably cost more than is shown.

2. Our estimate that manufacturing costs are 20% of sales price is probably appropriate for IBM, whose direct costs have, since 1968, been between 35% and 40% of revenues. It is likely to be unrealistically low for other systems manufacturers whose manufacturing costs are perhaps in the range of 25% to 35%. (See Table 4.5.2.)

3. We are here considering processor costs and revenues only, though the processor represents a relatively small proportion of total system value. Because many systems manufacturers buy some peripherals from other companies, their peripheral equipment cost is much higher than the 20% we have assumed for the processor. Even IBM's peripheral manufacturing costs seem to be slightly higher than processor costs. The 3211 printer, 2401 and 2415 tape units, 3330 moving-head file, and 2321 data cell had an average manufacturing cost 15.8% of revenue compared to the 14.8% average for the 370/135 and /145. Our maintenance model, developed in Section 4.4, indicated that peripherals would be substantially more costly to maintain than processors. Again, IBM's data seems to confirm our analysis: the five peripherals named above have an average maintenance cost 12.6% of revenue compared to an average 8.6% for the two processors (see Table II.4.5.1).

4. The results shown in Table 4.5.1 will of course vary depending on just how many systems are distributed. Specifically, we assumed that 1000 of the $100,000 processors were manufactured. If fewer were made, then manufacturing, marketing, and maintenance costs would drop proportionately, while development and sustaining costs would remain constant. The result would be that total life cycle costs would become a larger proportion of total revenues. For example, if only 500 processors were distributed, life cycle costs would increase from 42% to 49% of total revenues. On the other hand, if 2000 units were built, life cycle costs would fall from 42% to 39% of revenues—for the fixed development and sustaining costs would become a smaller proportion of the total.

5. Perhaps the most significant conclusion to be drawn from this analysis of life cycle costs has to do with the high cost of maintenance. Note that maintenance costs over the life of the processor are 7.5% of revenues, and almost 18% of total costs. They are higher than development and sustaining costs combined. Taking into account the probable effect of inflation and the undoubted fact that peripheral maintenance costs are substantially higher than processor maintenance costs, we would expect to find *system* maintenance costs running at ten to fifteen percent of revenues.

The implications for the system manufacturer are clear. It is extraordinarily important to pay careful attention to reliability and maintainability when planning and developing products; and there are likely to be many features that can be added to hardware and software at some slight initial cost, which will pay off many times over in reduced maintenance cost. It is also very important to build a competent, well-managed maintenance organization, to keep these costs under control and to respond promptly and ably to customer problems.

There are also implications for the system *user*. The user must pay, every month, for maintenance either directly in a maintenance contract or indirectly as part of his lease price. The payments must be made as long as he operates the system, and are therefore an important component in his own life cycle costs. Furthermore, high prices for maintenance generally imply high maintenance costs, and therefore relatively frequent failures and relatively long times to repair. And the resulting low system availability causes severe operating problems and leads to increased costs because of job re-runs and overtime for operating personnel.

**TABLE 4.5.2 SYSTEM COMPANY REVENUES AND EXPENSES**

| | | IBM 1971 | CDC 1971 | DEC 1971 | XDS 1968 |
|---|---|---|---|---|---|
| Revenues—Total | $M | 8274 | 571.2 | 146.9 | 98.5 |
| Sales | % | 26.3 | 60.9 | | 80.4 |
| Service & Rentals | % | 73.7 | 39.1 | | 19.6 |
| Costs—Direct | % | 38.6 | 75.0 | 52.0 | 45.5 |
| Selling, Adminis. | % | 24.7 | 15.9 | 24.4 | 22.6 |
| R & D | % | 6.5 | 5.8 | 11.4 | 8.0 |
| Other | % | 7.1 | 9.2 | | 4.0 |
| Total Costs | % | 76.9 | 105.9 | 87.8 | 80.1 |

Source: Tables II.1.311 to II.1.314

# Part II

## Introduction to Part II

The following pages contain tables of data on various aspects of the computer industry, notes describing the tables, and notes on some of the tables in Part I. Some of the tabular information is plotted in various figures in Part I, but there is a great deal of supplementary data in the tables which is neither plotted nor referred to in Part I.

The reader interested in some particular subject is advised to consult the index, which cross-references tables, text, and figures for the entire book.

## II.1.1 Background

### TABLE II.1.1.1 BACKGROUND DATA I—NOTES

**GNP.** 1-3. U.S. GNP and deflator figures are from CenColoTi60,65 for the period up to 1962. Later figures are from CenStatAb.

4-8. International GNP's at market prices for 1958 and later dates are given in UNStYe. CenLong66 gives (Tables D1-D5) values for *real* GNP (i.e. GNP at constant prices) for the United States, Japan, Western Germany, the United Kingdom, and France. These figures are given as relative values to an index of 100 in the year 1913. I have converted these indices into dollars by making them match with the 1958 values for GNP given in UNStYe. The figures for 1965 and later are taken directly from UNStYe. Note that lines 3 and 4 are both measures of the U.S. GNP at 1958 prices from two different sources. The difference is due to a difference in definition—line 4 is really Gross *Domestic* Product and does not include the effect of imports and exports.

**National Income.** 9-15. As was stated in the text, national income is the sum of wages and salaries, interest and rents, and profits from all enterprises. The figures for national income shown in line 9 come from CenColoTi60,65, as do the percentage distributions by industry in lines 10-15. For the period prior to 1929, this source gives only ten-year averages for the distribution of national income, and I have assumed that those averages occurred at the mid-point of the ten-year range. Data for the period after 1964 comes from appropriate issues of CenStatAb.

**Industry Data.** 16. Automobile sales figures represent the wholesale value of passenger cars sold in the years indicated. The source is once again CenColoTi60,65 with updates from CenStatAb. The original source is the Automobile Manufacturers' Association.

17. See the discussion in connection with lines 10-14 of Table II.1.1.2, below.

18. The data on telephone revenues comes from the same source as that for automobile sales in line 16 above. The figures include operating revenues both for the Bell System and for the Independent Telephone Companies.

19. Television sales are from EIAYrbk. They include the values of both black and white and color T.V.'s. Prior to 1971 the figures excluded foreign sets purchased by U.S. manufacturers, though it included foreign sets imported by distributors and dealers.

20. The source for data processing equipment shipments is given in the notes to Table II.1.20, line 24. It includes worldwide shipments of general-purpose and minicomputer systems by U.S. manufacturers.

21-24. U.S. population comes from CenColoTi60,65 and CenStatAb. Lines 22-24 are derived by dividing lines 16-18 by population, then dividing the result by the deflator on line 2.

25-28. This data is derived by dividing lines 16, and 18-20 by the GNP in current prices from line 1.

## TABLE II.1.1.1 BACKGROUND DATA, 1900-1974 ●

| Line | Item | Figure | Units | 1900 | 1904 | 1909 | 1914 | 1919 | 1924 | 1929 | 1934 | 1939 | 1944 | 1949 | 1954 | 1959 | 1962 | 1964 | 1966 | 1968 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **U.S. GNP Current Prices** | 1.1.1 | $B | 20 | 24 | 33 | 39 | 84 | 85 | 103 | 65 | 91 | 210 | 257 | 365 | 484 | 560 | 632 | 750 | 866 | 974 | 1152 | 1397 |
| 2. | Deflator | 1.1.1 | | 24 | 25 | 28.6 | 30.7 | 57.4 | 51.2 | 50.6 | 42.2 | 43.2 | 58.2 | 79.1 | 89.6 | 101.6 | 105.8 | 108.9 | 113.9 | 122.3 | 135.2 | 146.1 | 170.2 |
| 3. | 1958 Prices | 1.1.1 | $B | 83 | 96 | 117 | 126 | 146 | 166 | 204 | 154 | 209 | 361 | 324 | 407 | 476 | 530 | 580 | 658 | 708 | 720 | 789 | 821 |
| 4. | 1958 Prices | | $B | 75 | 85 | 105 | 110 | 140 | 170 | 200 | 155 | 200 | 355 | 325 | 415 | 485 | 540 | 585 | 669 | 720 | 742 | 809 | |
| | **Foreign GNP, 1958 Prices** | | | | | | | | | | | | | | | | | | | | | | |
| 5. | United Kingdom | 1.1.2 | $B | 30 | 31 | 31 | 34 | 32 | 34 | 39 | 39 | 45 | na | 53 | 60 | 68 | 74 | 82 | 85 | 90 | 94 | 97 | |
| 6. | France | 1.1.2 | $B | 24 | na | na | 27 | 21 | 30 | 35 | 31 | 29 | na | 33 | 41 | 51 | 62 | 68 | 76 | 83 | 95 | 105 | |
| 7. | West Germany | 1.1.2 | $B | 13 | 14 | 16 | 19 | na | 17 | 20 | 20 | 29 | na | 25 | 42 | 59 | 70 | 77 | 84 | 89 | 102 | 108 | |
| 8. | Japan | 1.1.2 | $B | 5.6 | 6.0 | 7.1 | 8.5 | 13 | 13 | 15 | 18 | 24 | 23 | 16 | 25 | 38 | 54 | 66 | 77 | 100 | 123 | 143 | |
| 9. | **US Nat'l Income, Curr.Pr.** | | $B | 15 | 21 | 27 | 35 | 70 | 75 | 88 | 47 | 73 | 183 | 218 | 302 | 401 | 454 | 518 | 621 | 711 | 799 | 942 | 1143 |
| 10. | Manufacturing | 1.1.4 | % | | 18.4 | 18.9 | 20.8 | 22.2 | 22.2 | 25.0 | 22.2 | 24.6 | 32.9 | 28.8 | 30.2 | 29.9 | 28.8 | 30.0 | 30.9 | 29.9 | 27.1 | 26.8 | 26.8 |
| 11. | Trade | 1.1.4 | % | | 15.3 | 15.0 | 14.5 | 14.0 | 13.7 | 15.3 | 16.5 | 17.2 | 14.1 | 18.7 | 16.8 | 16.6 | 16.2 | 15.3 | 14.7 | 14.9 | 15.2 | 14.8 | 14.5 |
| 12. | Government | 1.1.4 | % | | 5.6 | 5.4 | 6.3 | 7.9 | 8.6 | 5.8 | 12.8 | 11.7 | 18.5 | 10.1 | 11.9 | 12.2 | 13.3 | 13.5 | 13.6 | 14.7 | 15.9 | 15.9 | 15.6 |
| 13. | Services | 1.1.4 | % | | 9.6 | 8.9 | 8.2 | 8.3 | 9.4 | 11.7 | 12.6 | 11.4 | 7.4 | 9.8 | 10.0 | 11.5 | 12.2 | 11.4 | 11.5 | 12.1 | 12.9 | 13.0 | 13.1 |
| 14. | Finance | 1.1.4 | % | | 16 | 16 | 15 | 15 | 16 | 14.5 | 11.4 | 10.9 | 6.7 | 9.2 | 9.7 | 10.1 | 10.2 | 11.0 | 10.9 | 10.9 | 11.3 | 11.3 | 11.1 |
| 15. | Agriculture | 1.1.4 | % | | 16.7 | 17.0 | 17.7 | 15.2 | 12.2 | 9.5 | 7.5 | 8.1 | 7.9 | 7.8 | 5.6 | 4.1 | 4.2 | 3.5 | 3.6 | 3.1 | 3.2 | 3.2 | 4.0 |
| | **Industry Data** | | | | | | | | | | | | | | | | | | | | | | |
| 16. | Automobile Sales | 1.1.5 | $B | | .023 | .160 | .421 | 1.365 | 1.970 | 2.791 | 1.140 | 1.770 | - | 6.651 | 8.218 | 10.53 | 13.07 | 14.84 | 17.55 | 19.35 | 14.63 | 23.13 | 21.8 |
| 17. | Electronic Sales | 1.1.5 | $B | | | | .001 | .008 | .117 | .465 | .188 | .340 | na | 2.4 | 5.6 | 9.7 | 13.9 | 16.0 | 21.4 | 29.1 | 27.7 | 32.9 | 36.9 |
| 18. | Telephone Revenues | 1.1.5 | $B | | .085 | .149 | .225 | .550 | .722 | 1.154 | .949 | 1.212 | 1.940 | 3.198 | 5.350 | 8.373 | 10.32 | 11.94 | 14.15 | 16.58 | 20.16 | 25.24 | 31.4 |
| 19. | T.V. Sales | | $B | | | | | | | | | | | .574 | 1.042 | .843 | 1.005 | 1.384 | 2.617 | 2.677 | 2.202 | 3.474 | 3.201 |
| 20. | D.P. Equipment Shipments | | $B | | | | | | | | | | | | .010 | .600 | 1.408 | 2.447 | 5.115 | 7.090 | 7.145 | 8.915 | 11.275 |
| 21. | U.S. Population | | M | 76.1 | 82.2 | 90.5 | 99.1 | 104.5 | 114.1 | 121.8 | 126.5 | 131.0 | 138.4 | 149.2 | 162.4 | 177.8 | 186.7 | 192.1 | 196.9 | 201.2 | 204.9 | 208.8 | 211.9 |
| | **Per Capita, 1958 Dollars** | | | | | | | | | | | | | | | | | | | | | | |
| 22. | Automobile Sales | 1.1.6 | $ | | 1.12 | 6.19 | 13.82 | 22.77 | 33.74 | 45.32 | 21.34 | 31.30 | - | 56.30 | 56.40 | 58.38 | 66.20 | 70.95 | 78.26 | 78.63 | 52.89 | 75.82 | 60.45 |
| 23. | Electronic Sales | 1.1.6 | $ | | | | .03 | .13 | 2.00 | 7.55 | 3.52 | 6.03 | na | 20.33 | 38.18 | 53.99 | 70.37 | 76.48 | 95.42 | 118.6 | 100.1 | 107.9 | 102.4 |
| 24. | Telephone Revenues | 1.1.6 | $ | | 4.14 | 5.76 | 7.39 | 7.66 | 12.36 | 18.72 | 17.79 | 21.45 | 24.13 | 27.08 | 36.70 | 46.34 | 52.33 | 57.16 | 63.13 | 67.30 | 72.83 | 82.74 | 87.06 |
| | **Percent GNP** | | | | | | | | | | | | | | | | | | | | | | |
| 25. | Automobile Sales | 1.20.1 | % | | .10 | .48 | 1.09 | 1.62 | 2.33 | 2.70 | 2.36 | 1.96 | - | 2.60 | 2.25 | 2.18 | 2.33 | 2.35 | 2.34 | 2.24 | 1.50 | 2.01 | 1.56 |
| 26. | Telephone Revenues | 1.20.1 | % | | .35 | .45 | .58 | .55 | .85 | 1.12 | 1.38 | 1.34 | .92 | 1.25 | 1.47 | 1.73 | 1.84 | 1.89 | 1.89 | 1.91 | 2.07 | 2.19 | 2.25 |
| 27. | TV Sales | 1.20.1 | % | | | | | | | | | | | .22 | .29 | .17 | .18 | .22 | .35 | .31 | .22 | .30 | .23 |
| 28. | D.P. Equip. Shipments | 1.20.1 | % | | | | | | | | | | | | | .12 | .25 | .39 | .68 | .82 | .73 | .77 | .81 |

## TABLE II.1.1.2 BACKGROUND DATA, II. ●

| Line | Item | Figure | Units | 1950 | 1952 | 1954 | 1956 | 1958 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Foreign GNP, Curr. Pr.** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | France | 1.1.2 | $B | | | | | 50 | 61 | | | 83 | | 99 | 108 | 116 | 127 | 140 | 145 | 163 | 198 | | |
| 2. | West Germany | 1.1.2 | $B | | | | | 55 | 72 | | | 96 | | 113 | 123 | 124 | 135 | 153 | 188 | 219 | 260 | | |
| 3. | Japan | 1.1.2 | $B | | | | | 32 | 43 | | | 68 | | 88 | 102 | 120 | 142 | 167 | 198 | 229 | 299 | | |
| 4. | United Kingdom | 1.1.2 | $B | | | | | 65 | 71 | | | 84 | | 100 | 107 | 110 | 103 | 110 | 119 | 135 | 153 | | |
| 4a. | World | | $B | | | | | 980 | 1128 | | | 1392 | | 1650 | 1794 | 1913 | 2060 | 2268 | 2492 | | | | |
| | **GNP Per Capita, Curr. Pr.** | | | | | | | | | | | | | | | | | | | | | | |
| 5. | United States | 1.1.3 | $K | 1.88 | 2.20 | 2.24 | 2.49 | 2.56 | 2.78 | 2.83 | 3.00 | 3.12 | 3.29 | 3.50 | 3.81 | 3.98 | 4.30 | 4.56 | 4.80 | 5.12 | 5.55 | 6.15 | 6.59 |
| 6. | France | 1.1.3 | $K | | | | | 1.30 | 1.34 | | | 1.74 | | 2.02 | 2.18 | 2.32 | 2.55 | 2.78 | 2.90 | 3.18 | 3.82 | | |
| 7. | West Germany | 1.1.3 | $K | | | | | 1.08 | 1.30 | | | 1.67 | | 1.92 | 2.01 | 2.02 | 2.24 | 2.51 | 3.05 | 3.57 | 4.22 | | |
| 8. | Japan | 1.1.3 | $K | | | | | .34 | .46 | | | .71 | | .90 | .99 | 1.16 | 1.40 | 1.63 | 1.91 | 2.19 | 2.82 | | |
| 9. | United Kingdom | 1.1.3 | $K | | | | | 1.25 | 1.36 | | | 1.58 | | 1.83 | 1.94 | 1.97 | 1.87 | 1.98 | 2.16 | 2.45 | 2.47 | | |
| 10. | **Electronics Industry Sales** | 1.1.5 | $B | 2.71 | 5.21 | 5.62 | 6.70 | 8.32 | 10.49 | 12.21 | 13.90 | 15.28 | 16.00 | 17.53 | 21.40 | 26.45 | 29.11 | 29.79 | 27.74 | 29.30 | 32.85 | 35.03 | 36.89 |
| 11. | Consumer Products | | $B | 1.50 | 1.30 | 1.40 | 1.60 | 1.66 | 1.77 | 1.76 | 2.13 | 2.32 | 2.64 | 3.30 | 4.13 | 3.92 | 4.16 | 4.37 | 3.68 | 5.54 | 6.64 | 6.92 | 6.19 |
| 11a. | Percent | 1.1.7 | % | 55.3 | 25.0 | 24.9 | 23.9 | 20.0 | 16.9 | 14.4 | 15.3 | 15.2 | 16.5 | 18.8 | 19.3 | 14.8 | 14.3 | 14.7 | 13.3 | 18.9 | 20.2 | 19.8 | 16.9 |
| 12. | Commun./Industrial Prod. | | $B | .35 | .50 | .65 | .93 | 1.45 | 2.05 | 2.68 | 3.07 | 3.53 | 3.96 | 4.63 | 6.30 | 10.16 | 11.71 | 12.41 | 12.09 | 12.43 | 14.90 | 16.39 | 18.69 |
| 12a. | Percent | 1.1.7 | % | 12.9 | 9.6 | 11.6 | 13.9 | 17.4 | 19.5 | 21.9 | 22.1 | 23.1 | 24.8 | 26.4 | 29.4 | 38.4 | 40.2 | 41.7 | 43.6 | 42.4 | 45.4 | 46.8 | 50.7 |
| 13. | Government Products | | $B | .66 | 3.10 | 3.10 | 3.60 | 4.73 | 6.12 | 7.19 | 8.08 | 8.84 | 8.78 | 8.97 | 10.33 | 11.72 | 12.56 | 12.29 | 11.30 | 10.70 | 10.60 | 10.80 | 11.05 |
| 13a. | Percent | 1.1.7 | % | 24.4 | 59.5 | 55.2 | 53.7 | 56.9 | 58.3 | 58.9 | 58.1 | 57.9 | 54.9 | 51.2 | 48.3 | 44.3 | 43.1 | 41.3 | 40.7 | 36.5 | 32.3 | 30.8 | 30.0 |
| 14. | Replacement Components | | $B | .20 | .31 | .47 | .57 | .48 | .55 | .58 | .62 | .59 | .62 | .63 | .64 | .65 | .68 | .72 | .67 | .63 | .71 | .92 | .96 |
| 14a. | Percent | 1.1.7 | % | 7.4 | 6.0 | 8.4 | 8.5 | 5.8 | 5.2 | 4.8 | 4.5 | 3.9 | 3.9 | 3.6 | 3.0 | 2.5 | 2.3 | 2.4 | 2.4 | 2.2 | 2.2 | 2.6 | 2.6 |
| 15. | **Component Sales–Total** | 1.1.8 | $B | 1.158 | 1.730 | 2.008 | 2.280 | 2.368 | 3.093 | 3.381 | 3.631 | 3.698 | 3.853 | 4.479 | 5.502 | 5.356 | 5.294 | 5.692 | 5.056 | 4.724 | 5.490 | 6.725 | 6.972 |
| 16. | Vacuum Tubes | 1.1.8 | % | 22 | 25 | 24 | 25 | 30 | 26 | 24 | 24 | 23 | 23 | 24 | 25 | 25 | 24 | 22 | 21 | 23 | 23 | 20 | 17 |
| 17. | Semiconductors | 1.1.8 | % | | | | 4 | 10 | 18 | 17 | 16 | 16 | 18 | 17 | 17 | 16 | 16 | 17 | 17 | 13 | 14 | 15 | 16 |
| 18. | Monolithic IC's | 1.1.8 | % | | | | | | | | | | 1 | 2 | 3 | 4 | 6 | 7 | 9 | 11 | 13 | 16 | 16 |
| 19. | Passive Components | 1.1.8 | % | 39 | 30 | 25 | 24 | 24 | 23 | 26 | 25 | 24 | 23 | 23 | 23 | 23 | 22 | 22 | 23 | 22 | 21 | 22 | 23 |
| 20. | Other Components | 1.1.8 | % | 40 | 45 | 50 | 47 | 35 | 33 | 33 | 35 | 36 | 36 | 34 | 31 | 32 | 32 | 32 | 31 | 31 | 30 | 28 | 27 |

### TABLE II.1.1.2 BACKGROUND DATA II—NOTES

**GNP.** 1-4. These values of foreign GNP at current prices are from UNStYe. Note these figures are at current prices, in contrast to the figures on lines 5-8 of the previous table, which are at 1958 prices.

5-9. GNP per capita is found by dividing values of current GNP by appropriate population figures for the countries concerned. Line 5 is the quotient of lines 1 and 21 of the previous table. Lines 6-9 are the quotient of lines 1 through 4 of this table and population figures from various sources. CenLong66 provides data on the population of these major countries through 1965. Later data comes from the UNESCO Statistical Yearbooks for 1968 and 1970, and the Monthly Bulletin of Statistics of the U.N.

**Electronics Industry.** 10-14. Electronics industry sales data is basically from EIAYrbk. However, the EIA figures on "Computers and Peripheral Equipment" in the Communications and Industrial Products Category (line 12) are suspect, in my view, and I therefore substituted for them the figures given in line 5 of Table II.1.20. The total on line 10 and percentages on lines 11a-14a are thus based on this modified data. By way of explanation: consumer products include T.V. and radio receivers, phonograph and tape equipment, electronic musical instruments, and records and magnetic tapes (foreign label imports are not included); communications and industrial products include data processing equipment, communication and broadcast equipment, telephone equipment sales (since 1967 only), and medical, scientific, educational, and industrial control, testing, and measuring equipment; government products is the electronic content of equipment and R & D for the Department of Defense, National Aeronautics and Space Administration, and other government agencies; and replacement components represent the sales of components necessary for field repairs and maintenance.

15-20. Total component dollar sales, line 15, and its breakdown into various subcategories also come from EIAYrbk. Semiconductors, on line 17, does not include the monolithic IC's of line 18, though it does include hybrid circuits. Passive components are capacitors, resistors, and inductors. "Other" components include connectors, relays, switches, sockets, loudspeakers, etc. (It is interesting to note that roughly half of vacuum tube sales are sales of television picture tubes.)

In 1972 the major semiconductor manufacturers left the EIA, and the EIAYrbk has since not reported annual shipments of semiconductors and IC's. *Electronics* magazine, in its annual review and forecast issue each January, gives an estimate and detailed breakdown of component sales. For 1973 and 1974, I used the *Electronics* figures, discounted a little because in earlier years *Electronics* figures were slightly higher than EIA's.

## II.1.2 Data Processing Industry Sales

In the introduction to this book, I expressed agreement with Wiener's remark that 'economics is a one or two digit science', and added that the study of the economics of the data processing industry is probably a one *binary* digit science. I will begin these pages with a discussion of some of the facts which led me to this conclusion.

The primary source of data on industry shipments and installations resides in the files of the major system manufacturers. Early in the data-collecting phase of preparing this book, I wrote to the chief executives of each of the major system manufacturers, describing the project and asking for help. The replies I received were, as might be expected, various, ranging from a polite brush-off to an invitation to browse through and make copies of corporate files relating to market research. However, no company was willing to give me access to their primary files on shipments and installations. For example, I wrote asking whether IBM would be willing to publish the number of units shipped per year of each of their major model numbers for every year up to 1960—a request which seemed to me to be eminently reasonable, in that it involved data so old that it could hardly be of use to IBM's competitors. IBM replied that it was not their "practice" to release such data (they explicitly denied this was a policy, insisting on use of the word "practice"). To the extent that they were polite enough to reply, other manufacturers gave similar responses.

Other primary sources—smaller hardware manufacturers, software and service firms, supplies manufacturers—were, I felt, too numerous for an individual to tackle. And I therefore have made extensive use of secondary sources throughout the book. The secondary sources, unfortunately, often disagree with one another. Furthermore, they are, in general, unwilling to discuss the reasons for their differences. My approach has been to attempt to reconcile differences using logic and common sense wherever possible—though for the most part, I have accepted what has seemed to me to be the best secondary source. In the following notes, and accompanying tables, I will present my estimates along with the various secondary sources from which they were derived. In describing the sources of my data and the logic of my calculations and deductions, I expect to be challenged and corrected where I have misunderstood or misinterpreted the significance of source material; and I hope to encourage others to develop and collect better data, both about the past and about the present.

### TABLE II.1.20 THE DATA PROCESSING INDUSTRY—SUMMARY

Generally speaking, and with some exceptions, this table collects together information from other tables in this section, and presents certain calculated results based on the collected data.

**Domestic Revenue and Shipments.** 1-3. General purpose and minisystem shipments in the United States, as shown on line 1 and 2, come from Table II.1.21. Total system shipments, on line 3, is the sum of lines 1 and 2.

4-5. Various "independent" peripheral equipment manufacturers (e.g. Telex, Memorex, Potter Instruments, Ampex, Data Products, Calcomp) make peripheral equipment, data entry equipment, and terminals which they sell to system manufacturers or leasing companies, and sell or lease to end users. A recently-growing portion of their business has been the development and manufacture of "plug-compatible" peripherals, which are equivalent in performance to, and cheaper than, IBM peripherals, and which are sold or leased to end users to replace IBM equipment. Such plug-compatible shipments are included in line 1 above. *EDP/IR*, in its Annual Review issues through March, 1973, estimated the total shipments by these independent manufacturers, and that estimate is

## TABLE II.1.20 DATA PROCESSING INDUSTRY—SUMMARY ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Domestic Rev. & Shipments** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Shipments, GP, U.S. | | $B | .063 | .152 | .235 | .381 | .475 | .560 | .850 | 1.060 | 1.220 | 1.570 | 1.910 | 3.200 | 3.900 | 4.650 | 4.642 | 4.073 | 3.975 | 5.170 | 5.405 | 6.220 |
| 2. | Mini, U.S. | | $B | | .003 | .010 | .014 | .020 | .030 | .030 | .030 | .080 | .100 | .150 | .130 | .130 | .185 | .277 | .282 | .300 | .450 | .540 | .810 |
| 3. | Total Systems, U.S. | 1.20.3 | $B | .063 | .155 | .245 | .395 | .495 | .590 | .880 | 1.090 | 1.300 | 1.670 | 2.060 | 3.330 | 4.030 | 4.835 | 4.919 | 4.355 | 4.275 | 5.620 | 5.945 | 7.030 |
| 4. | Independent Peripherals—Tot. | | $B | .014 | .025 | .035 | .050 | .075 | .105 | .110 | .130 | .145 | .170 | .175 | .185 | .225 | .315 | .405 | .640 | .860 | 1.175 | 1.750 | 2.300 |
| 4a. | Plug-Compatible | | $B | | | | | | | | | | | | .015 | .025 | .050 | .110 | .280 | .370 | .410 | .574 | .735 |
| 4b. | Other Peripherals | | $B | .014 | .025 | .035 | .050 | .075 | .105 | .110 | .130 | .145 | .170 | .175 | .170 | .200 | .265 | .295 | .360 | .490 | .765 | 1.176 | 1.565 |
| 5. | Total Hardware, U.S. | | $B | .077 | .180 | .280 | .445 | .570 | .695 | .990 | 1.220 | 1.445 | 1.840 | 2.235 | 3.500 | 4.230 | 5.100 | 5.214 | 4.715 | 4.765 | 6.385 | 7.121 | 8.595 |
| 6. | Services—Batch, On-Line, etc. | | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .265 | .297 | .360 | .440 | .560 | .770 | 1.100 | 1.460 | 1.900 | 2.320 | 2.750 | 3.385 |
| 7. | Software | | $B | | | | | | | | | .005 | .020 | .050 | .100 | .175 | .270 | .360 | .440 | .450 | .717 | .868 | 1.000 |
| 8. | Total Services | | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .270 | .317 | .410 | .540 | .735 | 1.040 | 1.460 | 1.900 | 2.350 | 3.037 | 3.618 | 4.385 |
| 9. | Data Communications | | $B | | | | | | .001 | .005 | .012 | .018 | .029 | .046 | .069 | .111 | .175 | .261 | .369 | .531 | .656 | .777 | .891 |
| 10. | Supplies | | $B | .003 | .009 | .019 | .034 | .055 | .085 | .134 | .182 | .268 | .354 | .444 | .578 | .713 | .781 | .897 | .967 | .999 | 1.087 | 1.289 | 1.876 |
| 11. | Grand Total | 1.20.2 | $B | .095 | .209 | .324 | .519 | .715 | .906 | 1.309 | 1.634 | 2.001 | 2.540 | 3.135 | 4.687 | 5.789 | 7.096 | 7.832 | 7.951 | 8.645 | 11.165 | 12.805 | 15.747 |
| | Percent Of Total Shipments | | | | | | | | | | | | | | | | | | | | | | |
| 12. | GP Systems | 1.20.5 | % | 66.3 | 72.7 | 72.5 | 73.4 | 66.4 | 61.8 | 65.0 | 64.9 | 61.0 | 61.8 | 60.9 | 68.3 | 67.4 | 65.5 | 59.3 | 51.2 | 46.0 | 46.3 | 42.2 | 39.5 |
| 13. | Minisystems | 1.20.5 | % | | 1.4 | 3.1 | 2.7 | 2.8 | 3.3 | 2.3 | 1.8 | 4.0 | 3.9 | 4.8 | 2.8 | 2.2 | 2.6 | 3.5 | 3.5 | 3.5 | 4.0 | 4.2 | 5.1 |
| 14. | Systems | | % | 66.3 | 74.2 | 75.6 | 76.1 | 69.2 | 65.1 | 67.3 | 66.7 | 65.0 | 65.7 | 65.7 | 71.0 | 69.6 | 68.1 | 62.8 | 54.8 | 49.5 | 50.3 | 46.4 | 44.6 |
| 15. | Independent Peripherals | 1.20.5 | % | 14.7 | 12.0 | 10.8 | 9.6 | 10.5 | 11.6 | 8.4 | 8.0 | 7.2 | 6.7 | 5.6 | 3.9 | 3.9 | 4.4 | 5.2 | 8.0 | 9.9 | 10.5 | 13.7 | 14.6 |
| 15a. | Plug-Compatible | 1.20.5 | % | | | | | | | | | | | | .3 | .4 | .7 | 1.4 | 3.5 | 4.3 | 3.7 | 4.5 | 4.7 |
| 15b. | Other Peripherals | | % | 14.7 | 12.0 | 10.8 | 9.6 | 10.5 | 11.6 | 8.4 | 8.0 | 7.2 | 6.7 | 5.6 | 3.6 | 3.5 | 3.7 | 3.8 | 4.5 | 5.7 | 6.9 | 9.2 | 9.9 |
| 16. | All Hardware | 1.20.4 | % | 81.1 | 86.1 | 86.4 | 85.7 | 79.7 | 76.7 | 75.7 | 74.7 | 72.2 | 72.4 | 71.3 | 74.7 | 73.1 | 71.9 | 66.6 | 59.3 | 55.1 | 57.2 | 55.6 | 54.6 |
| 17. | Services—Batch, On-Line | 1.20.6 | % | 15.8 | 9.6 | 7.7 | 7.7 | 12.6 | 13.8 | 13.8 | 13.5 | 13.2 | 11.7 | 11.5 | 9.4 | 9.7 | 10.9 | 14.0 | 18.4 | 22.0 | 20.8 | 21.5 | 21.5 |
| 18. | Software | 1.20.6 | % | | | | | | | | | .2 | .8 | 1.6 | 2.1 | 3.0 | 3.8 | 4.6 | 5.5 | 5.2 | 6.4 | 6.8 | 6.4 |
| 19. | Total Services | 1.20.4 | % | 15.8 | 9.6 | 7.7 | 7.7 | 12.6 | 13.8 | 13.8 | 13.5 | 13.5 | 12.5 | 13.1 | 11.5 | 12.7 | 14.7 | 18.6 | 23.9 | 27.2 | 27.2 | 28.3 | 27.8 |
| 20. | Data Communications | 1.20.4 | % | | | | | | .1 | .4 | .7 | .9 | 1.1 | 1.5 | 1.5 | 1.9 | 2.5 | 3.3 | 4.6 | 6.1 | 5.9 | 6.1 | 5.7 |
| 21. | Supplies | 1.20.4 | % | 3.2 | 4.3 | 5.9 | 6.6 | 7.7 | 9.4 | 10.2 | 11.1 | 13.4 | 13.9 | 14.2 | 12.3 | 12.3 | 11.0 | 11.5 | 12.2 | 11.6 | 9.7 | 10.1 | 11.9 |

reproduced on line 4 for the years up to and including 1969. In 1975 IDC's annual briefing session on the computer industry contained a reappraisal of the peripheral industry retroactive to 1970, and I use those figures on line 4 for the years 1970-1974. (The original *EDP/IR* estimates for 1970-1972 were $525M, $665M, and $780M.) Since 1972, *EDP/IR* has identified the plug-compatible portion of the total; and the June 24, 1972 issue of *Business Week* magazine (IDCPerip72) supplied earlier data. The result is shown on line 4a. Line 4b, computed by subtracting plug-compatible from total independent peripherals, represents shipments of products such as data entry equipment, COM equipment, plotters, etc. Line 5 is the sum of lines 3 and 4b. To the extent that some of the "other" peripherals made by the independents are shipped to system manufacturers who incorporate them in their system products and ship to the end users, I am double-counting peripheral shipments. To the extent that some peripheral manufacturers ship their products abroad, I am misclassifying peripheral shipments as "domestic".

6-11. Lines 6 through 8 come from Table II.1.26; line 9 (revenue from the carriage of data, and from data sets) from Table II.1.24; and line 10 from Table II.1.27. Line 11 is the sum of lines 5, 8, 9, and 10.

12-21. These lines are the quotients of lines 1 through 10 and line 11, and indicate what proportion of total shipments each of the component parts represents.

**Worldwide Business by U.S. Firms.** 22-31. Lines 22 through 24, from Table II.1.21, show the total shipments of computer systems by U.S. manufacturers, both domestically and internationally. Line 25 simply repeats line 4b above, and line 26 is the sum of lines 24 and 25. Lines 27 and 28 repeat lines 8 and 9. Line 29 comes from Table II.1.27, and differs from line 10 in that it includes international shipments of disk packs. I suspect there are other supplies (e.g. magnetic tape) which are shipped abroad by American manufacturers, but I do not know how to estimate them. Line 30 is the sum of lines 26, 27, 28, and 29. Line 31, which shows the proportion of domestic shipments to worldwide shipments by American manufacturers, is the quotient of lines 3 and 24–it includes both shipments of GP and minisystems.

**Equipment Value in Use (U.S.).** 32-36. Lines 32 and 38, showing the value of GP and minisystems in use in the United States, come from Table II.1.21. The installed value of computer peripherals and controllers, on line 33, and of internal memory, on line 34, come from Table II.1.22. The estimated value of installed terminals, on line 35, is from Table II.1.24; and of optical character reading and magnetic ink character reading equipment on line 36, from Table II.1.23.

37. The GP system value on line 32 presumably includes each of the items on lines 33 through 36. The principal items of equipment remaining are processors and their options–central processing units, input/output processors, and communication processors. Line 37, then, is found by subtracting, from line 32, the sum of lines 33 through 36. Needless to say, there is a great deal of room for error in the resulting difference. I am subtracting large numbers from one another, and each of the numbers is accurate to perhaps plus or minus 10%. Since the difference is (over the last half of the period of interest) less than 30% of the total, it is easy to see my "processor value in use" figures may be wildly wrong.

39-40. Line 39, representing the value of keypunch equipment and verifiers, and key-to-tape and key-to-disk systems, comes from Table II.1.23. Line 40 is the sum of lines 32, 38, and 39.

41-45. These lines show the proportion of GP system value represented by processors, internal memory, peripherals and controllers, terminals, and OCR/MICR equipment. They are the ratios of the various lines 33 to 37 to line 32.

46-50. These lines show the proportion of total hardware in use (line 40) represented by GP and minisystems, and data entry equipment. Note that lines 46, 47, and 49 add to 100%. The OCR/MICR equipment on line 50 is included with GP systems–i.e., line 36 above is a component part of line 32.

51-55. These lines show the ratio of various user expenses to the value of total GP systems in use. Specifically, they are the ratios of lines 6, 7, 8, 9, and 10 to line 32.

## TABLE II.1.20 DATA PROCESSING INDUSTRY SUMMARY ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **WW Business by US Firms** | | | | | | | | | | | | | | | | | | | | | | |
| 22. | Shipments, GP, WW | | $B | .065 | .166 | .275 | .446 | .580 | .690 | 1.050 | 1.370 | 1.710 | 2.320 | 3.070 | 4.950 | 6.200 | 6.850 | 7.032 | 6.768 | 6.805 | 8.315 | 8.805 | 10.065 |
| 23. | Mini, WW | | $B | - | .003 | .010 | .014 | .020 | .030 | .030 | .038 | .092 | .127 | .180 | .165 | .175 | .240 | .357 | .377 | .400 | .600 | .815 | 1.210 |
| 24. | Total Systems, WW | 1.20.3 | $B | .065 | .169 | .285 | .460 | .600 | .720 | 1.080 | 1.408 | 1.802 | 2.447 | 3.250 | 5.115 | 6.375 | 7.090 | 7.389 | 7.145 | 7.205 | 8.915 | 9.620 | 11.275 |
| 25. | Other Peripherals | | $B | .014 | .025 | .035 | .050 | .075 | .105 | .110 | .130 | .145 | .170 | .175 | .170 | .200 | .265 | .295 | .360 | .490 | .765 | 1.176 | 1.565 |
| 26. | Total Hardware, WW | | $B | .079 | .194 | .320 | .510 | .675 | .825 | 1.190 | 1.538 | 1.947 | 2.617 | 3.425 | 5.285 | 6.575 | 7.355 | 7.684 | 7.505 | 7.695 | 9.680 | 10.796 | 12.840 |
| 27. | Total Services (U.S.) | | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .270 | .317 | .410 | .540 | .735 | 1.040 | 1.460 | 1.900 | 2.350 | 3.037 | 3.618 | 4.385 |
| 28. | Data Communications (U.S.) | | $B | | | | | | .001 | .005 | .012 | .018 | .029 | .046 | .069 | .111 | .175 | .261 | .369 | .531 | .656 | .777 | .891 |
| 29. | Supplies–WW | | $B | .003 | .009 | .019 | .034 | .055 | .085 | .134 | .182 | .268 | .354 | .444 | .578 | .718 | .797 | .921 | 1.006 | 1.045 | 1.116 | 1.312 | 1.884 |
| 30. | Grand Total | 1.20.2 | $B | .097 | .223 | .364 | .584 | .820 | 1.036 | 1.509 | 1.952 | 2.503 | 3.317 | 4.325 | 6.472 | 8.139 | 9.367 | 10.326 | 10.780 | 11.621 | 14.489 | 16.503 | 20.000 |
| 31. | U.S. Syst. Shipped, % WW | 1.20.3 | % | 96.9 | 91.7 | 86.0 | 85.9 | 82.5 | 81.9 | 81.5 | 77.4 | 72.1 | 68.2 | 63.4 | 65.1 | 63.2 | 68.2 | 66.6 | 61.0 | 59.3 | 63.0 | 61.8 | 62.4 |
| | **Equipment Val. in Use (US)** | | | | | | | | | | | | | | | | | | | | | | |
| 32. | GP Systems | | $B | .180 | .320 | .540 | .900 | 1.340 | 1.865 | 2.605 | 3.485 | 4.550 | 6.000 | 7.800 | 10.700 | 13.800 | 17.500 | 21.400 | 23.600 | 25.200 | 26.600 | 27.300 | 30.200 |
| 33. | Peripherals & Controllers | 1.22.1 | $B | .021 | .071 | .163 | .324 | .545 | .854 | 1.189 | 1.518 | 2.108 | 3.157 | 4.266 | 5.922 | 7.658 | 8.761 | 9.986 | 10.842 | 11.788 | 12.265 | 12.224 | 12.311 |
| 34. | Internal Memory | 1.22.1 | $B | .012 | .042 | .082 | .157 | .259 | .400 | .548 | .626 | 1.018 | 1.450 | 1.749 | 2.144 | 3.154 | 4.051 | 4.767 | 5.451 | 6.228 | 6.844 | 7.179 | 7.286 |
| 35. | Terminals | 1.22.1 | $B | | | | | | | | .040 | .055 | .080 | .140 | .230 | .410 | .630 | .900 | 1.220 | 1.550 | 1.970 | 2.600 | 3.470 |
| 36. | OCR/MICR Equipment | | $B | | | | | | | .010 | .030 | .050 | .070 | .110 | .150 | .215 | .308 | .410 | .490 | .570 | .650 | .720 | .825 |
| 37. | Processors | 1.22.1 | $B | .147 | .207 | .295 | .419 | .536 | .611 | .858 | 1.271 | 1.319 | 1.243 | 1.535 | 2.254 | 2.363 | 3.750 | 5.337 | 5.597 | 5.064 | 4.871 | 4.577 | 6.308 |
| 38. | Minisystems | | $B | | .003 | .012 | .025 | .045 | .075 | .105 | .135 | .210 | .300 | .434 | .565 | .690 | .865 | 1.135 | 1.385 | 1.665 | 2.107 | 2.641 | 3.400 |
| 39. | Data Entry Keyboard Systems | | $B | .005 | .015 | .027 | .046 | .067 | .095 | .136 | .179 | .258 | .374 | .483 | .637 | .811 | .975 | 1.193 | 1.445 | 1.775 | 2.045 | 2.422 | 2.538 |
| 40. | Total Hardware in Use | 1.20.8 | $B | .185 | .338 | .579 | .971 | 1.452 | 2.035 | 2.846 | 3.799 | 5.018 | 6.674 | 8.717 | 11.902 | 15.301 | 19.340 | 23.728 | 26.430 | 28.640 | 30.752 | 32.363 | 36.138 |
| | Percent of GP Systems | | | | | | | | | | | | | | | | | | | | | | |
| 41. | Processors | 1.22.2 | % | 81.7 | 64.7 | 54.6 | 46.6 | 40.0 | 32.8 | 32.9 | 36.5 | 29.0 | 20.7 | 19.7 | 21.1 | 17.1 | 21.4 | 24.9 | 23.7 | 20.1 | 18.3 | 16.8 | 20.9 |
| 42. | Internal Memory | 1.22.2 | % | 6.6 | 13.1 | 15.2 | 17.4 | 19.3 | 21.4 | 21.0 | 18.0 | 22.4 | 24.2 | 22.4 | 20.0 | 22.9 | 23.1 | 22.3 | 23.1 | 24.7 | 25.7 | 26.3 | 24.1 |
| 43. | Peripherals & Controllers | 1.22.2 | % | 11.7 | 22.2 | 30.2 | 36.0 | 40.7 | 45.8 | 45.6 | 43.6 | 46.3 | 52.6 | 54.7 | 55.3 | 55.5 | 50.1 | 46.7 | 45.9 | 46.8 | 46.1 | 44.8 | 40.8 |
| 44. | Terminals | 1.22.2 | % | | | | | | | | 1.1 | 1.2 | 1.3 | 1.8 | 2.1 | 3.0 | 3.6 | 4.2 | 5.2 | 6.2 | 7.4 | 9.5 | 11.5 |
| 45. | OCR/MICR Equipment | | % | | | | | | | 0.4 | 0.9 | 1.1 | 1.2 | 1.4 | 1.4 | 1.6 | 1.8 | 1.9 | 2.1 | 2.3 | 2.4 | 2.6 | 2.7 |
| | Percent of Total Hardware | | | | | | | | | | | | | | | | | | | | | | |
| 46. | GP Systems | 1.20.8 | % | 97.3 | 94.7 | 93.3 | 92.7 | 92.3 | 91.6 | 91.5 | 91.7 | 90.7 | 89.9 | 89.5 | 89.9 | 90.2 | 90.5 | 90.2 | 89.3 | 88.0 | 86.5 | 84.4 | 83.6 |
| 47. | Mini Systems | 1.20.8 | % | | .9 | 2.1 | 2.6 | 3.1 | 3.7 | 3.7 | 3.6 | 4.2 | 4.5 | 5.0 | 4.7 | 4.5 | 4.5 | 4.8 | 5.2 | 5.8 | 6.9 | 8.2 | 9.4 |
| 48. | Data Entry–Total | | % | 2.7 | 4.4 | 4.7 | 4.7 | 4.6 | 4.7 | 5.1 | 5.5 | 6.1 | 6.6 | 6.8 | 6.6 | 6.7 | 6.6 | 6.7 | 7.4 | 8.2 | 8.7 | 9.7 | 9.3 |
| 49. | Keyboard Systems | 1.20.8 | % | 2.7 | 4.4 | 4.7 | 4.7 | 4.6 | 4.7 | 4.8 | 4.7 | 5.1 | 5.6 | 5.5 | 5.3 | 5.3 | 5.0 | 5.0 | 5.5 | 6.2 | 6.6 | 7.5 | 7.0 |
| 50. | OCR/MICR Equipment | | % | | | | | | | 0.8 | 0.8 | 1.0 | 1.0 | 1.3 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 |
| | Percent of GP Systems in Use | | | | | | | | | | | | | | | | | | | | | | |
| 51. | Services–Batch, On-Line | 1.20.7 | % | 8.3 | 6.3 | 4.6 | 4.4 | 6.7 | 6.7 | 6.9 | 6.3 | 5.8 | 5.0 | 4.6 | 4.1 | 4.1 | 4.4 | 5.1 | 6.2 | 7.5 | 8.7 | 10.1 | 11.2 |
| 52. | Software | 1.20.7 | % | | | | | | | | | .1 | .3 | .6 | .9 | 1.3 | 1.5 | 1.7 | 1.9 | 1.8 | 2.7 | 3.2 | 3.3 |
| 53. | Total Services | | % | 8.3 | 6.3 | 4.6 | 4.4 | 6.7 | 6.7 | 6.9 | 6.3 | 5.9 | 5.3 | 5.3 | 5.0 | 5.3 | 5.9 | 6.8 | 8.1 | 9.3 | 11.4 | 13.3 | 14.5 |
| 54. | Data Communications | 1.20.7 | % | | | | | | | .2 | .3 | .4 | .5 | .6 | .6 | .8 | 1.0 | 1.2 | 1.6 | 2.1 | 2.5 | 2.8 | 3.0 |
| 55. | Supplies | 1.20.7 | % | 1.7 | 2.8 | 3.5 | 3.8 | 4.1 | 4.6 | 5.1 | 5.3 | 6.2 | 6.3 | 5.7 | 5.4 | 5.2 | 4.5 | 4.2 | 4.1 | 4.0 | 4.1 | 4.7 | 6.2 |

## II.1.21 COMPUTER SYSTEMS—NOTES

**AFIPS Study.** 1-3. In 1972, Bruce Gilchrist and Richard E. Weber of the American Federation of Information Processing Societies, Inc. (AFIPS) met with several organizations active in the collection and interpretation of statistics about the data processing industry. The organizations mentioned in the resulting report were Auerbach Associates, Inc., International Data Corp., Arthur D. Little, Inc., and Quantum Science Corp. The report (GilcB73) included these figures on general purpose computer system shipments and the installed base. In fact, the data comes directly from *EDP Industry Report* dated March 12, 1971. It even perpetuates a curious anomaly contained in that report: if we add 1965 shipments of $2.4B to the end-1964 installed base of $7.92B, we conclude that the installed base at the end of 1965 can be no more than $10.32B, and in fact should be less because some systems must have been removed during the year. The table shows an illogical installed value of $11.1B. A second error is the confusion between GP and minisystems. In its March 12, 1970 issue, *EDP/IR* for the first time published a separate census of GP and minisystems. Until that time, their census had included all of the GP systems and some of the minis (see comments in connection with lines 13-20, below). The *EDP/IR* figures shown in lines 1-3 thus include a number of mini and dedicated application computers—machines like the Control Data 160, the DEC PDP-8, the IBM 1800, and the SDS 930—though the AFIPS report indicates they refer to GP machines only.

**A.D. Little.** 4-5. Frederic G. Withington of Arthur D. Little, Inc. communicated to me the figures on line 4. They represent domestic net shipments (gross shipments less equipment returned, subtracted at original value) from the following manufacturers: IBM, UNIVAC, RCA, CDC, Burroughs, Honeywell, NCR, and GE. Remote terminals and data entry equipment are not included. The data on line 5 is calculated from line 4 assuming that $.11B in systems was installed at the beginning of 1955.

**Diebold.** 6. For many years the Diebold Group, Inc. has published an annual computer census in their *Automatic Data Processing Newsletter* (*ADP/N*). The census generally includes all the computers *EDP/IR* includes as GP systems, and a number of minicomputers as well. It includes installations in the United States only. The last two censuses, shown marked with an asterisk, are as of June 30 of their respective years. All others are as of December 31.

**Business Automation Magazine.** 7-8. For some years *Business Automation Magazine* published an annual computer count. It apparently was compiled by the magazine itself. (The first two years of the census included some 2500 IBM 632's, which were not included in later censuses and which I eliminated.)

**Computers & Automation Magazine.** 9-12. Between 1956 and January 1962, the magazine *Computers and Automation* reprinted a computer census from Diebold's *ADP/N*. Since 1962 *C & A* has published its own census periodically. (The history of these censuses is tied to the career of Patrick McGovern, President of the International Data Corporation. From 1960 to 1961, McGovern worked on the *ADP/N* census for the Diebold Group. In 1961, he joined the staff of *C & A*, and the 1962 census shown in the table is the first *C & A* independent census. In April of 1964, McGovern established IDC and from then until the end of 1966 he worked on *EDP/IR* and simultaneously was on the *C & A* staff. Starting in 1967, he left *C & A* and worked full time at IDC.) As is indicated above line 9, the C & A census sometimes included U.S. installations only, sometimes worldwide, and sometimes didn't specify.

Line 9 shows the total number of installations at the end of each year, as actually published in *C & A*. The next two lines identify corrections which I made to this data to identify and distinguish the GP systems, and thus to make this census comparable to the later *EDP/IR* censuses. Line 9 was determined by counting the specialized, dedicated-application small computers which were the forebears of the minis and subsequently were counted with that class of machine—the Bendix G-15, the Librascope LGP-30, the Autonetics Recomp, the Control Data 160 family, the SDS 900 series machines, the DEC PDP family (except for the PDP-6 and PDP-10), etc. Line 11 was similarly determined by eliminating a set of machines not normally included with stored programed computers—the IBM 604, 607, 608, 609, and 610, along with the UNIVAC 60-120 and Burroughs E101. Line 12 was then computed by subtracting lines 10 and 11 from line 9. Note that the fluctuations in line 11 are caused by changes in the census taker's definition of what equipment he will include: the 1962 census eliminated IBM 600 series tabulating machines; the 1963 census further eliminated the UNIVAC 60 and 120; and in the 1966 census a variety of small machines manufactured by Clary, Friden, and the Monroe Calculating Machine Co. were cut. Inasmuch as all the machines counted on line 11 perform data processing and therefore properly should be included in any analysis and description of the industry, it is a pity there seems to exist no continuous and continuing census of these machines and their successors.

**EDP/IR.** 13-20. The *EDP/IR* census published in the January 12, 1967, issue was exactly the same as the *C & A* census in the January 1967 issue. The *C & A* census subsequently deteriorated—for example, the enumeration of IBM machines in the January 1972 issue is exactly the same as that in the January 1970 issue, except that the number of 360/30 machines has been reduced by exactly 1000. Meanwhile, the IDC census continued and improved, as that organization built a file which by 1972 included 60% by number and 75% by value of the GP installations made worldwide by American companies. The censuses for 1967 and 1968 are exactly comparable to the previous *C & A* censuses, and in addition break the installations down into those in the United States and those abroad. However, by the end of 1969 it was apparent that the minicomputer revolution had arrived, and as a consequence starting with the 1969 census *EDP/IR* began publishing two censuses. The GP census was a subset of the previous censuses—the same subset I had counted in the 1967 and 1968 censuses on lines 15, 18, and 21. These lines thus are comparable from 1968 to 1969; and furthermore line 15 is comparable to line 12 above. The new mini census, however, included the minicomputer machines which had been in previous censuses, but added a host of additional machines from various new and old manufacturers. There is therefore a discontinuity in lines 14, 17, and 20 at the 1969 census—1969 and later figures are comparable, and 1968 and earlier figures are comparable, but the two parts are not comparable to one another. Since the totals given on lines 13, 16, and 19 are the sum of GP and mini installations, they contain the same discontinuity at the same place.

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **AFIPS Study** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | GP–WW–Value Shipped | | $B | .065 | .170 | .280 | .460 | .600 | .720 | 1.100 | 1.400 | 1.710 | 2.200 | 2.40 | | | | | | | | | |
| 2. | GP–WW–Value in Use | | $B | .180 | .340 | .600 | 1.030 | 1.600 | 2.270 | 3.260 | 4.510 | 5.970 | 7.920 | 11.10 | | | | | | | | | |
| 3. | GP–WW–No. in Use | | k | .250 | .800 | 1.700 | 2.900 | 4.500 | 6.500 | 9.300 | 12.600 | 16.800 | 24.000 | 31.0 | | | | | | | | | |
| | **AD Little** | | | | | | | | | | | | | | | | | | | | | | |
| 4. | GP–US–Net Shipments | | $B | .07 | .19 | .23 | .26 | .31 | .39 | .82 | 1.25 | 1.20 | 1.37 | 1.40 | 2.45 | 4.40 | | | | | | | |
| 5. | GP–US–Value in Use | | $B | .18 | .37 | .60 | .80 | 1.11 | 1.50 | 2.32 | 3.57 | 4.77 | 6.14 | 7.54 | 9.99 | 14.39 | | | | | | | |
| | **Diebold** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Total–US–No. in Use | | k | | .81 | 1.55 | 2.03 | 3.61 | 4.53 | 7.31 | 11.08 | 15.87 | 22.50 | 29.14 | | 53.76 | 55.6 | 62.1* | | 83.5* | | | |
| | **Business Automation** | | | | | | | | | | | | | | | | | | | | | | |
| 7. | GP–US–No. in Use | | k | | | | | | | 6.51 | 10.71 | 13.71 | 17.45 | | 30.79 | | | | | | | | |
| 8. | GP–WW–No. in Use | | k | | | | | | | 7.42 | 12.69 | 17.41 | 22.57 | | 41.26 | | | | | | | | |
| | **C&A–Computers in Use** | | | | US | US | | US | | ? | ? | ? | WW | WW | WW | WW | ? | | | | | | |
| 9. | Total, as Published | | k | | 4.16 | 6.00 | | 9.91 | | 14.45 | 12.88 | 16.48 | 23.50 | 30.72 | 39.98 | 56.75 | 67.20 | | | | | | |
| 10. | Minis Included | | k | | .04 | .24 | | .69 | | 1.17 | 1.45 | 1.82 | 2.24 | 2.63 | 3.65 | | | | | | | | |
| 11. | ADP Included | | k | | 3.52 | 4.59 | | 6.29 | | 7.21 | 1.52 | .79 | 1.16 | 1.52 | .12 | | | | | | | | |
| 12. | GP Included | | k | | .60 | 1.17 | | 2.93 | | 6.07 | 9.91 | 13.87 | 20.10 | 26.57 | 36.21 | | | | | | | | |
| | **EDP/IR's Census–No. in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 13. | Total–WW | | k | | | | | | | | | | | | 39.98 | 57.69 | 69.45 | 89.52 | 108.93 | 132.21 | 163.39 | 208.56 | 260.79 |
| 14. | Mini–WW | | k | | | | | | | | | | | | 3.65 | 5.39 | 6.68 | 19.02 | 30.67 | 41.73 | 64.87 | 101.77 | 148.94 |
| 15. | GP–WW | | k | | | | | | | | | | | | 36.20 | 52.30 | 62.77 | 70.50 | 78.26 | 90.48 | 98.52 | 106.79 | 111.84 |
| 16. | Total–US | | k | | | | | | | | | | | | | 40.16 | 47.06 | 62.69 | 73.71 | 87.99 | 108.79 | 138.96 | 176.21 |
| 17. | Mini–US | | k | | | | | | | | | | | | | 4.76 | 5.64 | 16.11 | 25.26 | 33.52 | 51.06 | 76.71 | 111.17 |
| 18. | GP–US | | k | | | | | | | | | | | | | 35.40 | 41.42 | 46.58 | 48.45 | 54.47 | 57.73 | 62.25 | 65.04 |
| 19. | Total–International | | k | | | | | | | | | | | | | 17.53 | 22.39 | 26.85 | 35.22 | 44.22 | 54.60 | 69.60 | 84.58 |
| 20. | Mini–International | | k | | | | | | | | | | | | | .63 | .91 | 2.92 | 5.41 | 8.21 | 13.81 | 25.06 | 37.77 |
| 21. | GP–International | | k | | | | | | | | | | | | | 16.90 | 21.48 | 23.93 | 29.81 | 36.01 | 40.79 | 44.54 | 46.81 |
| | **EDP/IR 3/12/70** | | | | | | | | | | | | | | | | | | | | | | |
| 22. | US–No. Shipped | | k | .145 | .550 | .850 | 1.180 | 1.395 | 1.790 | 2.700 | 3.470 | 4.200 | 5.600 | 5.350 | 7.250 | 11.200 | 9.100 | | | | | | |
| 23. | US–No. in Use | | k | .244 | .745 | 1.500 | 2.550 | 3.810 | 5.400 | 7.550 | 9.900 | 12.850 | 18.200 | 23.200 | 29.800 | 40.100 | 47.100 | | | | | | |
| 24. | US–Value Shipped | | $B | .063 | .155 | .240 | .395 | .495 | .590 | .880 | 1.090 | 1.300 | 1.670 | 1.770 | 2.640 | 3.900 | 4.950 | | | | | | |
| 25. | US–Value in Use | | $B | .180 | .320 | .550 | .920 | 1.390 | 1.940 | 2.710 | 3.620 | 4.720 | 6.100 | 7.650 | 10.000 | 13.600 | 17.350 | | | | | | |
| 26. | Int'l.–No. Shipped | | k | .005 | .050 | .150 | .220 | .305 | .410 | .700 | 1.030 | 1.400 | 1.900 | 2.050 | 2.950 | 7.500 | 5.600 | | | | | | |
| 27. | Int'l.–No. in Use | | k | .006 | .055 | .200 | .400 | .690 | 1.100 | 1.750 | 2.700 | 3.950 | 5.800 | 7.800 | 10.800 | 17.500 | 22.300 | | | | | | |
| 28. | Int'l.–Value Shipped | | $B | .002 | .014 | .040 | .065 | .105 | .130 | .220 | .310 | .410 | .530 | .630 | 1.020 | 2.000 | 2.200 | | | | | | |
| 29. | Int'l.–Value in Use | | $B | - | .020 | .050 | .110 | .210 | .330 | .550 | .890 | 1.250 | 1.820 | 2.450 | 3.470 | 5.300 | 7.150 | | | | | | |
| 30. | WW–No. Shipped | | k | .150 | .600 | 1.000 | 1.400 | 1.700 | 2.200 | 3.400 | 4.500 | 5.600 | 7.500 | 7.400 | 10.200 | 18.700 | 14.700 | | | | | | |
| 31. | WW–No. in Use | | k | .250 | .800 | 1.700 | 2.950 | 4.500 | 6.500 | 9.300 | 12.600 | 16.800 | 24.000 | 31.000 | 40.600 | 57.600 | 69.400 | | | | | | |
| 32. | WW–Value Shipped | | $B | .065 | .170 | .280 | .460 | .600 | .720 | 1.100 | 1.400 | 1.710 | 2.200 | 2.400 | 3.660 | 5.900 | 7.150 | | | | | | |
| 33. | WW–Value in Use | | $B | .180 | .340 | .600 | 1.030 | 1.600 | 2.270 | 3.260 | 4.510 | 5.970 | 7.920 | 10.100 | 13.500 | 18.900 | 24.600 | | | | | | |
| | **EDP/IR 3/12/71** | | | | | | | | | | | | | | | | | | | | | | |
| 34. | WW–No. Shipped | | k | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | | | | | | |
| 35. | WW–No. in Use | | k | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | | | | | | |
| 36. | WW–Value Shipped | | $B | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | 3.900 | 5.350 | 6.710 | | | | | | |
| 37. | WW–Value in Use | | $B | nc | nc | nc | nc | nc | nc | nc | nc | nc | nc | 11.100 | 14.300 | nc | 24.500 | | | | | | |

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS (Continued) ●

| Line | Item | Date | Units | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EDP/IR Data** | | | | | | | | | | | |
| 38. | GP–WW–No. Shipped | 1970 | k | | | | 13.430 | | | | | |
| 39. | | 1971 | k | | | | 13.400 | 11.610 | | | | |
| 40. | | 1972 | k | 9.500 | 11.100 | 13.300 | 13.430 | 11.610 | 15.230 | | | |
| 41. | | 1973 | k | 10.600 | 14.570 | 12.800 | 12.200 | 11.820 | 16.330 | 18.550 | | |
| 41a. | | 1974 | k | 9.000 | 15.700 | 13.000 | 11.000 | 12.000 | 14.300 | 18.300 | 21.450 | |
| 41b. | | 1975 | k | | | | 11.000 | 12.000 | 14.300 | 18.300 | 20.230 | 14.320 |
| 42. | GP–WW–No. in Use | 1970 | k | | | | 70.400 | | | | | |
| 43. | | 1971 | k | | | | 70.400 | 78.400 | | | | |
| 44. | | 1972 | k | 41.000 | 53.340 | 63.400 | 72.570 | 78.950 | 90.695 | | | |
| 45. | | 1973 | k | 40.100 | 53.330 | 63.385 | 71.925 | 79.490 | 90.485 | 98.520 | | |
| 45a. | | 1974 | k | 39.100 | 48.000 | 59.000 | 66.700 | 74.800 | 85.200 | 94.800 | 106.80 | |
| 45b. | | 1975 | k | | | | 66.700 | 74.800 | 85.200 | 94.800 | 106.80 | 111.84 |
| 46. | GP–WW–Value Shipped | 1970 | $B | | | | 6.740 | | | | | |
| 47. | | 1971 | $B | | | | 6.820 | 6.760 | | | | |
| 48. | | 1972 | $B | 3.895 | 5.315 | 6.575 | 6.992 | 6.768 | 7.328 | | | |
| 49. | | 1973 | $B | 3.790 | 5.285 | 6.715 | 7.032 | 6.768 | 6.805 | 8.315 | | |
| 49a. | | 1974 | $B | 3.700 | 5.200 | 6.150 | 6.450 | 6.300 | 6.700 | 8.035 | 8.805 | |
| 49b. | | 1975 | $B | | | | 6.450 | 6.300 | 6.700 | 8.000 | 8.800 | 10.065 |
| 50. | GP–WW–Value in Use | 1970 | $B | | | | 29.600 | | | | | |
| 51. | | 1971 | $B | | | | 29.500 | 35.000 | | | | |
| 52. | | 1972 | $B | 14.400 | 18.800 | 24.200 | 30.100 | 35.800 | 40.700 | | | |
| 53. | | 1973 | $B | 15.200 | 19.600 | 25.200 | 31.200 | 35.300 | 38.700 | 42.100 | | |
| 53a. | | 1974 | $B | 13.100 | 17.600 | 22.600 | 27.800 | 32.400 | 36.300 | 39.800 | 44.500 | |
| 53b. | | 1975 | $B | | | | 27.800 | 32.400 | 36.300 | 39.800 | 44.500 | 49.500 |
| 54. | GP–US–No. Shipped | 1970 | k | | | | 8.450 | | | | | |
| 55. | | 1971 | k | | | | 8.450 | 5.300 | | | | |
| 56. | | 1972 | k | 6.500 | 7.600 | 9.000 | 8.450 | 5.300 | 8.500 | | | |
| 57. | | 1973 | k | 7.600 | 9.670 | 7.400 | 6.600 | 5.040 | 8.560 | 10.970 | | |
| 57a. | | 1974 | k | 6.000 | 10.000 | 7.400 | 6.000 | 5.700 | 7.600 | 10.700 | 14.000 | |
| 57b. | | 1975 | k | | | | 6.000 | 5.700 | 7.600 | 10.700 | 14.000 | 8.900 |
| 58. | GP–US–No. in Use | 1970 | k | | | | 46.500 | | | | | |
| 59. | | 1971 | k | | | | 46.500 | 48.600 | | | | |
| 60. | | 1972 | k | 30.000 | 35.600 | 41.400 | 46.570 | 48.450 | 54.470 | | | |
| 61. | | 1973 | k | 27.100 | 35.800 | 41.000 | 45.700 | 48.450 | 54.470 | 57.730 | | |
| 61a. | | 1974 | k | 27.100 | 31.000 | 37.000 | 40.700 | 43.800 | 49.200 | 54.000 | 62.250 | |
| 61b. | | 1975 | k | | | | 40.700 | 43.800 | 49.200 | 54.000 | 62.250 | 65.040 |
| 62. | GP–US–Value Shipped | 1970 | $B | | | | 4.570 | | | | | |
| 63. | | 1971 | $B | | | | 4.555 | 3.970 | | | | |
| 64. | | 1972 | $B | 2.760 | 3.810 | 4.650 | 4.642 | 3.948 | 4.074 | | | |
| 65. | | 1973 | $B | 2.760 | 3.810 | 4.645 | 4.642 | 4.073 | 3.975 | 5.170 | | |
| 65a. | | 1974 | $B | 2.600 | 3.600 | 4.150 | 4.150 | 3.600 | 3.900 | 5.035 | 5.405 | |
| 65b. | | 1975 | $B | | | | 4.150 | 3.600 | 3.900 | 5.000 | 5.400 | 6.220 |
| 66. | GP–US–Value in Use | 1970 | $B | | | | 20.900 | | | | | |
| 67. | | 1971 | $B | | | | 20.800 | 23.800 | | | | |
| 68. | | 1972 | $B | 10.200 | 13.300 | 17.000 | 20.800 | 24.100 | 26.400 | | | |
| 69. | | 1973 | $B | 10.700 | 13.800 | 17.500 | 21.400 | 23.600 | 25.200 | 26.600 | | |
| 69a. | | 1974 | $B | 9.400 | 12.400 | 15.700 | 19.100 | 21.500 | 23.300 | 24.700 | 27.300 | |
| 69b. | | 1975 | $B | | | | 19.100 | 21.500 | 23.300 | 24.700 | 27.300 | 30.200 |

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS (Continued) ●

| Line | Item | Date | Units | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70. | Mini–WW–No. Shipped | 1970 | k | | | | 6.220 | | | | | |
| 71. | | 1971 | k | | | | 6.220 | 11.350 | | | | |
| 72. | | 1972 | k | 1.500 | 2.750 | 4.500 | 8.100 | 11.200 | 11.600 | | | |
| 73. | | 1973 | k | 1.500 | 2.750 | 4.500 | 8.100 | 11.200 | 12.210 | 18.800 | | |
| 73a. | | 1974 | k | 1.500 | 2.750 | 4.600 | 8.100 | 11.100 | 13.500 | 22.600 | 33.900 | |
| 73b. | | 1975 | k | | | | 8.100 | 11.100 | 13.500 | 22.600 | 33.900 | 48.000 |
| 74. | Mini–WW–No. in Use | 1970 | k | | | | 19.000 | | | | | |
| 75. | | 1971 | k | | | | 19.800 | 31.100 | | | | |
| 76. | | 1972 | k | 5.200 | 7.900 | 12.400 | 20.300 | 30.800 | 41.700 | | | |
| 77. | | 1973 | k | 5.200 | 7.900 | 12.400 | 20.300 | 32.000 | 43.825 | 62.125 | | |
| 77a. | | 1974 | k | 5.200 | 7.900 | 12.400 | 20.300 | 31.000 | 44.000 | 65.500 | 98.000 | |
| 77b. | | 1975 | k | | | | 20.300 | 31.000 | 44.000 | 65.500 | 98.000 | 144.00 |
| 78. | Mini–WW–Value Shipped | 1970 | $B | | | | .430 | | | | | |
| 79. | | 1971 | $B | | | | .420 | .525 | | | | |
| 80. | | 1972 | $B | .110 | .175 | .240 | .357 | .377 | .315 | | | |
| 81. | | 1973 | $B | .110 | .175 | .240 | .357 | .377 | .360 | .560 | | |
| 81a. | | 1974 | $B | .125 | .220 | .272 | .355 | .415 | .377 | .500 | .770 | |
| 81b. | | 1975 | $B | | | | .355 | .415 | .377 | .500 | .770 | 1.170 |
| 82. | Mini–WW–Value in Use | 1970 | $B | | | | 1.240 | | | | | |
| 83. | | 1971 | $B | | | | 1.240 | 1.750 | | | | |
| 84. | | 1972 | $B | .660 | .825 | 1.050 | 1.380 | 1.750 | 2.055 | | | |
| 85. | | 1973 | $B | .660 | .825 | 1.050 | 1.380 | 1.720 | 2.105 | 2.690 | | |
| 85a. | | 1974 | $B | .587 | .807 | 1.079 | 1.433 | 1.845 | 2.216 | 2.703 | 3.453 | |
| 85b. | | 1975 | $B | | | | 1.4 | 1.8 | 2.2 | 2.7 | 3.4 | 4.6 |
| 86. | Mini–US–No. Shipped | 1970 | k | | | | 5.285 | | | | | |
| 87. | | 1971 | k | | | | 5.285 | 9.680 | | | | |
| 88. | | 1972 | k | 1.000 | 2.000 | 3.500 | 6.700 | 9.500 | 9.000 | | | |
| 89. | | 1973 | k | 1.000 | 2.000 | 3.500 | 6.700 | 8.900 | 9.350 | 15.100 | | |
| 89a. | | 1974 | k | 1.000 | 2.000 | 3.600 | 6.700 | 8.900 | 10.000 | 16.700 | 24.700 | |
| 89b. | | 1975 | k | | | | 6.700 | 8.900 | 10.000 | 16.700 | 24.700 | 34.000 |
| 90. | Mini–US–No. in Use | 1970 | k | | | | 16.100 | | | | | |
| 91. | | 1971 | k | | | | 16.500 | 25.600 | | | | |
| 92. | | 1972 | k | 4.000 | 6.000 | 9.500 | 16.100 | 25.000 | 33.500 | | | |
| 93. | | 1973 | k | 4.000 | 6.000 | 9.500 | 16.100 | 25.560 | 34.615 | 49.345 | | |
| 93a. | | 1974 | k | 4.000 | 6.000 | 9.500 | 16.100 | 24.500 | 34.000 | 50.000 | 71.000 | |
| 93b. | | 1975 | k | | | | 16.100 | 24.500 | 34.000 | 50.000 | 71.000 | 100.00 |
| 94. | Mini–US–Value Shipped | 1970 | $B | | | | .345 | | | | | |
| 95. | | 1971 | $B | | | | .340 | .400 | | | | |
| 96. | | 1972 | $B | .075 | .125 | .180 | .277 | .307 | .249 | | | |
| 97. | | 1973 | $B | .075 | .130 | .185 | .277 | .282 | .245 | .410 | | |
| 97a. | | 1974 | $B | .090 | .175 | .217 | .280 | .320 | .277 | .360 | .540 | |
| 97b. | | 1975 | $B | | | | .280 | .320 | .277 | .360 | .540 | .810 |
| 98. | Mini–US–Value in Use | 1970 | $B | | | | 1.020 | | | | | |
| 99. | | 1971 | $B | | | | 1.000 | 1.390 | | | | |
| 100. | | 1972 | $B | .565 | .690 | .865 | 1.135 | 1.425 | 1.665 | | | |
| 101. | | 1973 | $B | .565 | .690 | .865 | 1.135 | 1.385 | 1.663 | 2.107 | | |
| 101a. | | 1974 | $B | .506 | .681 | .898 | 1.177 | 1.494 | 1.766 | 2.116 | 2.641 | |
| 101b. | | 1975 | $B | | | | 1.2 | 1.5 | 1.8 | 2.1 | 2.6 | 3.4 |

22-37. In each of its Annual Review and Forecasts for the four years 1968-1971, *EDP/IR* published a tabulated history of shipments and installations of computer systems covering the years 1955 to 1968. Lines 22-33 present the 1970 tabulations, and lines 34-37 show the changes which were included in the 1971 tabulation, which did not break down shipments into the U.S. and international components. (nc means no change from the previous tabulations.) The tabulation, which was of course begun before IDC counted GP and mini systems separately, is intended to provide the reader with historical data for reference and comparisons with later statistics. There are three blunders of the type "last year's in use plus this year's shipments are less than this year's in use". Two of them are in the international-value table (lines 28 and 29) at 1961 and 1963. The other is in the corrected worldwide-value table (lines 36 and 37) at 1964. Note that this is the table and the error which was adopted by AFIPS—see discussion in connection with lines 1-3 above.

Comparing the *EDP/IR* data with previous entries in the table, we see some general agreement along with a variety of anomalies. There is excellent agreement with the A. D. Little figures for U.S. value in use (lines 5 and 25) except for the period 1958-1961 and the year 1967. Comparing IDC and Diebold figures (lines 6 and 23), we find IDC substantially higher for the period 1958-1961, and then note the Diebold figures are increasingly larger starting in 1962. To some extent, this divergence is of course due to the fact that Diebold had begun to count the new minicomputers which IDC did not include until 1969. Looking at the *C & A* data, we might expect that line 31, the IDC figure for the number of systems in use worldwide, might agree with the sum of lines 10 and 12. The agreement is pretty tenuous. (Surprisingly, the *C & A* figures for GP plus mini systems—line 10 plus line 12—agree well with the Diebold numbers on line 6—surprising, because the former are suppose to be worldwide installations, where Diebold's figures are for American installations only.)

38-101. The data from *C & A* and *EDP/IR* are, as I have stated, the actual census figures published by those periodicals for the years indicated. The A.D. Little figures, the Diebold figures for the period 1956 through 1960, and the *EDP/IR* figures on lines 22 to 37, on the other hand, are retrospective recapitulations of industry data. Lines 38 through 101 of the table show how IDC has annually revised its data base in the light of new information. The table is divided into four parts: lines 38-53 describe worldwide activity on general purpose systems; 54-69 describe the domestic general purpose market; lines 70-85 the worldwide minicomputer market; and lines 86-101 the domestic minicomputer market. Each of the four parts provides information on the number of systems shipped during the year, the number in use at the end of the year, and the value of those shipped and those in use. And for each of these entries, I show the data as reported by *EDP/IR* in their Annual Review and Forecast for the years 1970 to 1975. Looking at lines 38 through 41, for example, we see that in 1970 IDC estimated that 13,430 general purpose computers were shipped, worldwide, by U.S. manufacturers in 1969. In their 1971 edition, they reduced that number by 30 computers, and further estimated that 11,610 were shipped in 1970. In the 1972 edition, shown on line 40, they enlarged the table, estimating the number of GP systems shipped annually starting in 1966. Note they added back the 30 computers omitted in their 1971 estimate of 1969 shipments, but did not change their estimate of 1970 shipments. Their 1973 review, however, resulted in a modification of all the previously published shipment numbers.

The reasons for these changes are not disclosed by IDC. Generally speaking, they are made to reflect new data which the organization acquired or which was made public since the previous review. Obviously, some changes must also be made to correct blunders and typographical errors. However, some of the changes seem quite remarkable. In reviewing 1968 shipments, for example, the March 25, 1969, edition of *EDP/IR* said, "The number of computer systems shipped actually decreased (from 1967 to 1968). It was down 21.4% to 14,700. (See line 30 above.) Reasons for this are: (1) Substantial deliveries of large systems announced several years ago but just now moving off the shipping docks; (2) Significant amounts of add/on equipment (up to 40% of total shipments for some companies); and (3) massive replacement of second-generation computers with fewer third-generation models." However, the recapitulation in the 1972 edition showed an *increase* in the number of systems shipped (see lines 40 and 56); and the 1973 version once again showed a reduction in GP system shipments. Of course, the figures given in lines 38 to 91 cannot be compared directly with those given in lines 22 to 37, because the latter include all GP systems and a fraction of the minis, while the former, based on *EDP/IR's* new definitions and censuses, separate minis from GP's, and include many more minis than had been counted previously.

The revisions IDC has made illustrate very nicely the problems involved in attempting to measure the progress of the volatile data processing industry. Nevertheless, it is my opinion that IDC's staff, files, and data sources make that organization's published statistics the best available. My conclusion was apparently shared by the AFIPS representatives in the report referred to in connection with lines 1-3 above—their report contains the data on lines 60, 64, 68, 92, 96, and 100 from the March 30, 1972, edition of *EDP/IR* as well as the previously described data from the March 12, 1971 edition.

**Data Base.** 102-137. In reviewing the above data, we observe that there has been no attempt to provide a continuous and consistent record describing both the GP and minicomputer market, in the United States and abroad, over the entire history of the industry. *EDP/IR* has come closest, with the data repeated on lines 22 to 101 above. However, as has been mentioned before, the earlier and later data from IDC is not comparable because of the reclassification instituted starting in 1969. Lines 102 to 137 of the table provide my estimate of this market, broken down into all combinations of interest. Note that the basic data is that contained in the lines which describe the general purpose and minicomputer market in the United States and abroad—that is to say, lines 106-113 and 118-125. The data in the remainder of this portion of the table is derived from those 16 lines simply by adding them together in various ways. This portion of Table II.1.21 will serve as the data base for various other tables and calculations used in the remainder of the book.

Without justifying every entry in this table, let me explain the general rules I used in devising it:

a. Wherever possible, I tried to use the *EDP/IR* data. I was forced to make modifications to patch over the reclassification discontinuity and to correct the occassional blunders in that data. My starting point basically was the number of GP and mini systems in use in the United States

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Data Base** | | | | | | | | | | | | | | | | | | | | | | |
| 102. | GP–WW–No. Shipped | | k | .155 | .550 | .810 | 1.190 | 1.455 | 1.910 | 2.920 | 4.020 | 5.200 | 7.200 | 8.500 | 11.200 | 14.100 | 12.800 | 12.200 | 11.820 | 16.330 | 18.550 | 20.230 | 14.320 |
| 103. | GP–WW–No. in Use | | k | .246 | .755 | 1.460 | 2.500 | 3.800 | 5.500 | 7.750 | 10.500 | 15.200 | 21.900 | 29.600 | 40.300 | 53.100 | 63.000 | 72.000 | 79.000 | 90.600 | 98.520 | 106.80 | 111.84 |
| 104. | GP–WW–Value Shipped | | $B | .065 | .166 | .275 | .446 | .580 | .690 | 1.050 | 1.370 | 1.710 | 2.320 | 3.070 | 4.950 | 6.200 | 6.850 | 7.032 | 6.768 | 6.805 | 8.315 | 8.805 | 10.065 |
| 105. | GP–WW–Value in Use | | $B | .180 | .340 | .590 | 1.010 | 1.550 | 2.195 | 3.105 | 4.255 | 5.730 | 7.800 | 10.650 | 15.200 | 19.600 | 25.200 | 31.200 | 35.300 | 38.700 | 42.100 | 44.500 | 49.500 |
| 106. | GP–US–No. Shipped | 1.21.3 | k | .150 | .500 | .660 | .970 | 1.150 | 1.500 | 2.300 | 3.100 | 3.800 | 5.100 | 5.300 | 7.000 | 8.500 | 7.400 | 6.600 | 5.040 | 8.560 | 10.970 | 14.000 | 8.900 |
| 107. | GP–US–No. in Use | 1.21.1 | k | .240 | .700 | 1.260 | 2.100 | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 28.300 | 35.600 | 41.000 | 46.000 | 48.500 | 54.400 | 57.730 | 62.250 | 65.040 |
| 108. | GP–US–Value Shipped | 1.21.4 | $B | .063 | .152 | .235 | .381 | .475 | .560 | .850 | 1.060 | 1.220 | 1.570 | 1.910 | 3.200 | 3.900 | 4.650 | 4.642 | 4.073 | 3.975 | 5.170 | 5.405 | 6.220 |
| 109. | GP–US–Value in Use | 1.21.2 | $B | .180 | .320 | .540 | .900 | 1.340 | 1.865 | 2.605 | 3.485 | 4.550 | 6.000 | 7.800 | 10.700 | 13.800 | 17.500 | 21.400 | 23.600 | 25.200 | 26.600 | 27.300 | 30.200 |
| 110. | GP–Int'l.–No. Shipped | | k | .005 | .050 | .150 | .220 | .305 | .410 | .620 | .920 | 1.400 | 2.100 | 3.200 | 4.200 | 5.600 | 5.400 | 5.600 | 6.780 | 7.770 | 7.580 | 6.230 | 5.420 |
| 111. | GP–Int'l.–No. in Use | | k | .006 | .055 | .200 | .400 | .690 | 1.100 | 1.600 | 2.400 | 3.500 | 5.200 | 8.000 | 12.000 | 17.500 | 22.000 | 26.000 | 30.500 | 36.200 | 40.790 | 44.550 | 46.800 |
| 112. | GP–Int'l.–Value Shipped | | $B | .002 | .014 | .040 | .065 | .105 | .130 | .200 | .310 | .490 | .750 | 1.160 | 1.750 | 2.300 | 2.200 | 2.390 | 2.695 | 2.830 | 3.145 | 3.400 | 3.845 |
| 113. | GP–Int'l.–Value in Use | | $B | - | .020 | .050 | .110 | .210 | .330 | .500 | .770 | 1.180 | 1.800 | 2.850 | 4.500 | 5.800 | 7.700 | 9.800 | 11.700 | 13.500 | 15.500 | 17.200 | 19.300 |
| 114. | Mini–WW–No. Shipped | | k | - | .050 | .190 | .210 | .250 | .300 | .400 | .450 | .500 | .750 | 1.100 | 1.500 | 2.750 | 4.500 | 8.100 | 12.000 | 12.210 | 20.900 | 37.200 | 51.500 |
| 115. | Mini–WW–No. in Use | | k | - | .050 | .240 | .450 | .700 | 1.000 | 1.400 | 1.850 | 2.250 | 2.900 | 3.800 | 5.200 | 7.900 | 12.400 | 20.300 | 32.000 | 43.825 | 64.345 | 98.000 | 144.00 |
| 116. | Mini–WW–Value Shipped | | $B | - | .003 | .010 | .014 | .020 | .030 | .030 | .038 | .092 | .127 | .180 | .165 | .175 | .240 | .357 | .377 | .400 | .600 | .815 | 1.210 |
| 117. | Mini–WW–Value in Use | | $B | - | .003 | .012 | .025 | .045 | .075 | .105 | .143 | .230 | .345 | .504 | .660 | .825 | 1.050 | 1.380 | 1.720 | 2.105 | 2.690 | 3.453 | 4.600 |
| 118. | Mini–US–No. Shipped | 1.21.3 | k | - | .050 | .190 | .210 | .250 | .300 | .400 | .400 | .400 | .500 | .800 | 1.000 | 2.000 | 3.500 | 6.700 | 9.500 | 9.350 | 15.100 | 24.700 | 34.000 |
| 119. | Mini–US–No. in Use | 1.21.1 | k | - | .050 | .240 | .450 | .700 | 1.000 | 1.400 | 1.800 | 2.100 | 2.500 | 3.100 | 4.000 | 6.000 | 9.500 | 16.100 | 25.560 | 34.615 | 49.345 | 71.000 | 100.00 |
| 120. | Mini–US–Value Shipped | 1.21.4 | $B | - | .003 | .010 | .014 | .020 | .030 | .030 | .030 | .080 | .100 | .150 | .130 | .130 | .185 | .277 | .282 | .300 | .450 | .540 | .810 |
| 121. | Mini–US–Value in Use | 1.21.2 | $B | - | .003 | .012 | .025 | .045 | .075 | .105 | .135 | .210 | .300 | .434 | .565 | .690 | .865 | 1.135 | 1.385 | 1.665 | 2.107 | 2.641 | 3.400 |
| 122. | Mini–Int'l.–No. Shipped | | k | - | - | - | - | - | - | - | .050 | .100 | .250 | .300 | .500 | .750 | 1.000 | 1.400 | 2.500 | 2.860 | 5.800 | 12.500 | 17.500 |
| 123. | Mini–Int'l.–No. in Use | | k | - | - | - | - | - | - | - | .050 | .150 | .400 | .700 | 1.200 | 1.900 | 2.900 | 4.200 | 6.440 | 9.210 | 15.000 | 27.000 | 44.000 |
| 124. | Mini–Int'l.–Value Shipped | | $B | - | - | - | - | - | - | - | .008 | .012 | .027 | .030 | .035 | .045 | .055 | .080 | .095 | .100 | .150 | .275 | .400 |
| 125. | Mini–Int'l.–Value in Use | | $B | - | - | - | - | - | - | - | .008 | .020 | .045 | .070 | .095 | .135 | .185 | .245 | .335 | .440 | .583 | .812 | 1.200 |
| 126. | Total–US–No. Shipped | 1.21.3 | k | .150 | .550 | .850 | 1.180 | 1.400 | 1.800 | 2.700 | 3.500 | 4.200 | 5.600 | 6.100 | 8.000 | 10.500 | 10.900 | 13.300 | 14.540 | 17.910 | 26.070 | 38.700 | 42.900 |
| 127. | Total–US–No. in Use | 1.21.1 | k | .240 | .750 | 1.500 | 2.550 | 3.810 | 5.400 | 7.550 | 9.900 | 13.800 | 19.200 | 24.700 | 32.300 | 41.600 | 50.500 | 62.100 | 74.060 | 89.015 | 107.08 | 133.25 | 165.04 |
| 128. | Total–US–Value Shipped | 1.21.4 | $B | .063 | .155 | .245 | .395 | .495 | .590 | .880 | 1.090 | 1.300 | 1.670 | 2.060 | 3.330 | 4.030 | 4.835 | 4.919 | 4.355 | 4.275 | 5.620 | 5.945 | 7.030 |
| 129. | Total–US–Value in Use | 1.21.2 | $B | .180 | .320 | .550 | .920 | 1.390 | 1.940 | 2.710 | 3.620 | 4.760 | 6.300 | 8.234 | 11.265 | 14.490 | 18.365 | 22.535 | 24.985 | 26.865 | 28.707 | 29.941 | 33.600 |
| 130. | Total–Int'l.–No. Shipped | | k | .005 | .050 | .150 | .220 | .305 | .410 | .620 | .970 | 1.500 | 2.350 | 3.500 | 4.700 | 6.350 | 6.400 | 7.000 | 9.280 | 10.630 | 13.380 | 18.730 | 22.920 |
| 131. | Total–Int'l.–No. in Use | | k | .006 | .055 | .200 | .400 | .690 | 1.100 | 1.600 | 2.450 | 3.650 | 5.600 | 8.700 | 13.200 | 19.400 | 24.900 | 30.200 | 36.940 | 45.410 | 55.790 | 71.550 | 90.800 |
| 132. | Total–Int'l.–Value Shipped | | $B | .002 | .014 | .040 | .065 | .105 | .130 | .200 | .318 | .502 | .777 | 1.190 | 1.785 | 2.345 | 2.255 | 2.470 | 2.790 | 2.930 | 3.295 | 3.675 | 4.245 |
| 133. | Total–Int'l.–Value in Use | | $B | - | .020 | .050 | .110 | .210 | .330 | .500 | .778 | 1.200 | 1.845 | 2.920 | 4.595 | 5.935 | 7.885 | 10.045 | 12.035 | 13.940 | 16.083 | 18.010 | 20.500 |
| 134. | Total–WW–No. Shipped | | k | .155 | .600 | 1.000 | 1.400 | 1.705 | 2.210 | 3.320 | 4.470 | 5.700 | 7.950 | 9.600 | 12.700 | 16.850 | 17.300 | 20.300 | 23.820 | 28.540 | 39.45 | 57.430 | 65.820 |
| 135. | Total–WW–No. in Use | | k | .246 | .805 | 1.700 | 2.930 | 4.500 | 6.500 | 9.150 | 12.350 | 17.450 | 24.800 | 33.400 | 45.500 | 61.000 | 75.400 | 92.300 | 111.00 | 134.43 | 162.87 | 204.80 | 255.84 |
| 136. | Total–WW–Value Shipped | | $B | .065 | .169 | .285 | .460 | .600 | .720 | 1.080 | 1.408 | 1.802 | 2.447 | 3.250 | 5.115 | 6.375 | 7.090 | 7.389 | 7.145 | 7.205 | 8.915 | 9.620 | 11.275 |
| 137. | Total–WW–Value in Use | | $B | .180 | .340 | .600 | 1.030 | 1.600 | 2.270 | 3.210 | 4.400 | 5.960 | 8.150 | 11.154 | 15.860 | 20.425 | 26.250 | 32.580 | 37.020 | 40.805 | 44.790 | 47.950 | 54.100 |
| | **Averages** | | | | | | | | | | | | | | | | | | | | | | |
| 138. | GP–US–Av. Val. Shipped | 1.21.5 | $k | 420 | 304 | 356 | 393 | 413 | 373 | 370 | 342 | 321 | 308 | 360 | 457 | 460 | 628 | 703 | 808 | 464 | 471 | 386 | 699 |
| 139. | GP–US–Av. Val. in Use | 1.21.5 | $k | 730 | 457 | 429 | 428 | 431 | 424 | 424 | 430 | 389 | 360 | 360 | 378 | 387 | 427 | 465 | 487 | 463 | 461 | 439 | 464 |
| 140. | Mini–US–Av. Val. Shipped | 1.21.5 | $k | | 50 | 50 | 67 | 80 | 100 | 75 | 75 | 200 | 200 | 188 | 130 | 65 | 53 | 41 | 30 | 32 | 30 | 22 | 24 |
| 141. | Mini–US–Av. Val. in Use | 1.21.5 | $k | | 50 | 50 | 55 | 64 | 75 | 75 | 75 | 100 | 120 | 140 | 141 | 115 | 91 | 70 | 54 | 48 | 43 | 37 | 34 |
| 142. | GP–Int'l.–Av. Value Shipped | | $k | 400 | 280 | 267 | 295 | 344 | 317 | 323 | 337 | 350 | 357 | 362 | 417 | 410 | 407 | 427 | 397 | 364 | 415 | 546 | 709 |
| 143. | GP–Int'l.–Av. Val. in Use | | $k | 400 | 364 | 250 | 275 | 304 | 300 | 312 | 320 | 337 | 346 | 356 | 354 | 331 | 350 | 377 | 384 | 373 | 380 | 386 | 412 |
| 144. | Mini–Int'l–Av. Value Shipped | | $k | | | | | | | | 160 | 120 | 110 | 100 | 70 | 60 | 55 | 57 | 38 | 35 | 26 | 22 | 23 |
| 145. | Mini–Int'l–Av. Val. in Use | | $k | | | | | | | | 160 | 133 | 112 | 100 | 79 | 71 | 64 | 58 | 52 | 48 | 39 | 30 | 27 |
| 146. | GP–US–Rtrns, of Ship'ts. | 1.21.7 | % | | 8 | 6 | 6 | 7 | 6 | 13 | 17 | 13 | 8 | 6 | 9 | 21 | 20 | 16 | 46 | 60 | 73 | 87 | 53 |

and internationally, and in general I used the IDC figures for the period 1955 to 1960 and 1968 to 1972.

b. The reconstruction of what happened in the period 1960 to 1968 or so was effected using different rationales for different parts of the census. For the GP machines, I attempted a smooth transition, and in addition decided to adopt IDC's conclusion that the number of systems shipped dropped from 1967 to 1968.

c. For minicomputer installations in the United States, I started with the *C & A* censuses for the years prior to 1967, counting all the machines which *EDP/IR* had later defined as minicomputers. I also counted the mini machines shown in an international computer census published by *Datamation* magazine in August 1962 (DataCens62). Reviewing these figures, I concluded the *C & A* census was low for the period after 1959, and therefore increased the "number in use" to effect a smooth transition to the later *EDP/IR* figures. I chose the "number shipped" figures to be consistent with the number in use, taking into account the fact that few minimachines are returned, and that their installed life is long. And I chose the "value shipped" figures based on the arguments that, in the late 1950's, most machines in this class were low cost machines like the LGP-30, and the Bendix G-15; between 1960 and 1965 the much bigger machines from ASI, Bunker-Ramo, Computer Control Company, Control Data, and SDS had the effect of substantially increasing the average shipped value; and then the minicomputers took over starting in 1965, and the average value has been dropping ever since.

d. With regard to minicomputers installed outside the United States, my starting point was the previously-mentioned *Datamation* census in 1962. That census shows only 25 American made minicomputers installed abroad as of July 1, 1962, and represents data which was reportedly supplied by the manufacturers. I therefore assumed that 1962 was the first year such machines were shipped in any quantity, and showed what seems to be a reasonable build-up to the *EDP/IR* figures for 1966, which for the most part I adopted without change.

e. In establishing the value of machines shipped, I took average system value into account, and attempted to maintain what seemed like reasonable and consistent trends in those figures.

138-145. These average values for machines shipped and installed in the United States are computed from shipment and installation figures in the table above. Row 138, for example, the average value of GP systems shipped domestically, is computed by dividing entries in line 108 by entries in line 106.

146. This line shows the value of domestic general purpose systems retired each year as a percent of shipments in that year. It is comp ted by adding the value in use at the end of a given year to the ship.nents during the next year, subtracting the value in use at the end of the next year from the result, and dividing the difference by the shipment value. (For example, the 73% figure for 1972 is computed from rows 108 and 109 by adding \$25.2B and \$5.17B, subtracting \$26.6B, and dividing the result by \$5.17B.) Note that, in view of the extraordinarily great uncertainty in shipment and in installation values, the results are highly suspect.

**Distribution—By System Size.** 147-153. This portion of the table shows the percentage distribution *by value* of computer systems in use. It was formed by identifying the systems in each price range, computing their total value, and dividing that number by the value of all computers in use. The data for the years 1959-1968 comes from GropA70, which contains a set of tables showing the monthly rental of systems by all manufacturers. Groppelli's source was the annual census published in *Computers and Automation.* It therefore contains a mixture of domestic and worldwide installations, and of general purpose and mini systems. Probably the international inclusion does not bias the percentages very much; and the minicomputers have such a low rental that they don't introduce much bias either. (The increase shown from 1966 to 1967 in the smallest category of machine comes primarily from an increase in the number of IBM's 360/20 computers.) I used a factor of 40 in converting rentals to the purchase price ranges shown.

The entries for the years 1969 and 1971 are not strictly comparable to the previous entries. The source is IDC (from *EDP/IR* May 29, 1970, and a later private IDC report), and the figures represent domestic GP installations only. Furthermore, and more important, IDC's price categorization differs from *C & A's*. For example, while *C & A* includes the 360/20 with systems selling for under \$125K (rental value \$2K/mo.), IDC estimates an average monthly rental \$2.9K/mo. Furthermore, IDC's 1969 and 1971 figures are not exactly comparable, because the former were published with the price distributions shown, while the latter were based on a monthly rental range starting at \$2.5K/mo. and increasing by a factor of 2 for each category: 0-\$2.5K, \$2.5K-\$5.0K, \$5.0K-\$10.0K, etc. The general effect is that the 1971 figures underestimate the percentage value of the smallest systems and overestimate that of the largest. The 1974 distribution is from Table II.1.31.2, q.v.

A sampling of the machines in each of the *C & A* categories is as follows: 0-\$125K, IBM 1130, 360/20, UNIVAC 1004; \$125K-\$250K, IBM 650, 1401, Burroughs 200; \$250K-\$500K, IBM 1460, 360/30, Honeywell 200, NCR 315, RCA 301; \$500K-\$1M, IBM 360/40, 1410, 7040, Burroughs 5000, 5500, RCA 70/45; \$1M-\$2M, IBM 705, 360/50, CDC 1604, GE 625, UNIVAC I, II, 490, 1108; \$2M-\$4M, IBM 7090, 360/65, 360/75, GE 625; over \$4M, IBM 360/67, CDC 6600.

**Distribution—By Manufacturer.** Note: *this portion of the table contains source data on system installations, by manufacturers. See Table II.1.31.1, lines 1-84, for the installation data base which was created from this information, from C & A* and *EDP/IR.*

155-171. These entries further break down the GP censuses 12 and 18 above, from *C & A* and *EDP/IR.* Note there is a discontinuity between 1966 and 1967, where we change over from a worldwide census to a domestic one. IBM's first generation machines include the 305, 650, and the 700 family. The second generation are the 1400, 1600, and 7000 families. Line 161 combines the individual Univac and RCA computer populations of lines 162-163; and line 164 does the same thing for the Honeywell and General Electric populations. The "others" category of line 170 includes companies such as SDS, DEC, Philco, and Friden.

172-187. This series is computed from lines 155 to 170, by dividing each by line 171. It provides an estimate of the proportion of all GP machines supplied by each of the principal manufacturers. Though it is based on a combination of worldwide and domestic data, I will assume the proportions are applicable to U.S. installations.

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Distributions by Value of Systems in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 147. | 0-$125k | 1.21.6 | % | | | | | 9 | 7 | 8 | 5 | 4 | 6 | 7 | 7 | 10 | 10 | 4 | | 4 | | | 11 |
| 148. | $125k-$250k | 1.21.6 | % | | | | | 25 | 24 | 24 | 27 | 30 | 33 | 31 | 28 | 19 | 15 | 10 | | 10 | | | 7 |
| 149. | $250k-$500k | 1.21.6 | % | | | | | 9 | 11 | 11 | 11 | 10 | 14 | 20 | 22 | 25 | 21 | 28 | | 12 | | | 14 |
| 150. | $500k-$1M | 1.21.6 | % | | | | | 7 | 9 | 8 | 7 | 9 | 10 | 15 | 17 | 18 | 20 | 20 | | 21 | | | 20 |
| 151. | $1M-$2M | 1.21.6 | % | | | | | 41 | 39 | 34 | 28 | 22 | 17 | 13 | 12 | 14 | 15 | 16 | | 27 | | | 18 |
| 152. | $2M-$4M | 1.21.6 | % | | | | | 7 | 8 | 14 | 20 | 24 | 19 | 13 | 13 | 12 | 16 | 17 | | 20 | | | 23 |
| 153. | Over $4M | 1.21.6 | % | | | | | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 4 | 5 | | 6 | | | 7 |
| | **Distr.—By Manufacturer** | | | | | | | | | | | | | | | | | | | | | | |
| | **GP Systems—No. in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 155. | IBM—Total | | k | | .482 | .935 | | 2.397 | | 4.799 | 8.003 | 10.548 | 14.076 | 17.442 | 24.438 | 25.075 | 27.103 | 31.390 | 32.681 | 36.362 | 38.482 | 40.931 | 42.819 |
| 156. | First Generation | | k | | .482 | .935 | | 2.395 | | 2.319 | 2.225 | 1.382 | .913 | .546 | .410 | .263 | .197 | .066 | .035 | .017 | .007 | .004 | .004 |
| 157. | Second Generation | | k | | | | | .002 | | 2.480 | 5.778 | 9.166 | 13.163 | 16.129 | 18.067 | 12.570 | 8.132 | 5.775 | 4.024 | 3.722 | 2.840 | 2.219 | 1.772 |
| 158. | 360 Series | | k | | | | | | | | | | | .765 | 5.261 | 10.222 | 15.573 | 21.939 | 23.697 | 22.385 | 17.755 | 11.187 | 8.522 |
| 159. | 370 Series | | k | | | | | | | | | | | | | | | | | 1.028 | 3.480 | 6.286 | 8.926 |
| 160. | System 3 and 1130 | | k | | | | | | | | | | | .002 | .700 | 2.020 | 3.200 | 3.610 | 4.925 | 9.210 | 14.400 | 21.235 | 23.595 |
| 161. | Univac—Total (with RCA) | | k | | .054 | .090 | | .284 | | .755 | .958 | 1.731 | 3.490 | 4.844 | 5.559 | 4.605 | 5.078 | 5.620 | 5.705 | 6.176 | 6.155 | 5.921 | 5.361 |
| 162. | Univac | | k | | .052 | .087 | | .284 | | .635 | .711 | 1.264 | 2.845 | 4.059 | 4.592 | 3.677 | 3.912 | 4.495 | 4.634 | 5.124 | 5.033 | 4.960 | 4.508 |
| 163. | RCA | | k | | .002 | .003 | | .016 | | .120 | .247 | .467 | .645 | .785 | .967 | .928 | 1.166 | 1.125 | 1.071 | 1.052 | 1.122 | .961 | .853 |
| 164. | Honeywell (HIS, with GE) | | k | | | | | .007 | | .131 | .224 | .398 | .652 | 1.438 | 2.615 | 3.059 | 3.677 | 3.838 | 3.586 | 4.581 | 5.419 | 5.899 | 5.851 |
| 165. | Honeywell | | k | | | | | .007 | | .048 | .100 | .148 | .375 | .922 | 1.597 | 1.894 | 2.239 | 2.424 | | 3.386 | 4.036 | 4.246 | 4.198 |
| 166. | General Electric | | k | | | | | | | .083 | .124 | .250 | .277 | .516 | 1.018 | 1.165 | 1.438 | 1.414 | | 1.195 | 1.383 | 1.653 | 1.653 |
| 167. | National Cash Register (NCR) | | k | | .025 | .031 | | .033 | | .126 | .395 | .686 | 1.057 | 1.578 | 1.971 | 1.943 | 3.448 | 3.086 | 3.696 | 3.837 | 3.985 | 4.441 | 5.045 |
| 168. | Burroughs | | k | | .040 | .081 | | .151 | | .161 | .215 | .364 | .627 | .877 | 1.042 | 1.160 | 1.341 | 1.638 | 1.703 | 2.253 | 2.260 | 2.801 | 3.257 |
| 169. | Control Data Corp. (CDC) | | k | | | | | | | .027 | .040 | .087 | .131 | .295 | .450 | .398 | .485 | .513 | .528 | .487 | .522 | .515 | .529 |
| 170. | Others | | k | | .003 | .040 | | .060 | | .072 | .072 | .064 | .064 | .097 | .135 | .153 | .289 | .494 | .547 | .772 | .909 | 1.739 | 2.174 |
| 171. | Total | | k | | .604 | 1.177 | | 2.932 | | 6.071 | 9.907 | 13.878 | 20.097 | 26.571 | 36.210 | 36.393 | 41.421 | 46.579 | 48.446 | 54.468 | 57.732 | 62.247 | 65.036 |
| | **GP Systems—% of No. in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 172. | IBM—Total | 1.31.1 | % | 79.2 | 79.8 | 79.4 | 80.0 | 81.8 | 80.0 | 79.0 | 80.8 | 76.0 | 70.0 | 65.6 | 67.5 | 68.9 | 65.4 | 67.4 | 67.5 | 66.8 | 66.6 | 65.8 | 65.8 |
| 173. | First Generation | 1.31.1 | % | 79.2 | 79.8 | 79.4 | 80.0 | 81.7 | 60.0 | 38.2 | 22.4 | 10.0 | 4.5 | 2.1 | 1.1 | .7 | .5 | .1 | .1 | 0 | - | - | - |
| 174. | Second Generation | 1.31.1 | % | | | | | .1 | 20.0 | 40.8 | 58.3 | 66.0 | 65.5 | 60.6 | 50.0 | 34.5 | 19.6 | 12.4 | 8.3 | 6.8 | 4.9 | 3.6 | 2.7 |
| 175. | 360 Series | 1.31.1 | % | | | | | | | | | | | 2.9 | 14.5 | 28.1 | 37.6 | 47.1 | 48.9 | 41.1 | 30.8 | 18.0 | 13.1 |
| 176. | 370 Series | 1.31.1 | % | | | | | | | | | | | | | | | | | 1.9 | 6.0 | 10.0 | 13.7 |
| 177. | System 3 and 1130 | 1.31.1 | % | | | | | | | | | | | | 1.9 | 5.6 | 7.7 | 7.8 | 10.2 | 16.9 | 24.9 | 34.1 | 36.3 |
| 178. | Univac—Total (with RCA) | 1.31.2 | % | 9.2 | 8.9 | 7.4 | 9.0 | 10.2 | 11.0 | 12.5 | 9.7 | 12.5 | 17.4 | 18.3 | 15.4 | 12.6 | 12.2 | 12.0 | 11.8 | 11.3 | 10.7 | 9.5 | 8.2 |
| 179. | Univac | 1.31.2 | % | | 8.6 | 7.4 | 9.0 | 9.7 | 10.0 | 10.5 | 7.2 | 9.1 | 14.2 | 15.3 | 12.7 | 10.1 | 9.4 | 9.6 | 9.6 | 9.4 | 8.7 | 8.0 | 6.9 |
| 180. | RCA | 1.31.2 | % | | .3 | | | .5 | 1.0 | 2.0 | 2.5 | 3.4 | 3.2 | 3.0 | 2.7 | 2.5 | 2.8 | 2.4 | 2.2 | 1.9 | 1.9 | 1.5 | 1.3 |
| 181. | Honeywell (HIS, with GE) | 1.31.3 | % | | | | | | 1.0 | 2.2 | 2.3 | 2.9 | 3.2 | 5.4 | 7.2 | 8.4 | 8.9 | 8.2 | 7.4 | 8.4 | 9.4 | 9.5 | 9.0 |
| 182. | Honeywell | 1.31.3 | % | | | | | | .8 | .8 | 1.0 | 1.1 | 1.9 | 3.5 | 4.4 | 5.2 | 5.4 | 5.2 | | 6.2 | 7.0 | 6.8 | 6.5 |
| 183. | General Electric | 1.31.3 | % | | | | | | .2 | 1.4 | 1.3 | 1.8 | 1.4 | 1.9 | 2.8 | 3.2 | 3.5 | 3.0 | | 2.2 | 2.4 | 2.7 | 2.5 |
| 184. | National Cash Register | 1.31.4 | % | 5.0 | 4.1 | 2.6 | 2.0 | 1.1 | 1.5 | 2.1 | 4.0 | 4.9 | 5.3 | 5.9 | 5.4 | 5.3 | 8.3 | 6.6 | 7.6 | 7.0 | 6.9 | 7.1 | 7.8 |
| 185. | Burroughs | 1.31.4 | % | 7.1 | 6.6 | 6.9 | 6.0 | 5.2 | 4.0 | 2.7 | 2.2 | 2.6 | 3.1 | 3.3 | 2.9 | 3.2 | 3.2 | 3.5 | 3.5 | 4.1 | 3.9 | 4.5 | 5.0 |
| 186. | Control Data Corp. (CDC) | 1.31.4 | % | | | | | | | .4 | .4 | .6 | .7 | 1.1 | 1.2 | 1.1 | 1.2 | 1.1 | 1.1 | .9 | .9 | .8 | .8 |
| 187. | Others | | % | | .5 | 9.4 | 3.0 | 1.5 | 2.5 | 1.2 | .7 | .5 | .3 | .4 | .4 | .4 | .7 | 1.1 | 1.1 | 1.4 | 1.6 | 2.8 | 3.3 |
| | **Mini Systems—No. in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 188. | CDC—Total | | k | | .020 | .206 | | .630 | | .968 | 1.030 | 1.259 | 1.401 | 1.206 | 1.126 | 1.162 | 1.187 | 1.528 | 1.559 | 1.730 | 1.788 | 1.729 | 1.789 |
| 189. | Bendix | | k | | .020 | .104 | | .280 | | .362 | .348 | .280 | .320 | .325 | .310 | | | | | | | | |
| 190. | Librascope | | k | | | .102 | | .350 | | .486 | .467 | .629 | .668 | .412 | .295 | | | | | | | | |
| 191. | CDC | | k | | | | | | | .120 | .215 | .350 | .413 | .469 | .521 | | | | | | | | |

188-203. These entries summarize the mini-computer censuses in the same way that lines 155-171 summarized the GP censuses. The total on line 203 is comparable to the totals on lines 10 and 17, and the sources are *C & A* through 1966 and *EDP/IR* in 1967 and later. CDC took over the Bendix machines (G-15 and G-20) in 1963, and the old Librascope systems (LGP-21, LGP-30, RPC-4000) in 1966. In addition, Control Data's 160 and 1700 family machines are included with the minis. All DEC machines are classified as minis except for the PDP-6 and PDP-10. The XDS 90, 900, and CE series are minis, along with the Sigma 2 and Sigma 3. Honeywell took over the Computer Control Company's systems in 1966, and has since introduced a variety of special application machines. IBM's 1800 and System 7 are classified as minis, as are General Electric's communication and process control systems–the computer activity GE retained after it sold the greater part of its business to Honeywell. The remaining manufacturers–Hewlett Packard, Varian Data Machines, Data General Corp., Interdata, and General Automation–are the principal (but by no means the only) remaining manufacturers of minicomputers. All the products of these companies are minis–none are classified as GP systems.

204-218. These entries are calculated by dividing the numbers on lines 188 to 202 by the totals given on line 203.

219-232. Since 1967, *EDP/IR* has distinguished domestic, international, and worldwide (the sum of domestic and international) installations in its annual census of computer systems in use, by manufacturer and model number. The percentages in this table for the years after 1966 were computed from the "worldwide" censuses. (For the years 1967 and 1968, *EDP/IR* did not distinguish GP and minisystems. However, the data for those two years was derived by separating out the model numbers which subsequently became part of the minicomputer population. The percentages shown on lines 219 through 228 are thus based on the resulting GP system population, while those on lines 229-232 are based on the mini population.) For the years 1955 through 1966, the percentages shown were derived from *EDP/IR* and its predecessor *C & A*, and are the same as those given above on lines 172, 178 through 186, 204, 208, 210, and 211.

**GP System Life.** 233-236. These lines show the results of computations of the average life of GP systems in the United States–or rather, the average life of a dollar's worth of installed equipment. The computations are based on the value in use and the value shipped of GP U.S. systems, from lines 108 and 109 of this table. In addition, I estimated the value of shipments for the years 1950 through 1954 as .005, .005, .020, .040, and .055; and the value of systems in use for those years as .005, .010, .030, .070, and .125, all in $B. I've computed two values for average life, shown in lines 235 and 236. The first, average life for systems shipped to date, was calculated as follows. For simplicity, I assume that the systems installed at the end of the year were actually in use for the entire year. Then the total installed life of all the systems which have been shipped up to a given year is found by adding together the "value in use" figures for each year up to and including that year. This result, which can be thought of as $-years of system usage, is then divided by the dollar value of all systems shipped to date, computed simply by adding the "value shipped" figures for all years up to and including the current one. The resulting average life for all systems shipped to date is shown on line 235. Note that it is biased on the low side by inclusion of the most recent shipments.

I also compute the life of the systems which were last retired in the current year, employing the following logic. I first compute the total retirements to date (line 234) by subtracting the "value in use" for each year from the total value shipped to date for that year (line 233). I next assume that the oldest systems in use are the ones retired each year. I then simply compare the total retirements to date in a given year with the total value shipped to date, searching for the year in which the two figures matched. For example, the total retirements to date in 1965 were $801M. By the end of 1957, $575M had been shipped, and by the end of 1958 $956M. Assuming that the oldest systems are always retired first, this means that the system last retired in 1965 had been shipped sometime in 1958; and the figure of 7.4 years shown in the table was obtained by interpolating between the 1957 and 1958 figures.

**Commercial CPU Models.** 237-242. Lines 237 and 239 list the number of new commercial computer processor models introduced each year in the GP and mini computer categories. The figures only include machines designed by American companies, and exclude special processors built by universities or on government contract. There are two sources for the data. For the years up to 1966, I used KnigK66,68. Data for subsequent years comes from the *EDP/IR* annual censuses, which include a date of first installation. As usual, I use *EDP/IR's* definition of GP and minisystems. The number of systems introduced in the years 1950 through 1954 are: GP systems–1, 1, 2, 7, 6; minisystems–0, 0, 0, 0, 1. Line 241 is the sum of lines 237 and 239. Lines 238, 240 and 242 are the cumulative counts of lines 237, 239, and 241, respectively–each entry is found by adding the number of computers introduced in the current year to the previous cumulative total.

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 192. | Digital Equipment Corp. (DEC) | | k | | | | | | | | .039 | .068 | .187 | .358 | .887 | 1.496 | 1.666 | 6.558 | 9.868 | 12.153 | 16.349 | 21.954 | 30.583 |
| 193. | Xerox (SDS, XDS) | | k | | | | | | | | .010 | .064 | .182 | .376 | .561 | .841 | .930 | .716 | .772 | .888 | .986 | .960 | .998 |
| 194. | Honeywell (Computer Control) | | k | | | | | | | | .009 | .017 | .051 | .122 | .293 | .425 | .601 | 1.178 | 1.820 | 2.525 | 3.239 | 3.949 | 4.739 |
| 195. | IBM | | k | | | | | | | | | | | | .100 | .250 | .445 | .840 | .942 | .903 | 1.503 | 2.593 | 4.413 |
| 196. | General Electric | | k | | | | | | | | | | | | | | .165 | .395 | .393 | .507 | .581 | .547 | .635 |
| 197. | Hewlett Packard | | k | | | | | | | | | | | | | | | 1.123 | 2.065 | 2.510 | 3.638 | 5.405 | 8.850 |
| 198. | Varian Data Machines | | k | | | | | | | | | | | | | | | .910 | 1.653 | 2.293 | 2.835 | 3.389 | 4.100 |
| 199. | Data General | | k | | | | | | | | | | | | | | | .225 | .755 | 1.734 | 4.040 | 7.190 | 11.780 |
| 200. | Interdata | | k | | | | | | | | | | | | | | | .312 | .614 | .740 | 1.224 | 1.590 | 2.288 |
| 201. | General Automation | | k | | | | | | | | | | | | | | | .200 | .605 | 1.165 | 2.130 | 3.730 | 7.125 |
| 202. | Others | | k | | .020 | .039 | | .059 | | .207 | .362 | .410 | .419 | .570 | .681 | .581 | .920 | 2.122 | 4.526 | 6.375 | 12.743 | 23.673 | 33.866 |
| 203. | Total | | k | | .040 | .245 | | .689 | | 1.175 | 1.450 | 1.818 | 2.240 | 2.362 | 3.648 | 4.755 | 5.914 | 16.106 | 25.572 | 33.523 | 51.056 | 76.709 | 111.17 |
| | **Mini Syst.–% of No. in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 204. | CDC–Total | 1.31.5 | % | | 50.0 | 84.0 | 93.3 | 91.4 | 82.0 | 82.4 | 71.0 | 69.3 | 62.5 | 45.8 | 30.9 | 24.4 | 20.1 | 9.5 | 6.1 | 5.2 | 3.5 | 2.3 | 1.6 |
| 205. | Bendix | 1.31.5 | % | | 50.0 | 42.4 | 44.4 | 40.6 | 37.0 | 30.8 | 24.0 | 15.4 | 14.3 | 12.3 | 8.5 | | | | | | | | |
| 206. | Librascope | 1.31.5 | % | | | 41.6 | 48.9 | 50.8 | 46.0 | 41.4 | 32.2 | 34.6 | 29.8 | 15.7 | 8.1 | | | | | | | | |
| 207. | CDC | 1.31.5 | % | | | | | | 3.0 | 10.2 | 14.8 | 19.3 | 18.4 | 17.8 | 14.3 | | | | | | | | |
| 208. | Digital Equipment Corp. | 1.31.6 | % | | | | | | | | 2.7 | 3.7 | 8.3 | 13.6 | 24.4 | 31.6 | 28.2 | 40.7 | 38.6 | 36.3 | 32.0 | 28.6 | 27.5 |
| 209. | Xerox (SDS, XDS) | 1.31.6 | % | | | | | | | | .7 | 3.5 | 8.1 | 14.3 | 15.4 | 17.7 | 15.7 | 4.4 | 3.0 | 2.6 | 1.9 | 1.3 | .9 |
| 210. | Honeywell | 1.31.6 | % | | | | | | | | .6 | .9 | 2.3 | 4.5 | 8.0 | 8.9 | 10.2 | 7.3 | 7.1 | 7.5 | 6.3 | 5.1 | 4.3 |
| 211. | IBM | 1.31.8 | % | | | | | | | | | | | | 2.7 | 5.3 | 7.5 | 5.2 | 3.7 | 2.7 | 2.9 | 3.4 | 4.0 |
| 212. | General Electric | 1.31.8 | % | | | | | | | | | | | | | | 2.8 | 2.4 | 1.5 | 1.5 | 1.1 | .7 | .6 |
| 213. | Hewlett Packard | 1.31.7 | % | | | | | | | | | | | | | | | 7.0 | 8.1 | 7.5 | 7.1 | 7.0 | 8.0 |
| 214. | Varian Data Machines | 1.31.7 | % | | | | | | | | | | | | | | | 5.7 | 6.5 | 6.8 | 5.6 | 4.4 | 3.7 |
| 215. | Data General | 1.31.7 | % | | | | | | | | | | | | | | | 1.4 | 3.0 | 5.2 | 7.9 | 9.4 | 10.6 |
| 216. | Interdata | 1.31.7 | % | | | | | | | | | | | | | | | 1.9 | 2.4 | 2.2 | 2.4 | 2.1 | 2.1 |
| 217. | General Automation | 1.31.7 | % | | | | | | | | | | | | | | | 1.2 | 2.4 | 3.5 | 4.2 | 4.9 | 6.4 |
| 218. | Others | 1.31.8 | % | | 50.0 | 15.9 | 6.7 | 8.6 | 18.0 | 17.6 | 25.0 | 22.6 | 18.7 | 21.7 | 18.7 | 12.2 | 15.6 | 13.2 | 17.7 | 19.0 | 25.0 | 30.9 | 30.5 |
| | **Systems in Use, WW** | | | | | | | | | | | | | | | | | | | | | | |
| | GP Systems–% of No. in Use | | | | | | | | | | | | | | | | | | | | | | |
| 219. | IBM | | % | 80. | 79.8 | 79.4 | 80. | 81.8 | 80. | 79.0 | 80.8 | 76.0 | 70.0 | 65.6 | 67.5 | 71.1 | 67.8 | 64.4 | 62.7 | 62.6 | 63.7 | 63.1 | 63.1 |
| 220. | Univac–Total with RCA | | % | 9. | 8.9 | 7.4 | 9. | 10.2 | 11. | 12.5 | 9.7 | 12.5 | 17.4 | 18.3 | 15.4 | 12.3 | 11.8 | 13.3 | 13.2 | 11.1 | 10.1 | 9.2 | 8.1 |
| 221. | Univac | | % | 9. | 8.6 | 7.4 | 9. | 9.7 | 10. | 10.5 | 7.2 | 9.1 | 14.2 | 15.3 | 12.7 | 10.0 | 9.2 | 10.8 | 10.9 | 9.9 | 8.9 | 8.3 | 7.3 |
| 222. | RCA | | % | | .3 | | | .5 | 1. | 2.0 | 2.5 | 3.4 | 3.2 | 3.0 | 2.7 | 2.3 | 2.6 | 2.5 | 2.3 | 1.2 | 1.2 | .9 | .8 |
| 223. | Honeywell (HIS, with GE) | | % | | | | | | 1. | 2.2 | 2.3 | 2.9 | 3.2 | 5.4 | 7.2 | 7.5 | 8.3 | 10.0 | 10.6 | 12.6 | 13.0 | 13.1 | 12.6 |
| 224. | Honeywell | | % | | | | | | .8 | .8 | 1.0 | 1.1 | 1.9 | 3.5 | 4.4 | 4.5 | 4.7 | 4.7 | | 5.7 | 6.0 | 5.7 | 5.4 |
| 225. | GE | | % | | | | | | .2 | 1.4 | 1.3 | 1.8 | 1.4 | 1.9 | 2.8 | 3.0 | 3.6 | 5.4 | | 6.9 | 7.0 | 7.3 | 7.1 |
| 226. | National Cash Register | | % | 5. | 4.5 | 2.6 | 2. | 1.1 | 1.5 | 2.1 | 4.0 | 4.9 | 5.3 | 5.9 | 5.4 | 5.3 | 8.0 | 7.2 | 8.4 | 7.8 | 7.5 | 7.2 | 7.8 |
| 227. | Burroughs | | % | 7. | 6.6 | 6.9 | 6. | 5.2 | 4. | 2.7 | 2.2 | 2.6 | 3.1 | 3.3 | 2.9 | 2.5 | 2.5 | 3.1 | 3.2 | 3.8 | 3.5 | 4.1 | 4.6 |
| 228. | Control Data Corp. | | % | | | | | | | .4 | .4 | .6 | .7 | 1.1 | 1.2 | .9 | 1.0 | 1.1 | 1.1 | .9 | .9 | .9 | .9 |
| | Mini Systems–% of Mini in Use | | | | | | | | | | | | | | | | | | | | | | |
| 229. | IBM | | % | | | | | | | | | | | | 2.7 | 6.3 | 8.6 | 5.9 | 4.1 | 3.2 | 3.2 | 3.4 | 4.0 |
| 230. | Honeywell | | % | | | | | | | | .6 | .9 | 2.3 | 4.6 | 8.0 | 9.4 | 10.4 | 7.6 | 7.6 | 7.9 | 6.6 | 5.2 | 4.3 |
| 231. | Control Data Corp. | | % | | 50.0 | 84.0 | 85. | 91.4 | 80. | 82.4 | 71.0 | 69.3 | 62.5 | 45.8 | 30.9 | 23.3 | 18.6 | 9.7 | 6.1 | 6.2 | 4.1 | 2.7 | 2.0 |
| 232. | Digital Equipment Corp. | | % | | | | | | | | 2.7 | 3.7 | 8.3 | 13.6 | 24.4 | 31.5 | 29.1 | 41.4 | 39.8 | 38.0 | 34.8 | 32.4 | 31.6 |
| | **GP System Life, U.S.** | | | | | | | | | | | | | | | | | | | | | | |
| 233. | Tot. Value Shipped to Date | | $B | .188 | .340 | .575 | .956 | 1.431 | 1.991 | 2.841 | 3.901 | 5.121 | 6.691 | 8.601 | 11.801 | 15.701 | 20.351 | 24.993 | 29.066 | 33.041 | 38.211 | 43.616 | 49.836 |
| 234. | Tot. Retirements to Date | | $B | .008 | .020 | .035 | .056 | .091 | .126 | .236 | .416 | .571 | .691 | .801 | 1.101 | 1.901 | 2.851 | 3.593 | 5.466 | 7.841 | 11.611 | 16.316 | 19.636 |
| | Average Life | | | | | | | | | | | | | | | | | | | | | | |
| 235. | Syst. Shipped to Date | 1.21.7 | yrs. | 2.23 | 2.18 | 2.23 | 2.28 | 2.46 | 2.70 | 2.81 | 2.94 | 3.13 | 3.29 | 3.47 | 3.43 | 3.46 | 3.53 | 3.73 | 4.02 | 4.30 | 4.41 | 4.49 | 4.54 |
| 236. | Syst. Retired This Year | 1.21.7 | yrs. | 4.6 | 4.5 | 4.9 | 5.4 | 5.6 | 6.0 | 5.7 | 5.7 | 6.0 | 6.7 | 7.4 | 7.7 | 7.2 | 7.0 | 7.3 | 6.8 | 6.4 | 6.1 | 5.9 | 6.2 |

## Table II.1.22.1 SYSTEM COMPONENTS—NOTES

Unfortunately, there seems to be very little published data describing the make-up of data processing systems. The data provided here is based on scraps and fragments of information, on some exhibits from the IBM-Telex Corp. lawsuits, on one or two confidential reports I have been able to look at, and on a certain amount of guessing on my part—hopefully, informed guessing. The reader is therefore warned to be even more skeptical than usual about the numbers he finds here. (And the author would be delighted to receive informed corrections.) Generally speaking, my approach has been: to start with the fragmentary and usually unpublished data I have found on the proportions of systems having a given peripheral, and the number of peripherals on those systems; to extrapolate those figures backward in time, attempting to make sensible guesses about trends; and to apply that extrapolated data to the data from Table II.1.21 on number of systems in use.

Because I have found virtually no data on the composition of minicomputer systems or of systems installed outside the United States, I confine my estimates to domestic GP systems.

**Systems In Use.** 1-7. I start by asserting that, at any given time, the average configuration of system components (average memory capacity, and the average number of peripheral and terminal devices) for non-IBM systems is very nearly the same as that of IBM systems. I have no data to support this assertion. I base it on the argument that IBM's dominant position in the marketplace, discussed and described above in Table II.1.21, causes every prospective buyer of a GP system to compare IBM equipment costs and performance with that of one or more of IBM's competitors. Therefore the competitors generally must offer comparable equipment. Furthermore, I speculate that a purchaser's choice between IBM and some competitor is not strongly a function of the purchaser's equipment configuration requirements. That is to say, his decision is not generally based on some vendor's unique offering of some specific system component, but is more often based on intangibles such as the assistance he believes he will receive from the vendor in implementing his application. From this assertion I conclude that, by and large, an average non-IBM installation will have roughly the same complement of peripherals as does an average IBM installation. In the notes which follow I will describe some exceptions to this general rule, but I make use of it in a number of places and believe it to be a reasonable presumption, taking into account the enormous uncertainty associated with all this data.

I therefore begin with a data base counting the various IBM computer generations and the non-IBM installations. The basic data comes from Table II.1.21. Line 7 is the same as line 107 of that table. Lines 1-5 were found by applying the percentages of lines 172 through 176 to the number on line 7; and line 6 was found by subtracting the IBM installations so calculated from the total. In other words, I base my estimate for IBM and non-IBM installations each year on the *C & A* and *EDP/IR* censuses for each year, and assume that though the total quantities of computers in use each year have been corrected in the light of later information, nevertheless the proportions in use of each manufacturer's model number were the same, as applied to the new totals.

**Magnetic Tape Units.** 8-18. These are the critical lines containing the assumptions upon which our estimate of magnetic tape unit installations is based. Line 8 is a guess that first generation systems with tape units averaged four units each, and that originally 10%, and ultimately 30%, of all first generation installations had magnetic tape equipment. Lines 9-10 and 12-13 are extrapolations and interpolations based on various considerations and sources. The second-generation estimates agree in 1963-1965 with a private analysis of magnetic tape systems for those years; later figures on lines 9-10 were chosen to make the number of second-generation drives in use in 1970-1971 (line 20) equal to IBM-Telex data shown in Table II.1.22.2. Other numbers are extrapolations—note I generally assume that the proportions of systems having tapes decreases with time, on the grounds that bigger and more expensive systems, more likely to include tapes, are installed early in the life of a generation.

The proportions on lines 12-13 were chosen to agree roughly with the proportions given in IBM-Telex data for the year 1968, and to agree with the number of tape units in use given by the same source for the years 1965 to 1969, inclusive (see Table II.1.22.2 for data and associated notes.) Later figures are an estimate on my part. Line 15 is my guess as to tape units in use with IBM System 3, and is not based on any hard data. Line 11 is derived by multiplying lines 9 and 10: looking at 1971, for example, we note that, if 80 out of every 100 systems have tape units, and if those 80 each average 5 tapes, there will be 400 tapes on the 100 systems, or an average of 4.00 tapes per system. Similarly, line 14 is derived from lines 12 and 13.

Lines 16 and 17 are based on the assumption that other manufacturers were generally slower to develop and market their tape units than was IBM—it was not until the early '60's, when other manufacturers marketed IBM-compatible tape units, that non-IBM installations began to approach the tape concentration of IBM installations. The drop since 1968 of the percentage of non-IBM installations having tapes results from my assumption that the increased use of disk memories has resulted in the reduced use of tape. Note that my resulting estimate of the number of non-IBM tape units in use (line 24) is substantially higher than that given in some internal IBM reports, as shown in Table II.1.22.2. I have used the higher figures because they agree better with figures from the private analysis referred to above, and because IBM's figures seem to me to be too low.

19-25. Lines 19-22 and line 24 were computed by applying the "number per system" figures on lines 8, 11, 14, 15, and 18 to the computer populations of lines 2-5. For example, the 1971 entry on line 21 states that there were 53,700 tape units in use on IBM 360 and 370 systems in that year. Fifty-three thousand, seven hundred is the product of 2.295 tapes per system on line 14 (51% of the systems times 4.5 units per system) and 23,400 systems on line 4. Line 23 is the sum of lines 19 through 22, and line 25 the sums of lines 23 and 24.

The resulting tape populations shown here can be compared with the relatively few published figures on this subject. The summaries on lines 9-14 of Table II.1.22.2 are presumably comparable to the totals on lines 23-25 of the present table (note that "Total IBM Drives" on line 23 is intended to be drives on IBM systems and thus includes plug-compatible tapes.) Another report, from the International Data Corporation, was published in a special advertising section of *Business Week* magazine in 1972

## TABLE II.1.21 COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Commerical CPU Models** | | | | | | | | | | | | | | | | | | | | | | |
| 237. | GP Comp.–Intro. This Yr. | 1.21.8 | | 9 | 6 | 7 | 6 | 9 | 13 | 14 | 10 | 12 | 20 | 18 | 14 | 14 | 9 | 16 | 12 | 25 | 18 | 14 | 8 |
| 238. | Cumulative Total Introd. | | | 26 | 32 | 39 | 45 | 54 | 67 | 81 | 91 | 103 | 123 | 141 | 155 | 169 | 178 | 194 | 206 | 231 | 249 | 263 | 271 |
| 239. | Minis–Intro. This Yr. | 1.21.8 | | 1 | 1 | 0 | 1 | 1 | 9 | 6 | 8 | 10 | 14 | 14 | 16 | 13 | 24 | 36 | 54 | 30 | 32 | 15 | 16 |
| 240. | Cumulative Total Introduced | | | 2 | 3 | 3 | 4 | 5 | 14 | 20 | 28 | 38 | 52 | 66 | 82 | 95 | 119 | 155 | 209 | 239 | 271 | 286 | 302 |
| 241. | Total–Intro. This Year | 1.21.8 | | 10 | 7 | 7 | 7 | 10 | 22 | 20 | 18 | 22 | 34 | 32 | 30 | 27 | 33 | 52 | 66 | 55 | 50 | 29 | 24 |
| 242. | Cumulative Tot. Introduced | | | 28 | 35 | 42 | 49 | 59 | 81 | 101 | 119 | 141 | 155 | 207 | 237 | 264 | 297 | 349 | 415 | 470 | 520 | 549 | 573 |

## TABLE II.1.22.1 SYSTEM COMPONENTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GP Systems in Use–US** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | IBM–Total | | k | .190 | .560 | 1.000 | 1.680 | 2.545 | 3.520 | 4.860 | 6.545 | 8.890 | 11.690 | 14.170 | 19.100 | 24.530 | 26.900 | 31.060 | 32.685 | 36.337 | 38.480 | 40.930 | 42.820 |
| 2. | First Generation | | k | .190 | .560 | 1.000 | 1.680 | 2.542 | 2.640 | 2.350 | 1.820 | 1.170 | .750 | .455 | .310 | .250 | .200 | .060 | .035 | .017 | .007 | .004 | .004 |
| 3. | Second Generation | | k | | | | | .003 | .880 | 2.510 | 4.725 | 7.720 | 10.940 | 13.090 | 14.150 | 12.280 | 8.100 | 5.700 | 4.025 | 3.720 | 2.840 | 2.220 | 1.772 |
| 4. | 360/370 | | k | | | | | | | | | | | .625 | 4.105 | 10.000 | 15.400 | 21.700 | 23.700 | 23.400 | 21.233 | 17.473 | 17.450 |
| 5. | System 3 & 1130 | | k | | | | | | | | | | | | .535 | 2.000 | 3.200 | 3.600 | 4.925 | 9.200 | 14.400 | 21.233 | 23.594 |
| 6. | Non-IBM | | k | .050 | .140 | .260 | .420 | .565 | .880 | 1.290 | 1.555 | 2.810 | 5.010 | 7.430 | 9.200 | 11.070 | 14.100 | 14.940 | 15.815 | 18.063 | 19.250 | 21.320 | 22.220 |
| 7. | Total | | k | .240 | .700 | 1.260 | 2.100 | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 28.300 | 35.600 | 41.000 | 46.000 | 48.500 | 54.400 | 57.730 | 62.250 | 65.040 |
| | **Magnetic Tape Units (MTU)** | | | | | | | | | | | | | | | | | | | | | | |
| 8. | IBM–1st Gen.–No. Per System | | | – | .4 | .6 | .8 | 1.0 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| 9. | 2nd Gen.–% Having Tapes | | % | – | | | | | 55 | 54 | 52 | 48 | 47 | 46 | 45 | 44 | 42 | 41 | 40 | 40 | 40 | 40 | 40 |
| 10. | Tapes on Those Having | | | – | | | | | 5.0 | 5.0 | 5.0 | 4.9 | 4.9 | 4.9 | 4.8 | 4.8 | 4.8 | 4.7 | 4.7 | 4.6 | 4.6 | 4.5 | 4.5 |
| 11. | No. Per System | | | – | | | | | 2.8 | 2.7 | 2.6 | 2.4 | 2.3 | 2.3 | 2.2 | 2.1 | 2.0 | 1.9 | 1.9 | 1.8 | 1.8 | 1.8 | 1.8 |
| 12. | 360/370–% Having Tapes | | % | | | | | | | | | | | 70 | 62 | 60 | 58 | 54 | 52 | 51 | 54 | 60 | 60 |
| 13. | Tapes on Those Having | | | | | | | | | | | | | 5.0 | 5.0 | 5.0 | 4.5 | 4.2 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 |
| 14. | No. Per System | | | | | | | | | | | | | 3.52 | 3.07 | 2.99 | 2.63 | 2.25 | 2.3 | 2.3 | 2.5 | 2.8 | 2.9 |
| 15. | S3 & 1130–No. Per System | | | | | | | | | | | | | | | | | | | | .1 | .2 | .3 |
| 16. | Non-IBM–% Having Tapes | | % | | 5 | 10 | 15 | 20 | 26 | 33 | 40 | 44 | 46 | 48 | 50 | 52 | 54 | 52 | 52 | 51 | 50 | 50 | 50 |
| 17. | Tapes on Those Having | | | | 3 | 3.3 | 3.6 | 3.8 | 4.1 | 4.3 | 4.5 | 4.7 | 4.8 | 4.9 | 5.0 | 5.0 | 4.9 | 4.7 | 4.6 | 4.5 | 4.5 | 4.4 | 4.4 |
| 18. | No. Per System | | | | .15 | .33 | .54 | .76 | 1.1 | 1.4 | 1.8 | 2.1 | 2.2 | 2.4 | 2.5 | 2.6 | 2.6 | 2.4 | 2.4 | 2.3 | 2.3 | 2.2 | 2.2 |
| | Magnetic Tape Units in Use | | | | | | | | | | | | | | | | | | | | | | |
| 19. | IBM–1st Generation | | k | | .2 | .6 | 1.3 | 2.5 | 2.9 | 2.8 | 2.1 | 1.4 | .9 | .5 | .4 | .3 | .2 | .1 | | | | | |
| 20. | 2nd Generation | | k | | | | | | 2.4 | 6.8 | 12.3 | 18.2 | 25.2 | 29.5 | 30.6 | 25.9 | 16.3 | 11.0 | 7.6 | 6.8 | 5.2 | 4.0 | 3.2 |
| 21. | 360/70 | | k | | | | | | | | | | | 2.2 | 12.6 | 29.9 | 40.5 | 48.9 | 54.2 | 53.7 | 52.7 | 49.3 | 50.3 |
| 22. | System 3 & 1130 | | k | | | | | | | | | | | | | | | | | | 1.4 | 4.2 | 7.1 |
| 23. | Total IBM | | k | | .2 | .6 | 1.3 | 2.5 | 5.3 | 9.6 | 14.4 | 19.6 | 26.1 | 32.2 | 43.6 | 56.1 | 57.0 | 60.0 | 61.8 | 60.5 | 59.3 | 57.5 | 60.6 |
| 24. | Non-IBM | | k | | | .1 | .2 | .4 | .9 | 1.8 | 2.8 | 5.8 | 11.1 | 17.5 | 23.0 | 28.8 | 37.3 | 36.5 | 37.8 | 41.5 | 43.3 | 46.9 | 48.9 |
| 25. | Grand Total | 1.22.9 | k | | .2 | .7 | 1.5 | 2.9 | 6.2 | 11.4 | 17.2 | 25.4 | 37.2 | 49.7 | 66.6 | 84.9 | 94.3 | 96.5 | 99.6 | 102.0 | 102.6 | 104.4 | 109.5 |
| | MTU Controllers in Use | | | | | | | | | | | | | | | | | | | | | | |
| 26. | IBM–1st Generation | | k | | | .2 | .3 | .6 | .7 | .7 | .5 | .4 | .2 | .1 | .1 | .1 | .1 | | | | | | |
| 27. | 2nd Generation | | k | | | | | | .5 | 1.4 | 2.5 | 3.7 | 5.1 | 6.0 | 6.4 | 5.4 | 3.4 | 2.3 | 1.6 | 1.5 | 1.1 | .9 | .7 |
| 28. | 360/370 | | k | | | | | | | | | | | .4 | 2.5 | 6.0 | 8.9 | 11.7 | 12.3 | 11.9 | 11.5 | 10.5 | 10.5 |
| 29. | System 3 & 1130 | | k | | | | | | | | | | | | | | | | | | .7 | 2.1 | 3.5 |
| 30. | Non-IBM | | k | | | | .1 | .1 | .2 | .4 | .6 | 1.2 | 2.3 | 3.6 | 4.6 | 5.8 | 7.6 | 7.8 | 8.2 | 9.2 | 9.6 | 10.7 | 11.1 |
| | Tape System Value in Use | | | | | | | | | | | | | | | | | | | | | | |
| 31. | Magnetic Tape Units | | $B | .001 | .004 | .013 | .028 | .054 | .138 | .278 | .444 | .666 | .995 | 1.336 | 1.781 | 2.230 | 2.468 | 2.518 | 2.598 | 2.659 | 2.654 | 2.609 | 2.644 |
| 32. | MTU Controllers | | $B | | .001 | .005 | .012 | .021 | .042 | .071 | .105 | .153 | .222 | .295 | .397 | .506 | .590 | .644 | .655 | .668 | .664 | .672 | .696 |
| 33. | Total Tape System Value | 1.22.3 | $B | .001 | .005 | .018 | .040 | .075 | .180 | .349 | .549 | .819 | 1.217 | 1.631 | 2.178 | 2.736 | 3.058 | 3.162 | 3.253 | 3.327 | 3.318 | 3.281 | 3.340 |

(IDCPerip72). It states that, at the end of 1971, there were 122,000 tape drives installed in the United States with a value of $3.7B. This compares with the 102,000 drives shown on line 25 valued (with their controllers) at $3.3B, from line 33. The IDC article does not indicate whether controller value is included in the $3.7B. A final report, again from IDC, was published in the *Wall Street Transcript* early in 1971 (MisdW71). At year-end 1969 and 1970, respectively, it estimated there were 54,000 and 61,500 tape drives installed on IBM 360 systems. Note these numbers are a little higher than the figures I give on line 21 for those two years.

26-30. Each system having tapes must have a magnetic tape controller. The number of controllers for a generation is found by multiplying the population of that generation by the per cent of systems having tapes. For example, the 11,900 IBM 360/370 tape controllers shown on line 28 for 1971 was found by multiplying the 360/370 population on line 4 by the percentage on line 12.

31-33. The value of the installed equipment was found by multiplying the number of units installed for each generation by an average price per unit for that generation. The average prices used, and the rationale for their use, are as follows: the predominant first generation tape was the 727, which sold for $18k and had a $29k controller. The principal second generation tapes were the 7330 and 729. The former sold for $22k and had a $23k controller; the latter was available in a range of models selling for $36k to $41k, and had a $43.5k controller. I was unable to find any data on the relative proportions of installions of these two systems, and therefore guessed that 75% of them were 7330's, and 25% 729's. This gave me an average unit value of $27k for second generation tape units and $29k for controllers. With regard to the 360/370 installations, I employed data from IBM-Telex Exhibit 225, page 142, to compute an average value for the tape drives and controllers in use at the end of 1968. The result was $26k for the tape unit and $29k for the controller, (including the effect of built-in controllers in the 2415, 2403, and 2404), and I assumed those averages have remained constant over the years. For the 341x tape units used on System 3 I assumed an $11k average value for both tapes and controllers. Multiplying each of these average values by the appropriate numbers of installed tape units given in line 19 through 22 I computed a total value of IBM tape units. Dividing by the total number of tape units, I found an average tape unit value (shown in line 36 below). I assumed that the average value of non-IBM units was the same as that of all the IBM units taken together; and I thus used that variable value to multiply by the number of non-IBM units on line 24. Line 31 is then the resulting sum of the value of both IBM and non-IBM units. The controller value on line 32 was found in a similar way, and line 33 is the sum of lines 31 and 32.

34-36. The total on-line tape storage capacity shown on line 34a is computed assuming that each tape drive is loaded with a full size reel of tape recorded, from beginning to end, with 1000-character blocks. I assumed that IBM first, second, and third generation drives could store 5, 13, and 18 million characters, respectively; I then computed the total storage capacity in each year for the IBM tape units, and divided the result by the total number of IBM units. The resulting average capacity per tape reel (line 34) I then multiplied by the total number of drives—thus assuming that non-IBM drives in each year had the same capacity as did the IBM drives. Note that I am not altogether consistent in my definition of what comprises a character: first- and second-generation tape drives handled six-bit characters, while third-generation systems use eight-bit characters, and I have treated them all the same.

The number of tape units per system, on line 35, was computed by dividing line 25 by line 7; and the average price per tape unit by dividing line 31 by line 25. The average price per kilobyte, on line 36a, is the quotient of total tape unit value on line 31 and total capacity in line 34a.

**Moving-Head Files** 37-53. These lines describe my basic assumptions about disk file installactions, just as lines 8-18 describe my assumptions about tape unit installations. The first-generation figures on line 37 represent nothing more than a guess on my part as to the number of 350 and 355 disks installed on early systems. I have been able to locate no pertinent data. The IBM second- and third-generation figures on lines 38-49 are based on the same studies referred to in connection with the discussion of tape unit installation data. Second-generation estimates are again based on the results of a private analysis of peripheral installations covering the years 1963-1965. I assumed, also, that moving-head files were installed on relatively few second-generation IBM systems until after the 1311 became available, in 1963. For third-generation systems, I chose the "percent having" and "spindles on those having" figures in lines 41-49 so that lines 57-59 would agree with the 1970-1972 data in Table II.1.22.2, lines 15, 17, 19, 21 and 23—that is, with the IBM-Telex data base. The actual percentages and spindle figures were also based on some unpublished data. For example, a private report asserted that 46% of 360/370's had 2311's in 1970, and that each such system averaged 2.8 spindles. Since there were 23,700 360/370's in use at year-end 1970, that would imply a total of 30,500 (23,700 x 0.46 x 2.8) 2311 spindles in use at that time. But Table II.1.22.2 shows 20,800 spindles (18,600 IBM and 2,200 by plug-compatible manufacturers). I therefore reduced the "percent having" and "spindles" figures to achieve agreement with the totals. The trends shown for the data—the falling-off in 2311 spindles per system, the "peaking" in 2314/19 spindles per system and their replacement by the 3330— are extrapolations on the 1970-1972 data and are consistent with trends shown in the private reports.

The System 3/1130 figures on line 50 represent another guess on my part.

51-53. Before the mid-sixties, there were a few moving-head-files on non-IBM systems. They were very large files, and, compared to IBM's first- and second-generation systems, were not widely used. I have therefore ignored them and show, on lines 51 and 52, an estimate of the growth in use of non-IBM equivalents to the 2311, 2314, and 3330. Note that the results do *not* agree precisely with the data shown on line 26 of Table II.1.22.2, from IBM exhibit 40. Private reports suggest that IBM underestimates the use of both tape and disk drives on non-IBM systems.

54-63. These populations were computed from the assumptions on lines 37-53, and the computer populations of lines 1-6. Once again, as with the estimates of magnetic tape units in use, the figures agree with what little data is publicly available. In the *Business Week* article (IDCPerip72), IDC estimated that 135,000 spindles worth 3.6 billion dollars were installed in the U.S. on GP

## TABLE II.1.22.1 SYSTEM COMPONENTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MTU Storage Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 34. | Capacity Per Tape Reel | | M ch | | 5.0 | 5.0 | 5.0 | 5.0 | 8.7 | 10.6 | 11.8 | 12.4 | 12.7 | 13.3 | 14.4 | 15.6 | 16.5 | 17.0 | 17.4 | 17.5 | 17.6 | 17.7 | 17.7 |
| 34a. | Total On-Line Capacity | 1.22.9 | B ch | | 1 | 3 | 8 | 15 | 54 | 122 | 204 | 315 | 473 | 659 | 957 | 1326 | 1558 | 1643 | 1732 | 1781 | 1805 | 1845 | 1938 |
| | Averages | | | | | | | | | | | | | | | | | | | | | | |
| 35. | MTU Per System | 1.22.10 | | | .3 | .6 | .7 | .9 | 1.4 | 1.9 | 2.1 | 2.2 | 2.2 | 2.3 | 2.4 | 2.4 | 2.3 | 2.1 | 2.1 | 1.9 | 1.8 | 1.7 | 1.7 |
| 36. | Price Per MTU | 1.22.10 | $K | | 18 | 18 | 18 | 18 | 22 | 24 | 26 | 26 | 27 | 27 | 27 | 26 | 26 | 26 | 26 | 26 | 26 | 25 | 24 |
| 36a. | Price per Kbyte | 2.12.10 | $/Kb | | 3.6 | 3.6 | 3.6 | 3.6 | 2.5 | 2.3 | 2.2 | 2.1 | 2.1 | 2.0 | 1.9 | 1.7 | 1.6 | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 | 1.4 |
| | **Moving-Head Files (MHF)** | | | | | | | | | | | | | | | | | | | | | | |
| 37. | IBM—1st Gen.—No. Per System | | | | | .3 | .5 | .7 | .9 | .9 | .9 | 1.0 | 1.3 | 1.8 | 1.7 | 1.5 | 1.5 | 2 | | | | | |
| 38. | 2nd Generation—% Having MHF | | % | | | | | | 10 | 10 | 20 | 30 | 40 | 50 | 60 | 65 | 60 | 56 | 53 | 50 | 50 | 50 | 50 |
| 39. | Spindles on Those Having | | | | | | | | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.4 | 2.3 | 2.2 |
| 40. | No. Per System | | | | | | | | .2 | .2 | .4 | .6 | .8 | 1.0 | 1.2 | 1.37 | 1.32 | 1.29 | 1.27 | 1.25 | 1.2 | 1.2 | 1.1 |
| 41. | 360/370—% Having 2311 | | % | | | | | | | | | | | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 35 | 34 | 33 |
| 42. | Spindles on Those Having | | | | | | | | | | | | | 3.0 | 2.8 | 2.6 | 2.4 | 2.3 | 2.2 | 2.1 | 2.0 | 1.9 | 1.8 |
| 43. | No. Per System | | | | | | | | | | | | | 1.95 | 1.68 | 1.43 | 1.20 | 1.04 | .88 | .74 | .70 | .65 | .59 |
| 44. | 360/370—% Having 2314/19 | | % | | | | | | | | | | | | | 5 | 10 | 15 | 23 | 29 | 30 | 29 | 25 |
| 45. | Spindles on Those Having | | | | | | | | | | | | | | | 10.0 | 10.0 | 9.4 | 9.1 | 8.7 | 8.6 | 8.5 | 8.0 |
| 46. | No. Per System | | | | | | | | | | | | | | | .50 | 1.00 | 1.41 | 2.09 | 2.52 | 2.58 | 2.47 | 2.00 |
| 47. | 360/370—% Having 3330 | | % | | | | | | | | | | | | | | | | | 1.2 | 6.7 | 10 | 15 |
| 48. | Spindles on Those Having | | | | | | | | | | | | | | | | | | | 10 | 9 | 8 | 7.5 |
| 49. | No. Per System | | | | | | | | | | | | | | | | | | | .12 | .60 | .80 | 1.13 |
| 50. | S3 & 1130—No. Per System | | | | | | | | | | | | | | .5 | .5 | .5 | .5 | .5 | .5 | .5 | .5 | .5 |
| 51. | Non-IBM—% Having MHF | | % | | | | | | | | | | | | 10 | 15 | 25 | 40 | 45 | 50 | 55 | 58 | 60 |
| 52. | Spindles on Those Having | | | | | | | | | | | | | | 1 | 1.2 | 1.4 | 1.6 | 2.0 | 2.2 | 2.3 | 2.4 | 2.5 |
| 53. | No. Per System | | | | | | | | | | | | | | .1 | .18 | .35 | .64 | .90 | 1.10 | 1.27 | 1.39 | 1.50 |
| | Moving-Head Files in Use | | | | | | | | | | | | | | | | | | | | | | |
| 54. | IBM—1st Generation | | k | | | .3 | .8 | 1.8 | 2.4 | 2.1 | 1.6 | 1.2 | 1.0 | .8 | .5 | .4 | .3 | .1 | | | | | |
| 55. | 2nd Generation | | k | | | | | | .2 | .5 | 1.9 | 4.6 | 8.8 | 13.1 | 17.0 | 16.8 | 10.7 | 7.4 | 5.1 | 4.7 | 3.4 | 2.6 | 1.9 |
| 56. | 360/70—Total | | k | | | | | | | | | | | 1.2 | 6.9 | 19.3 | 33.9 | 53.1 | 70.4 | 78.9 | 82.5 | 68.4 | 64.9 |
| 57. | 2311's | | k | | | | | | | | | | | 1.2 | 6.9 | 14.3 | 18.5 | 22.5 | 20.8 | 17.1 | 14.9 | 11.3 | 10.4 |
| 58. | 2314/19's | | k | | | | | | | | | | | | | 5.0 | 15.4 | 30.6 | 49.6 | 59.0 | 54.8 | 43.1 | 34.9 |
| 59. | 3330's | | k | | | | | | | | | | | | | | | | | 2.8 | 12.8 | 14.0 | 19.6 |
| 60. | System 3 & 1130 | | k | | | | | | | | | | | | .3 | 1.0 | 1.6 | 1.8 | 2.5 | 4.6 | 7.2 | 10.6 | 11.8 |
| 61. | Total IBM | | k | | | .3 | .8 | 1.8 | 2.6 | 2.6 | 3.5 | 5.8 | 9.8 | 15.1 | 24.7 | 37.5 | 46.5 | 62.4 | 78.0 | 88.2 | 93.1 | 81.6 | 78.6 |
| 62. | Non-IBM Spindles | | k | | | | | | | | | | | | .9 | 2.0 | 4.9 | 9.6 | 14.2 | 19.9 | 24.4 | 29.7 | 33.3 |
| 63. | Grand Total Spindles | 1.22.11 | k | | | .3 | .8 | 1.8 | 2.6 | 2.6 | 3.5 | 5.8 | 9.8 | 15.1 | 25.6 | 39.5 | 51.4 | 72.0 | 92.2 | 108.1 | 117.5 | 111.3 | 111.9 |
| | MHF Controllers in Use | | | | | | | | | | | | | | | | | | | | | | |
| 64. | 2nd Gen. | | k | | | | | | .1 | .3 | .9 | 2.3 | 4.4 | 6.5 | 8.5 | 8.0 | 4.9 | 3.2 | 2.1 | 1.9 | 1.4 | 1.1 | .9 |
| 65. | 2311's | | k | | | | | | | | | | | .4 | 2.5 | 5.5 | 7.7 | 9.8 | 9.5 | 8.2 | 7.4 | 5.9 | 5.8 |
| 66. | 3330's | | k | | | | | | | | | | | | | | | | | .3 | 1.4 | 1.7 | 2.6 |
| 67. | Non-IBM | | k | | | | | | | | | | | | .9 | 1.7 | 3.5 | 6.0 | 7.1 | 9.0 | 10.6 | 12.4 | 13.3 |
| | MHF Value in Use | | | | | | | | | | | | | | | | | | | | | | |
| 68. | Moving Head Files | | $B | | | .015 | .040 | .090 | .128 | .125 | .156 | .244 | .402 | .595 | .917 | 1.286 | 1.551 | 2.107 | 2.692 | 3.126 | 3.277 | 2.979 | 2.913 |
| 69. | MHF Controllers | | $B | | | | | | .003 | .010 | .029 | .074 | .141 | .219 | .365 | .451 | .466 | .539 | .531 | .575 | .695 | .761 | .830 |
| 70. | Total MHF System Val. | 1.22.3 | $B | | | .015 | .040 | .090 | .131 | .135 | .185 | .318 | .543 | .814 | 1.282 | 1.737 | 2.017 | 2.646 | 3.223 | 3.701 | 3.972 | 3.740 | 3.743 |
| | MHF Storage Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 71. | Total On-Line Capacity | 1.22.11 | B By | | | 2 | 5 | 11 | 16 | 18 | 29 | 53 | 94 | 145 | 233 | 447 | 771 | 1308 | 1953 | 2669 | 3820 | 3787 | 4409 |
| | Averages | | | | | | | | | | | | | | | | | | | | | | |
| 72. | MHF Spindles per System | 1.22.12 | | | | .2 | .4 | .6 | .6 | .4 | .4 | .5 | .6 | .7 | .9 | 1.1 | 1.3 | 1.6 | 1.9 | 2.0 | 2.0 | 1.8 | 1.7 |
| 73. | Price per Spindle | 1.22.12 | $k | | | 50 | 50 | 50 | 49 | 48 | 45 | 42 | 41 | 39 | 36 | 33 | 30 | 29 | 29 | 29 | 28 | 27 | 26 |

systems at the end of 1971. However, they estimated that 88,000 of those spindles were installed on IBM 360's and 370's; and since that figure is 10,000 spindles higher than the "official" IBM-Telex figure for the end of 1971, I have assumed that the *Business Week* figures are a little high. Finally, the *Wall Street Transcript* figures (MisdW71) estimated the number of 2311 spindles on System 360's in 1969 and 1970 at 28,000 each year, and the number of 2314 spindles at 30,400 and 50,000 respectively, for those two years. My figures are a little lower for the 2311, and about the same for the 2314/19, aiming at agreement with the numbers in Table II.1.22.2.

64-67. The MHF Controller population was estimated in the same way the magnetic tape unit controller population was estimated, using my various figures for "percent having" the various moving-head-files.

68-70. The total value of installed spindles and controllers was computed from the populations of lines 54 to 67 using various estimated fixed values for the various components. For the first-generation 350's and 355's, I used an average $50k, including the controller. For the second-generation IBM systems, the principal devices were the 1301, 1302, 1311, and 1405, having a wide range of capacities and prices. Once again, I was unable to find any specific data on the relative usage of the different models. I therefore guessed that 75% of installed spindles were 1311's, and 25% 1301's, giving me an average value of $40k for the spindles and $32k for the controllers. For the 2311's and 3330's, I used $25.5k and $26k, respectively, for the spindle prices and $26.4k and $95.5k for the controllers. I used $30.5k per spindle for the 2314's and 2319's. This figure is based on the original 2314 price of $244.4k for 9 spindles and a controller—I simply divided that number by eight, the number of on-line spindles possible, and used a zero value for the controller. I have thus over-stated the installed value of these devices by failing to take into consideration the $13k per spindle 2319, introduced in 1970. System 3's and 1130's employ 5444, 5445, and 2310 disk drives, with prices ranging from $8k to $16k. In the absence of any data on the relative populations of different drives, I have used an average of $11k, including the controller. Lines 68 and 69 show the resulting file and controller total values, and line 70 is the sum of lines 68 and 69.

71. On-line capacity I computed using various average figures for file capacity for the different generations. For first-generation equipment, I assumed an average six million bytes (12 million, 4-bit characters) per spindle. For second-generation machines I used 10 million bytes (six-bit bytes, this time), representing the assumed proportion of 1301 and 1311 spindles. For the 2311, 2314/19, and 3330, I used 7.5 million, 29 million, and 100 million bytes, respectively. And for the System 3 and 1130 I assumed an average two million bytes.

72-73. The average number of spindles per system is found by dividing total spindles on line 63 by total systems on line 7. The average price per spindle is the quotient of the total MHF spindle value in line 68 and the number of installed spindles on line 63. Average capacity per spindle is the quotient of total capacity on line 71 and total spindles on line 63. And average price per kilobyte is the quotient of total MHF value in use, line 68, and total capacity in line 71.

**Punched Card Equipment.** 74-77. Punched card equipment includes readers, reader/punches, and punches. I found no published data, and very little private data on the relative use of these three kinds of equipment alone or in various combinations. The little private data I found covered the mid-sixties only, indicated that the percentage of systems having card equipment was in the eighties and increasing until 1966-1968, whereupon there was a slight decrease. It also indicated that systems which employed punched card equipment usually had one reader or one punch. (In fact, the data indicated that roughly 5% more installations had readers than had punches; but I will assume that the populations were equal, for simplicity.) Line 74 thus represents my extrapolated assumption of the percentage of systems having card readers and punches. The total units in use on line 75 is computed by multiplying line 74 by line 7, the total number of GP systems. The average card reader/punch price on line 76 is an estimate on my part based on a review of the price of IBM card equipment, and the assumption that competitive equipment was comparably priced. I assumed the first-generation computers mostly used the IBM 537 with a selling price of $40k. In the early sixties the IBM 533 at $25k became available and led to a reduction in average equipment cost. Second-generation systems, I assumed, mostly used equipment equivalent to the IBM 1402-1, at a price of $30k. And third-generation equipment used equipment comparable to the IBM 1442N1, at $26k, and the IBM 2540-1, at $34k. I assumed an average price, including controller, at about $30k. Finally, the IBM 5424, at $10k to $13k, has led to a recent reduction in average price because of the success of IBM's System 3. The total value of card equipment in use, on line 77a, is the product of lines 75 and 76.

**Printers.** 80-89. My figures on the percentage of GP systems having printers are based on data from a private report which covered the mid-sixties and showed an increasing proportion of printer sites. The same report indicated that the average number of computers per site was also increasing. The earlier data on line 80 and 81 is a guess on my part. The increases shown in the late sixties and early seventies are also a guess, based on the assumption that printing requirements have continued to increase as system files have grown.

The number of printers per system on line 82 is the product of lines 80 and 81, and the total number of printers in use on line 83 is the product of line 82 and total number of GP systems on line 7. The total controllers on line 84, similarly, is the product of line 80 and of line 7. The average printer and controller prices are estimates on my part, based on the following considerations: In 1955, more than 90% of the printers were comparable to the 150 line per minute (LPM) IBM 716 at $55k with a $44k controller. A few 600 and 1000 LPM printers helped raise the average price slightly. By 1960, 15% of line printers operated at 600 LPM and 5% at 1000 LPM. These faster printers, with selling prices around $100k and $200K, respectively, increased the average printer price to $70k. By 1965 the IBM 1403-class of printer had taken over, and I assumed roughly 70% of installed printers were 600 LPM at $33k, with a remaining 30% 1000 LPM at $41k. The controller price was about $25k. By 1970, a new generation of lower speed, lower cost units had led to a redistribution, with roughly a third of the printers in the 150 to 350 LPM range, another third at 600

## TABLE II.1.22.1 SYSTEM COMPONENTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73a. | Capacity Per Spindle | | M By | | | 6 | 6 | 6 | 6 | 7 | 8 | 9 | 10 | 10 | 9 | 11 | 15 | 18 | 21 | 25 | 33 | 34 | 39 |
| 73b. | Price per Kbyte | 2.12.1 | $/Kby | | | 8.3 | 8.3 | 8.3 | 8.2 | 6.9 | 5.6 | 4.7 | 4.1 | 4.1 | 3.9 | 2.9 | 2.0 | 1.6 | 1.4 | 1.2 | .9 | .8 | .9 |
| | **Punched Card Equipment** | | | | | | | | | | | | | | | | | | | | | | |
| 74. | No. Per System | 1.22.15 | | .5 | .55 | .6 | .65 | .69 | .73 | .77 | .80 | .82 | .84 | .85 | .86 | .87 | .86 | .86 | .85 | .84 | .83 | .82 | .81 |
| 75. | Total Units | 1.22.14 | k | .12 | .39 | .76 | 1.37 | 2.14 | 3.21 | 4.73 | 6.48 | 9.59 | 14.03 | 18.36 | 24.34 | 30.97 | 35.26 | 39.56 | 41.23 | 45.70 | 47.92 | 51.05 | 52.68 |
| 76. | Average Price | 1.22.15 | $k | 40 | 40 | 40 | 40 | 40 | 38 | 36 | 33 | 31 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 29 | 28 | 26 | 24 |
| 77. | Total Value in Use | 1.22.4 | $B | .005 | .016 | .030 | .055 | .086 | .122 | .170 | .214 | .297 | .421 | .551 | .730 | .929 | 1.058 | 1.187 | 1.237 | 1.325 | 1.342 | 1.327 | 1.264 |
| | **Line Printers** | | | | | | | | | | | | | | | | | | | | | | |
| 80. | Percent Having Printers | | % | 50 | 55 | 60 | 65 | 69 | 73 | 77 | 80 | 82 | 84 | 85 | 87 | 89 | 91 | 93 | 94 | 95 | 95 | 95 | 95 |
| 81. | No. on Those Having | | | 1 | 1 | 1 | 1.01 | 1.02 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.04 | 1.04 | 1.05 | 1.07 | 1.11 | 1.14 | 1.15 | 1.16 | 1.17 | 1.18 |
| 82. | No. Per System | 1.22.16 | | .50 | .55 | .60 | .66 | .70 | .75 | .79 | .82 | .84 | .87 | .88 | .90 | .93 | .97 | 1.03 | 1.07 | 1.09 | 1.10 | 1.11 | 1.12 |
| 83. | Total Printers | 1.22.14 | k | .12 | .39 | .76 | 1.39 | 2.18 | 3.30 | 4.86 | 6.64 | 9.83 | 14.53 | 19.01 | 25.47 | 33.11 | 39.77 | 47.38 | 51.90 | 59.30 | 63.62 | 69.19 | 72.91 |
| 84. | Total Controllers | | k | .12 | .39 | .76 | 1.37 | 2.14 | 3.21 | 4.73 | 6.48 | 9.59 | 14.03 | 18.36 | 24.62 | 31.68 | 37.31 | 42.78 | 45.59 | 51.68 | 54.84 | 59.14 | 61.79 |
| 85. | Average Printer Price | 1.22.16 | $k | 60 | 63 | 66 | 69 | 71 | 70 | 60 | 46 | 36 | 35 | 35 | 34 | 34 | 32 | 29 | 26 | 25 | 25 | 25 | 24 |
| 86. | Average Controller Price | | $k | 45 | 45 | 44 | 44 | 43 | 42 | 38 | 30 | 25 | 25 | 24 | 23 | 21 | 19 | 17 | 15 | 14 | 13 | 13 | 13 |
| 87. | Printer Value in Use | | $B | .007 | .025 | .050 | .096 | .155 | .231 | .292 | .305 | .354 | .509 | .665 | .866 | 1.126 | 1.273 | 1.374 | 1.349 | 1.483 | 1.590 | 1.730 | 1.750 |
| 88. | Controller Value in Use | | $B | .005 | .018 | .033 | .060 | .092 | .135 | .180 | .194 | .240 | .351 | .441 | .560 | .665 | .709 | .727 | .684 | .723 | .713 | .769 | .803 |
| 89. | Total Value in Use | 1.22.4 | $B | .012 | .043 | .083 | .156 | .247 | .366 | .472 | .499 | .594 | .860 | 1.106 | 1.432 | 1.791 | 1.982 | 2.101 | 2.033 | 2.206 | 2.303 | 2.499 | 2.553 |
| | **Other Memories** | | | | | | | | | | | | | | | | | | | | | | |
| | Head-Per-Track Devices | | | | | | | | | | | | | | | | | | | | | | |
| 90. | No. Per System | | | .10 | .10 | .15 | .20 | .20 | .15 | .11 | .08 | .05 | .04 | .03 | .03 | .04 | .06 | .09 | .12 | .14 | .15 | .15 | .15 |
| 91. | Total Units | 1.22.13 | k | .02 | .07 | .19 | .42 | .62 | .66 | .68 | .65 | .59 | .67 | .65 | .85 | 1.42 | 2.46 | 4.14 | 5.82 | 7.62 | 8.66 | 9.34 | 9.76 |
| 92. | Average Price | | $k | 58 | 58 | 57 | 56 | 55 | 55 | 54 | 54 | 55 | 56 | 58 | 67 | 72 | 78 | 78 | 78 | 75 | 74 | 72 | 70 |
| 93. | Total Value in Use | 1.22.3 | $B | .001 | .004 | .011 | .024 | .034 | .036 | .037 | .035 | .032 | .038 | .038 | .057 | .102 | .192 | .323 | .454 | .572 | .641 | .672 | .683 |
| | Data Cells | | | | | | | | | | | | | | | | | | | | | | |
| 94. | No. Per System | | | | | | | | | | | | .006 | .014 | .032 | .042 | .044 | .041 | .039 | .033 | .029 | .025 | .020 |
| 95. | No. in Use | 1.22.13 | k | | | | | | | | | | .1 | .3 | .9 | 1.5 | 1.8 | 1.9 | 1.9 | 1.8 | 1.7 | 1.6 | 1.3 |
| 96. | Tot.Val. in Use at $145k | 1.22.3 | $B | | | | | | | | | | .015 | .044 | .131 | .218 | .261 | .276 | .276 | .261 | .247 | .226 | .189 |
| | **Other Peripherals** | | | | | | | | | | | | | | | | | | | | | | |
| | Computer Output Microfilm | | | | | | | | | | | | | | | | | | | | | | |
| 97. | No. in Use | | k | | | | | | | | | | | | | | .05 | .43 | .76 | .83 | 1.00 | 1.20 | 1.40 |
| 98. | Total Value in Use at $140k | | $B | | | | | | | | | | | | | | .007 | .060 | .106 | .116 | .140 | .168 | .196 |
| | Plotters | | | | | | | | | | | | | | | | | | | | | | |
| 99. | No. in Use | | k | | | | | | | .05 | .20 | .40 | .70 | 1.00 | 1.40 | 2.00 | 3.00 | 4.50 | 6.40 | 7.50 | 9.0 | 10.0 | 11.0 |
| 100. | Total Value in Use at $15k | | $B | | | | | | | .001 | .003 | .006 | .011 | .015 | .021 | .030 | .045 | .068 | .096 | .113 | .135 | .150 | .165 |
| 101. | On GP Systems | | $B | | | | | | | | .001 | .002 | .003 | .004 | .005 | .007 | .011 | .017 | .024 | .028 | .036 | .038 | .041 |
| | Others | | | | | | | | | | | | | | | | | | | | | | |
| 102. | Value in Use at 1% | | $B | .002 | .003 | .006 | .009 | .013 | .019 | .026 | .035 | .046 | .060 | .078 | .107 | .138 | .175 | .214 | .236 | .252 | .266 | .273 | .302 |
| 102a. | Value in Use–Misc. | 1.22.4 | $B | .002 | .003 | .006 | .009 | .013 | .019 | .026 | .036 | .048 | .063 | .082 | .112 | .145 | .193 | .291 | .366 | .396 | .442 | .479 | .539 |
| | **Summary–Peripherals** | | | | | | | | | | | | | | | | | | | | | | |
| 103. | Total Value in Use | 1.22.1 | $B | .021 | .071 | .163 | .324 | .545 | .854 | 1.189 | 1.518 | 2.108 | 3.157 | 4.266 | 5.922 | 7.658 | 8.761 | 9.986 | 10.842 | 11.788 | 12.265 | 12.224 | 12.311 |
| 104. | Subtotal Memory | 1.22.4 | $B | .002 | .009 | .044 | .104 | .199 | .347 | .521 | .769 | 1.169 | 1.813 | 2.527 | 3.648 | 4.793 | 5.528 | 6.407 | 7.206 | 7.861 | 8.178 | 7.919 | 7.955 |
| | Percent of Peripheral Value | | | | | | | | | | | | | | | | | | | | | | |
| 105. | Tape Systems | 1.22.5 | % | 5 | 7 | 11 | 12 | 14 | 21.1 | 29.4 | 36.2 | 38.9 | 38.5 | 38.2 | 36.8 | 35.7 | 34.9 | 31.7 | 30.0 | 28.2 | 27.1 | 26.8 | 27.1 |
| 106. | Moving-Head-Files | 1.22.5 | % | | | 9 | 12 | 17 | 15.3 | 11.4 | 12.2 | 15.1 | 17.2 | 19.1 | 21.6 | 22.7 | 23.0 | 26.5 | 29.7 | 31.4 | 32.4 | 30.6 | 30.4 |
| 107. | Head-Per-Track Systems | 1.22.5 | % | 5 | 6 | 7 | 7 | 6 | 4.2 | 3.1 | 2.3 | 1.5 | 1.2 | 0.9 | 1.0 | 1.3 | 2.2 | 3.2 | 4.2 | 4.9 | 5.2 | 5.5 | 5.5 |
| 108. | Data Cells | 1.22.5 | % | | | | | | | | | | 0.4 | 1.0 | 2.2 | 2.8 | 3.0 | 2.8 | 2.5 | 2.2 | 2.0 | 1.8 | 1.5 |
| 109. | Subtotal Memory | 1.22.6 | % | 10 | 13 | 27 | 32 | 37 | 40.6 | 43.8 | 50.7 | 55.5 | 57.4 | 59.2 | 61.6 | 62.6 | 63.1 | 64.2 | 66.5 | 66.7 | 66.7 | 64.8 | 64.6 |
| 110. | Punched Card Equip. | 1.22.6 | % | 24 | 23 | 18 | 17 | 16 | 14.3 | 14.3 | 14.1 | 14.1 | 13.3 | 12.9 | 12.3 | 12.1 | 12.1 | 11.9 | 11.4 | 11.2 | 10.9 | 10.9 | 10.3 |

LPM, and the final third at 1000 LPM. I estimated selling prices for the three ranges at $14k, $30k, and $35k, with a resulting average about $26k. As the printer prices have fallen, so have the controller prices. Lines 87 and 88 were computed by multiplying average prices by number of units in use, and the total value of printer equipment in use on line 89 is the sum of printer and controller values on lines 87 and 88.

**Other Memories.** 90-93. Head-per-track devices are rotating disks or drums having a read/write head for each magnetically recorded track. In the early days, these memories were widely used (e.g. on the IBM 650, LGP 30) as internal memory. However, I do *not* count internal memory uses here–I only include head-per-track devices which are used as auxilliary memory. The figures on number of units per system and average price, on line 90 and 92, are once again estimates on my part. In the early days, drum memories were developed for many of the larger computer systems, and the average number per system increased. In the early sixties the magnetic tape unit, and then the moving-head-files took over, and the drum population held steady and perhaps dropped. Then in the mid-sixties an emphasis on system performance led manufacturers to develop software systems which used high speed drums as temporary storage for data and programs (see discussion on multi-programming in Section 2.) The result has been a recent increase in the use of head-per-track devices. The average prices are based on an estimated mix of observed prices of various IBM and non-IBM drums. The total units on line 91 were computed by multiplying the number of devices per system on line 90 by the number of systems on line 7; and the total value in use on line 93 is the product of lines 91 and 92.

94-96. The data cell, or cartridge of magnetic strips as exemplified by the IBM 2321 or the NCR CRAM, was introduced in the mid-sixties as a means of providing very large memory capacity, and faded as a product partly because of reliability problems and partly because of the growth in the capacity of moving-head disks. Line 95 is my estimate of the number of cells in use, based on some private data I have seen. The number per system on line 94 is computed from lines 95 and 7. The total value in use on line 96 is computed from line 95 assuming an average price of $145k for a device and one-half a controller–I assume that most installations included two devices.

**Other Peripherals.** 97-98. The number of computer output microfilm (COM) units in use on line 97 comes from a *Datamation* article (July 15, 1971, page 72) and *Modern Data* article in December 1972. These published reports agree with some private analyses I have seen. The total value in use is computed assuming a single system with controller cost $140k.

99-101. The plotter population on line 99 is based on my evaluation of some private data. So are my estimates of $15k as an average plotter price (including controller), and my estimate that one-quarter of plotter value is on GP systems–the remainder mostly being connected to minicomputers.

102. There are an enormous variety of miscellaneous peripherals used with GP systems. They include keyboard-printers (teletypes and typewriters located in the computer room–not including terminals connected to the computer by communication lines), paper tape punches and readers, audio response units, graphic CRT consoles, and instrumentation (analog/digital) subsystems. I arbitrarily estimate that these various devices account for 1% of the total value of all GP systems. Note that terminals, data entry equipment, internal memory, and special processors (I/O processors, communication processors) are *not* included as peripherals.

**Summary Peripherals.** 103-104. The total value in use includes tape systems (line 33), moving-head-file systems (line 70), head-per-track systems (line 93), data cells (line 96), punched card equipment (line 77), line printers (line 89), COM's (line 98), plotters (line 101), and others (line 102). The first four of these–tapes, MHF's, head-per-tracks, and data cells–represent the "subtotal memory" on line 104.

105-123. The first set of figures show the individual peripherals, and the memory subtotals, as percentages of all the installed peripherals; the second set shows the same categories as percentages of the total value of GP systems in use in the United States. Note that the last line, 123, is the quotient of line 103 and the value of all GP systems in use. (Columns in this portion of the table may not sum properly because of rounding problems.)

It is worthwhile comparing the results computed above with corresponding data for U.S. Government computers, as reported in Tables II.1.22.3 and II.1.22.4. The first of these shows that the average number of tape units per government system is 2.72, made up of a 3.76 average for IBM systems and a 2.22 average for non-IBM systems. The corresponding averages for all U.S. GP computers for the year 1972 are only 1.78 (total), 1.54 (IBM), and 2.25 (non-IBM), as computed from the data here in Table II.1.22.1. Non-IBM figures are closely comparable. The average tape unit per IBM system is much higher in the government inventory than in the general population of computers. In part this is because the government does not use IBM System/3 computers. But even if we subtract System/3's and 1130's and their tapes from the IBM inventory for 1972 (subtract line 22 from line 23 and divide the result by the difference between lines 1 and 5), we find an average 2.40 tapes per IBM system, still far under the government's 3.76. The disk unit data in Table II.1.22.3 is not comparable because the government count did not distinguish spindles, and a 2314, with eight spindles, is counted as a single unit.

Examining the data in Table II.1.22.4, we find the government had .07 drums, .40 card units, and .35 printers for every tape unit in the inventory. The corresponding figures from Table II.1.22.1 for 1972 are .08, .45, and .62. And as a percentage of total system value, tapes, disks, drums, card units, and printers represented 13.2, 7.7, 2.6, 3.3, and 4.5 percent of the government inventory compared with 12.5, 14.9, 2.5, 5.0, and 8.7 percent of all U.S. GP computers. It seems likely that the government's high tape unit ratios reflect the fact that government data bases are more lik ly to reside on tape, where the general user's data bases are on disks.

**Internal Memory.** Internal memory is the high speed memory, associated with the CPU, from which instructions are executed. The analysis which follows is based on a variety of assumptions. Memory capacity is consistently measured in 8-bit bytes, and first- and second-generation machines having word- or character-oriented memories are treated by dividing memory capacity in bits by eight. Average memory capacity per computer is estimated by starting with the principal IBM machines, assuming that the initial memory size of each is roughly twice the minimum size, and further assuming an increase of roughly 15% per

## TABLE II.1.22.1 SYSTEM COMPONENTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 111. | Line Printers | 1.22.6 | % | 57 | 61 | 51 | 48 | 45 | 42.9 | 39.7 | 32.9 | 28.2 | 27.2 | 25.9 | 24.2 | 23.4 | 22.6 | 21.0 | 18.8 | 18.7 | 18.8 | 20.4 | 20.7 |
| 112. | COM | 1.22.6 | % | | | | | | | | | | | | | | 0.1 | 0.6 | 1.0 | 1.0 | 1.1 | 1.4 | 1.6 |
| 113. | Others | 1.22.6 | % | 10 | 4 | 4 | 3 | 2 | 2.2 | 2.2 | 2.4 | 2.3 | 2.0 | 1.9 | 1.9 | 1.9 | 2.1 | 2.3 | 2.4 | 2.4 | 2.5 | 2.5 | 2.8 |
| | Percent of GP System Value | | | | | | | | | | | | | | | | | | | | | | |
| 114. | Tape Systems | 1.22.7 | % | 1 | 2 | 3 | 4 | 6 | 9.7 | 13.4 | 15.8 | 18.0 | 20.3 | 20.9 | 20.4 | 19.8 | 17.5 | 14.8 | 13.8 | 13.2 | 12.5 | 12.0 | 11.1 |
| 115. | Moving-Head-Files | 1.22.7 | % | | | 3 | 4 | 7 | 7.0 | 5.2 | 5.3 | 7.0 | 9.1 | 10.4 | 12.0 | 12.6 | 11.5 | 12.4 | 13.7 | 14.7 | 14.9 | 13.7 | 12.4 |
| 116. | Head-Per-Track Systems | 1.22.7 | % | 1 | 1 | 2 | 3 | 3 | 1.9 | 1.4 | 1.0 | 0.7 | 0.6 | 0.5 | 0.5 | 0.7 | 1.1 | 1.5 | 1.9 | 2.3 | 2.4 | 2.5 | 2.3 |
| 117. | Data Cells | 1.22.7 | % | | | | | | | | | | 0.3 | 0.6 | 1.2 | 1.6 | 1.5 | 1.3 | 1.2 | 1.0 | 0.9 | 0.8 | 0.6 |
| 118. | Subtotal Memory | 1.22.8 | % | 1 | 3 | 8 | 12 | 15 | 18.6 | 20.0 | 22.1 | 25.7 | 30.2 | 32.4 | 34.1 | 34.7 | 31.6 | 29.9 | 30.5 | 31.2 | 30.7 | 29.0 | 26.3 |
| 119. | Punched Card Equipment | 1.22.8 | % | 3 | 5 | 6 | 6 | 6 | 6.5 | 6.5 | 6.1 | 6.5 | 7.0 | 7.1 | 6.8 | 6.7 | 6.0 | 5.5 | 5.2 | 5.3 | 5.0 | 4.9 | 4.2 |
| 120. | Line Printers | 1.22.8 | % | 7 | 13 | 15 | 17 | 18 | 19.6 | 18.1 | 14.3 | 13.1 | 14.3 | 14.2 | 13.4 | 13.0 | 11.3 | 9.8 | 8.6 | 8.8 | 8.7 | 9.2 | 8.5 |
| 121. | COM | 1.22.8 | % | | | | | | | | | | | | | | | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 |
| 122. | Others | 1.22.8 | % | 1 | 1 | 1 | 1 | 1 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| 123. | All Peripherals | 1.22.2 | % | 12 | 22 | 30 | 36 | 41 | 45.8 | 45.6 | 43.6 | 46.3 | 52.6 | 54.7 | 55.3 | 55.5 | 50.1 | 46.7 | 45.9 | 46.8 | 46.1 | 44.8 | 40.8 |
| | **Internal Memory** | | | | | | | | | | | | | | | | | | | | | | |
| | IBM Systems | | | | | | | | | | | | | | | | | | | | | | |
| 124. | 1st Gen.—Av. Size | | M By | .013 | .014 | .015 | .016 | .017 | .017 | .017 | .018 | .021 | .024 | .027 | .029 | .031 | .032 | .033 | | | | | |
| 125. | Total Bytes in Use | 1.22.19 | B By | .003 | .008 | .015 | .027 | .043 | .045 | .040 | .031 | .025 | .018 | .012 | .009 | .008 | .006 | .002 | | | | | |
| 126. | Av. Price Per Byte | | $/By | 4.0 | 4.3 | 4.6 | 4.8 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | | | | |
| 127. | Value in Use | 1.22.20 | $B | .012 | .034 | .069 | .129 | .216 | .224 | .200 | .156 | .123 | .090 | .061 | .045 | .039 | .032 | .010 | | | | | |
| 128. | 2nd Gen.—Av. Size | | M By | | | | | | .020 | .017 | .015 | .016 | .015 | .014 | .014 | .016 | .018 | .020 | .023 | .024 | .023 | .023 | .023 |
| 129. | Total Bytes in Use | 1.22.19 | B By | | | | | | .018 | .043 | .071 | .124 | .164 | .183 | .198 | .196 | .146 | .114 | .093 | .089 | .065 | .051 | .041 |
| 130. | Av. Price Per Byte | | $/By | | | | | | 6.0 | 5.7 | 4.8 | 5.3 | 5.7 | 5.5 | 5.4 | 5.3 | 5.2 | 5.2 | 5.3 | 5.2 | 5.1 | 5.0 | 5.0 |
| 131. | Value in Use | 1.22.20 | $B | | | | | | .106 | .243 | .340 | .655 | .935 | 1.008 | 1.070 | 1.041 | .758 | .593 | .491 | .464 | .333 | .255 | .205 |
| | 3rd Generation | | | | | | | | | | | | | | | | | | | | | | |
| 132. | No. in Use—All 360's | | k | | | | | | | | | | | .625 | 4.105 | 10.000 | 15.400 | 21.700 | 23.700 | 22.370 | 17.760 | 11.187 | 8.522 |
| 133. | 360/2x | | k | | | | | | | | | | | .002 | .940 | 3.470 | 5.680 | 8.640 | 10.490 | 11.140 | 9.370 | 5.271 | 3.410 |
| 134. | 360/30 | | k | | | | | | | | | | | .325 | 1.950 | 3.520 | 5.360 | 7.960 | 7.270 | 6.000 | 4.300 | 3.104 | 2.685 |
| 135. | 360/4x | | k | | | | | | | | | | | .285 | 1.070 | 2.070 | 2.770 | 3.190 | 3.720 | 3.250 | 2.640 | 1.578 | 1.328 |
| 136. | 360/50 | | k | | | | | | | | | | | .010 | .110 | .630 | 1.020 | 1.240 | 1.420 | 1.225 | .870 | .662 | .585 |
| 137. | 360/6x | | k | | | | | | | | | | | .001 | .020 | .280 | .530 | .600 | .720 | .675 | .510 | .521 | .463 |
| 138. | 360/75, 85, 195 | | k | | | | | | | | | | | | .010 | .030 | .040 | .070 | .080 | .080 | .070 | .051 | .051 |
| 139. | Av. Memory—360/2x | | M By | | | | | | | | | | | .009 | .010 | .011 | .013 | .015 | .017 | .020 | .023 | .026 | .030 |
| 140. | 360/30 | | M By | | | | | | | | | | | .026 | .030 | .034 | .039 | .045 | .052 | .060 | .063 | .066 | .069 |
| 141. | 360/4x | | M By | | | | | | | | | | | .071 | .082 | .094 | .108 | .125 | .143 | .165 | .190 | .218 | .251 |
| 142. | 360/50 | | M By | | | | | | | | | | | .173 | .199 | .229 | .263 | .302 | .348 | .400 | .460 | .483 | .507 |
| 143. | 360/6x | | M By | | | | | | | | | | | .367 | .423 | .486 | .559 | .643 | .739 | .850 | .978 | 1.026 | 1.078 |
| 144. | 360/75, 85, 195 | | M By | | | | | | | | | | | .432 | .497 | .572 | .658 | .756 | .870 | 1.000 | 1.150 | 1.323 | 1.521 |
| 145. | Total 360 Memory in Use | 1.22.19 | B By | | | | | | | | | | | .030 | .191 | .650 | 1.172 | 1.700 | 2.184 | 2.263 | 1.969 | 1.608 | 1.494 |
| 146. | 360/2x | | B By | | | | | | | | | | | | .009 | .038 | .074 | .130 | .178 | .223 | .216 | .137 | .102 |
| 147. | 360/30 | | B By | | | | | | | | | | | .008 | .059 | .120 | .209 | .358 | .378 | .360 | .271 | .205 | .185 |
| 148. | 360/4x | | B By | | | | | | | | | | | .020 | .088 | .195 | .299 | .399 | .532 | .536 | .502 | .344 | .333 |
| 149. | 360/50 | | B By | | | | | | | | | | | .002 | .022 | .144 | .268 | .374 | .494 | .490 | .400 | .320 | .297 |
| 150. | 360/6x | | B By | | | | | | | | | | | | .008 | .136 | .296 | .386 | .532 | .574 | .499 | .535 | .499 |
| 151. | 360/75, 85, 195 | | B By | | | | | | | | | | | | .005 | .017 | .026 | .053 | .070 | .080 | .081 | .067 | .078 |
| 152. | Average 360 Memory | | M By | | | | | | | | | | | .048 | .047 | .065 | .076 | .078 | .092 | .101 | .111 | .144 | .175 |
| | Av. Price per Byte | | | | | | | | | | | | | | | | | | | | | | |
| 153. | 360/2x | | $/By | | | | | | | | | | | 2.4 | 2.4 | 2.5 | 2.6 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 |
| 154. | 360/30 | | $/By | | | | | | | | | | | 2.6 | 2.5 | 2.3 | 2.1 | 1.9 | 1.8 | 1.7 | 1.7 | 1.6 | 1.6 |
| 155. | 360/4x | | $/By | | | | | | | | | | | 1.5 | 1.4 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 |

year in the number of bytes in use. This increase comes about partly because existing customers added to their original memory capacity to improve the performance of their systems and to handle new applications; and partly because IBM (and other manufacturers) kept developing new software which encouraged new customers to purchase systems with larger memories.

The memory cost figures I use are *incremental* costs. That is to say, I compute memory cost per byte by finding the difference in selling price between two memory modules having different capacities, and divide by the difference in capacity measured in bytes. For example, the IBM 650 with 2000, 10-digit words sold for $115k, and the price for the 650 with 4000 words was $150k. A 10-digit word is the equivalent of 5 bytes, so the additional 2000 words are 10,000 bytes. The incremental cost is $35k, so the incremental cost per byte is $3.50. In effect, this approach underestimates total memory value by including only the cost, to the customer, of the raw memory–the memory elements and their directly associated electronics. The electronic interface between that raw memory and various processors are not included here and are thus are included later with processor costs.

Non-IBM systems are assumed to have the same average memory size as IBM systems.

Further details on the assumptions I made are given in the paragraphs below. For the most part, the analysis depends on assumptions which are not supported by any available data. Wherever data *has* been made public, I have noted it below.

124-127. The estimate of average size of a first-generation IBM memory is based on the relative populations of the 305, 650, 704, 705 and 709, on the assumption that these systems had memories of 1k, 12k, 36k, 22k, and 36k bytes respectively, and that the average capacity of each system increased by 15% per year until it reached its maximum size. Note that the average size does *not* increase by 15% per year, in general, because the relative proportions of the number of computers in use of the various models changes from year to year, and because of the maximum-size limitation. Line 125 is the product of the average size on line 124 and the number of first-generation IBM computers from line 2. The average price per byte on line 126 is a weighted average of the 650 drum at $3.50 per byte, and the 700 series memories at an incremental cost of $9 per byte in 1956, dropping down to $6 per byte by 1965–this reduction occurring because large increments cost less per byte than did small ones. Line 127 is the product of lines 125 and 126.

128-131. To establish the average size and average price on lines 128 and 130, I used the same techniques for second-generation systems as I used for the first-generation systems. Changes in the relative proportion of the lower cost systems, and particularly of the 1401, are responsible for the peculiar-looking changes in the averages.

132-138. Because of the increasing importance of internal memory to new systems, and because some additional information is available about the memory complement of the IBM 360 family, it will be instructive to look at 360 memories in some detail. This portion of the table presents a count of the number of 360's of various models in use in the United States at the end of each of the designated years. It is derived using the proportions given in the *C & A* and *EDP/IR* censuses, corrected to reflect differences between the general population shown at census time and the populations used here. The 360/2x includes the 20, 22, and 25; the 4x includes the 40 and 44; and the 6x includes 65 and 67.

139-144. The starting point for the data on average memory of each of the portions of the 360 family is the 1971 column in lines 139 to 144. In its February 22, 1972 issue, *EDP/IR* presented a graph showing average memory size, and in the same year Modern Data Services, Inc. published results of a sample survey (MoDa72). The data in the 1971 column is a compromise between the two sources, weighted a little toward the Modern Data figures, which were larger, because they clearly reflect the fact that users were buying plug-compatible memories to increase capacity beyond that offerred as standard by IBM. Earlier and later figures were computed assuming a constant growth rate in memory capacity of 15% per year–the same growth rate used for first- and second-generation systems. However, when that growth rate would result in an average capacity greater than IBM's official maximum for that computer, I reduced the growth rate to 5% per year.

145-152. Lines 146 through 151 were found by multiplying the number of 360's in use on lines 133-138 by the average memory size of each model from lines 139-144. The total memory capacity in use on line 145 is the sum of lines 146 through 151, and the average 360 memory on line 152 is the total memory on line 145 divided by the number of 360's on line 132.

153-158. The average price per byte of memory for the different models is based on an analysis of the incremental price of 360 memory, as applied to the various memory sizes, lines 139-144.

159-166. The memory value in use of each model, lines 160-165, is found by multiplying the amount of memory in use on lines 146 to 151 by average price per byte from lines 153 to 158. Total memory value on line 159 is the sum of lines 160 through 165; and the average value per byte is the quotient of total memory value on line 159 and total 360 memory in use on line 145.

167-171. The IBM 370 memory size estimates are based on the same 1971 sources as those used for the 360 (see note on lines 139-144, above), and on the same growth rate in memory size. Size estimates for the systems introduced after 1971 are guesses on my part. Average prices per byte are once again incremental prices–see Table II.2.11.2.

172-176. The System 3 and 1130 figures are based on the *EDP/IR* censuses for those machines; on an initial average memory size of 8, 9, 16, and 60 Kbytes, respectively, for the 1130, System 3/6, System 3/10, and System 3/15; on a 15% per year increase in average size; and on average prices of $2 for the 1130 (increasing by $0.1 per year to $2.60), $1.30 for the System 3/6 (falling to $1.00 by 1974), $1.10 for the System 3/10, and $0.30 for the System 3/15 (see Table II.2.11.2). Using the above data I computed total bytes in use and total value in use, and then computed average memory size and average price per byte.

177-180. Total IBM memory bytes in use is the sum of the totals for first-, second-, and third-generation systems on lines 125, 129, 145, 169, and 174. Total value in use on line 178 is the sum of the values of those same memories on lines 127, 131, 159, 171, and 176. The average bytes per system on IBM equipment is the quotient of the total

## TABLE II.1.22.1 SYSTEM COMPONENTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 156. | 360/50 | | $/By | | | | | | | | | | | 1.4 | 1.4 | 1.3 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 |
| 157. | 360/6x | | $/By | | | | | | | | | | | 2.4 | 2.0 | 1.6 | 1.5 | 1.4 | 1.2 | 1.0 | .9 | .8 | .8 |
| 158. | 360/75, 85, 195 | | $/By | | | | | | | | | | | | 1.1 | 1.1 | 1.0 | 1.0 | .9 | .9 | .9 | .9 | .9 |
| 159. | Total 360 Memory Value | 1.22.20 | $B | | | | | | | | | | | .051 | .325 | 1.048 | 1.782 | 2.514 | 3.043 | 3.042 | 2.608 | 1.870 | 1.693 |
| 160. | 360/2x | | $B | | | | | | | | | | | | .022 | .095 | .192 | .351 | .481 | .602 | .583 | .356 | .265 |
| 161. | 360/30 | | $B | | | | | | | | | | | .021 | .148 | .276 | .439 | .680 | .680 | .612 | .461 | .328 | .296 |
| 162. | 360/4x | | $B | | | | | | | | | | | .030 | .123 | .253 | .359 | .479 | .638 | .643 | .602 | .378 | .366 |
| 163. | 360/50 | | $B | | | | | | | | | | | | .011 | .187 | .322 | .411 | .543 | .539 | .440 | .320 | .297 |
| 164. | 360/6x | | $B | | | | | | | | | | | | .016 | .218 | .444 | .540 | .638 | .574 | .449 | .428 | .399 |
| 165. | 360/75, 85, 195 | | $B | | | | | | | | | | | | .005 | .019 | .026 | .053 | .063 | .072 | .073 | .060 | .070 |
| 166. | Average Value Per Byte | | $/By | | | | | | | | | | | 1.7 | 1.7 | 1.61 | 1.52 | 1.48 | 1.39 | 1.34 | 1.32 | 1.16 | 1.13 |
| 167. | 370 Family–No. in Use | | k | | | | | | | | | | | | | | | | | 1.028 | 3.480 | 6.286 | 8.926 |
| 167a. | 370/115 | | k | | | | | | | | | | | | | | | | | | | | .850 |
| 167b. | 370/125 | | k | | | | | | | | | | | | | | | | | | | .770 | 1.750 |
| 167c. | 370/135 | | k | | | | | | | | | | | | | | | | | | .970 | 2.200 | 2.750 |
| 167d. | 370/145 | | k | | | | | | | | | | | | | | | | | .450 | 1.270 | 1.700 | 1.925 |
| 167e. | 370/155 | | k | | | | | | | | | | | | | | | | | .490 | 1.045 | 1.190 | .695 |
| 167f. | 370/158 | | k | | | | | | | | | | | | | | | | | | | .147 | .635 |
| 167g. | 370/165 | | k | | | | | | | | | | | | | | | | | .088 | .195 | .210 | .150 |
| 167h. | 370/168 | | k | | | | | | | | | | | | | | | | | | | .050 | .151 |
| 167i. | 370/195 | | k | | | | | | | | | | | | | | | | | | | .019 | .020 |
| 168a. | Average Mem. 370/115 | | MBy | | | | | | | | | | | | | | | | | | | | .080 |
| 168b. | 370/125 | | MBy | | | | | | | | | | | | | | | | | | | .120 | .138 |
| 168c. | 370/135 | | MBy | | | | | | | | | | | | | | | | | | .230 | .265 | .304 |
| 168d. | 370/145 | | MBy | | | | | | | | | | | | | | | | | .350 | .403 | .463 | .532 |
| 168e. | 370/155 | | MBy | | | | | | | | | | | | | | | | | 1.024 | 1.178 | 1.354 | 1.557 |
| 168f. | 370/158 | | MBy | | | | | | | | | | | | | | | | | | | 1.600 | 1.840 |
| 168g. | 370/165 | | MBy | | | | | | | | | | | | | | | | | 2.100 | 2.415 | 2.777 | 3.194 |
| 168h. | 370/168 | | MBy | | | | | | | | | | | | | | | | | | | 2.777 | 3.194 |
| 168i. | 370/195 | | MBy | | | | | | | | | | | | | | | | | | | 2.777 | 3.194 |
| 169. | Total 370 Bytes in Use | 1.22.19 | BBy | | | | | | | | | | | | | | | | | .814 | 2.437 | 4.083 | 5.445 |
| | Av. Price per Byte | | | | | | | | | | | | | | | | | | | | | | |
| 170a. | 370/115 | | $/By | | | | | | | | | | | | | | | | | | | | .30 |
| 170b. | 370/125 | | $/By | | | | | | | | | | | | | | | | | | | .30 | .30 |
| 170c. | 370/135 | | $/By | | | | | | | | | | | | | | | | | | .80 | .70 | .60 |
| 170d. | 370/145 | | $/By | | | | | | | | | | | | | | | | | .60 | .55 | .50 | .45 |
| 170e. | 370/155 | | $/By | | | | | | | | | | | | | | | | | .55 | .52 | .50 | .48 |
| 170f. | 370/158 | | $/By | | | | | | | | | | | | | | | | | | | .25 | .25 |
| 170g. | 370/165 | | $/By | | | | | | | | | | | | | | | | | .55 | .55 | .55 | .55 |
| 170h. | 370/168 | | $/By | | | | | | | | | | | | | | | | | | | .25 | .25 |
| 170i. | 370/195 | | $/By | | | | | | | | | | | | | | | | | | | 1.00 | 1.00 |
| 171. | Total 370 Value in Use | 1.22.20 | $B | | | | | | | | | | | | | | | | | .473 | 1.359 | 2.104 | 2.315 |
| 172. | System 3 & 1130–No. in Use | | k | | | | | | | | | | | | .535 | 2.000 | 3.200 | 3.600 | 4.925 | 9.200 | 14.400 | 21.235 | 23.595 |
| 173. | Av. Memory Size | | M By | | | | | | | | | | | | .008 | .009 | .011 | .012 | .015 | .016 | .019 | .022 | .028 |
| 174. | Total Bytes in Use | 1.22.19 | B By | | | | | | | | | | | | .004 | .018 | .035 | .043 | .072 | .144 | .279 | .468 | .649 |
| 175. | Av. Price Per Byte | | $/By | | | | | | | | | | | | 2.0 | 2.1 | 2.2 | 2.3 | 2.0 | 1.8 | 1.5 | 1.3 | 1.1 |
| 176. | Value in Use | 1.22.20 | $B | | | | | | | | | | | | .008 | .038 | .077 | .099 | .141 | .253 | .422 | .594 | .740 |

## TABLE II.1.22.1 SYSTEM COMPONENTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| | IBM Memory (GP, U.S.) | | | | | | | | | | | | | | | | | | | | | | |
| 177. | Total Bytes in Use | | B By | .003 | .008 | .015 | .027 | .043 | .063 | .083 | .102 | .149 | .182 | .225 | .402 | .872 | 1.359 | 1.859 | 2.349 | 3.310 | 4.750 | 6.210 | 7.629 |
| 178. | Total Value in Use | | $B | .012 | .034 | .069 | .129 | .216 | .330 | .443 | .496 | .778 | 1.025 | 1.120 | 1.448 | 2.166 | 2.649 | 3.216 | 3.675 | 4.232 | 4.722 | 4.823 | 4.953 |
| 179. | Av. Bytes Per System | | M By | .013 | .014 | .015 | .016 | .017 | .018 | .017 | .016 | .017 | .016 | .016 | .021 | .036 | .051 | .060 | .072 | .091 | .123 | .152 | .178 |
| 180. | Av. Value Per Byte | | $/By | 4.00 | 4.25 | 4.60 | 4.78 | 5.02 | 5.24 | 5.34 | 4.86 | 5.22 | 5.63 | 4.98 | 3.60 | 2.48 | 1.95 | 1.73 | 1.56 | 1.28 | .99 | .78 | .65 |
| | Non-IBM Memory (GP, U.S.) | | | | | | | | | | | | | | | | | | | | | | |
| 181. | Bytes Per System | | M By | .015 | .015 | .015 | .015 | .016 | .016 | .016 | .017 | .017 | .017 | .017 | .021 | .036 | .051 | .060 | .072 | .085 | .105 | .130 | .150 |
| 182. | Total Bytes in Use | | B By | | .002 | .003 | .006 | .009 | .014 | .021 | .026 | .048 | .085 | .126 | .193 | .399 | .719 | .896 | 1.139 | 1.535 | 2.021 | 2.772 | 3.333 |
| 183. | Av. Value Per Byte | | $/By | 4.00 | 4.20 | 4.40 | 4.60 | 4.80 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 4.98 | 3.60 | 2.48 | 1.95 | 1.73 | 1.56 | 1.30 | 1.05 | .85 | .70 |
| 184. | Total Value in Use | | $B | | .008 | .013 | .028 | .043 | .070 | .105 | .130 | .240 | .425 | .629 | .696 | .988 | 1.402 | 1.551 | 1.776 | 1.996 | 2.122 | 2.356 | 2.333 |
| | Total U.S. GP Memory | | | | | | | | | | | | | | | | | | | | | | |
| 185. | Bytes in Use | 1.22.17 | B By | .003 | .010 | .018 | .033 | .052 | .077 | .104 | .128 | .197 | .267 | .351 | .595 | 1.271 | 2.078 | 2.755 | 3.488 | 4.845 | 6.771 | 8.982 | 10.962 |
| 186. | Value in Use | 1.22.17 | $B | .012 | .042 | .082 | .157 | .259 | .400 | .548 | .626 | 1.018 | 1.450 | 1.749 | 2.144 | 3.154 | 4.051 | 4.767 | 5.451 | 6.228 | 6.844 | 7.179 | 7.286 |
| 187. | Average U.S. Bytes/Syst. | 1.22.18 | M By | .013 | .015 | .015 | .016 | .017 | .017 | .017 | .017 | .017 | .017 | .016 | .021 | .036 | .051 | .060 | .072 | .089 | .117 | .144 | .169 |
| 188. | Price/Byte | 1.22.18 | $/By | 4.00 | 4.20 | 4.55 | 4.76 | 4.98 | 5.19 | 5.27 | 4.89 | 5.17 | 5.43 | 4.98 | 3.60 | 2.48 | 1.95 | 1.73 | 1.56 | 1.29 | 1.01 | .80 | .66 |
| | Grand Total Memory In use | | | | | | | | | | | | | | | | | | | | | | |
| 189. | WW, GP Systems | 1.22.17 | B By | .003 | .011 | .021 | .039 | .064 | .096 | .131 | .166 | .256 | .350 | .474 | .846 | 1.91 | 3.21 | 4.32 | 5.69 | 8.06 | 11.53 | 15.38 | 18.90 |
| 190. | WW, Mini Systems | | B By | | .001 | .002 | .005 | .007 | .010 | .014 | .019 | .025 | .032 | .046 | .062 | .10 | .15 | .26 | .42 | .61 | .90 | 1.37 | 2.02 |
| 191. | WW, All Systems | | B By | .003 | .012 | .023 | .044 | .071 | .106 | .145 | .185 | .281 | .382 | .520 | .908 | 2.01 | 3.36 | 4.58 | 6.11 | 8.67 | 12.43 | 16.75 | 20.92 |
| 192. | Value in Use, WW, GP | 1.22.17 | $B | .012 | .045 | .095 | .187 | .316 | .500 | .690 | .812 | 1.32 | 1.90 | 2.36 | 3.05 | 4.74 | 6.26 | 7.47 | 8.88 | 10.40 | 11.65 | 12.30 | 12.47 |
| 193. | Int. Mem.—% of GP Value | | % | 6.6 | 13.1 | 15.2 | 17.4 | 19.3 | 21.4 | 21.0 | 18.0 | 22.4 | 24.2 | 22.2 | 20.1 | 24.2 | 24.8 | 23.9 | 25.2 | 26.9 | 27.7 | 27.6 | 27.9 |

bytes on line 177 and the total computers on line 1. And the average value per byte on line 180 is the quotient of lines 178 and 177.

181-184. I have had to make various assumptions about non-IBM internal memories, in the absence of any specific data bearing on the subject. In line 181 I assume that the average non-IBM memory size is close to the IBM average size, until 1971-1974 where I felt the effect of large IBM 370's had no counterpart in non-IBM installations, so the latter trailed IBM in average size. Line 182 is the product of line 181 and the number of non-IBM systems, from line 6. For non-IBM average price per byte, line 183, I assumed the competitors undercut IBM prices slightly in early years, and equalled them in the sixties. Again, I felt the very low-price IBM 370 memories, which reduced IBM's average value between 1971 and 1974, had no general counterpart in non-IBM systems. Total value of non-IBM memories, on line 180, is the product of lines 182 and 183.

185-188. Total GP bytes in use, on line 185, is the sum of lines 177 and 182. Similarly, line 186 is the sum of lines 184 and 178. Average bytes per system, on line 187, is the quotient of lines 185 and the total number of systems, on line 7. Line 188 is the quotient of lines 186 and 185.

189-192. To form an estimate of the internal memory installed on all U.S. computers, worldwide, I assumed that international GP systems had memories the same size as domestic ones; and so I computed line 189 by multiplying line 187 by the number of GP systems in use, worldwide, from Table II.1.21. To estimate minicomputer memory in use, I assumed the average memory size of a mini was 10k bytes from 1955 to 1967 (the LGP-30 had a 16k byte memory, the G-15 7.5k bytes), and has since increased to 14k. Line 190 is based on those assumptions and on the count of minisystems in use, worldwide, from Table II.1.21. Line 191 is the sum of lines 189 and 190. And the value of all GP U.S. internal memory in use, worldwide, on line 192, is computed by multiplying lines 188 and 189.

193. The ratio of GP internal memory value to total GP value, expressed as a percent, on line 193, is found by dividing line 186 by total GP value from Table II.1.21.

## TABLE II.1.22.2 PERIPHERALS IN USE—NOTES

The data in this table comes from various documents which served as exhibits in the lawsuit between IBM and the Telex Corp. Many of the documents were confidential IBM reports never intended to be distributed outside the company. In many of them the terms used are not defined. Most provide data without giving sources. Many are copies of charts which were used in connection with oral presentations. As a result, it is easy to misinterpret the information given; and it is not unusual to find two reports whose listings are seemingly inconsistent with one another.

All data shown represents equipment in use at year-end. The last two columns specify the reference source, usually by giving an IBM/Telex Exhibit number, and the date of the report being exhibited. Often the exhibits present forecasts. I have not included forecast data for periods more than a year after the year of the source report.

### TABLE II.1.22.2 PERIPHERALS IN USE—IBM/TELEX EXHIBITS

| Line | Item | 1968 | 1969 | 1970 | 1971 | 1972 | Reference Ex. No. | Date |
|---|---|---|---|---|---|---|---|---|
| | | | (All Entries in Thousands) | | | | | |
| | **Mag. Tape Units** | | | | | | | |
| 1. | IBM 24xx Drives | 40.5 | 48.9 | | | | 225 | 4/69 |
| 2. | IBM 24xx Drives | | | 45.1 | 45.5 | | 65 | 9/70 |
| 3. | Plug-Compat. 24xx | | | (4.2) | (5.9) | 4.9 | 1* | |
| 4. | Plug-Compat. 24xx | | 1.7 | (4.0) | | | 312 | 4Q/70 |
| 5. | Plug-Compat. 24xx | | | 4.6 | 7.2 | | 65 | 9/70 |
| 6. | IBM 7xx Drives | | | 6.2 | 5.5 | | 65 | 9/70 |
| 7. | Plug-Compat. 24xx | | | 1.3 | 1.3 | | 65 | 9/70 |
| 8. | IBM 3420 Drives | | | 0 | 3.1 | 21.9 | 1* | |
| 9. | Subtotal IBM Drives | | | 51.3 | 54.1 | | | |
| 10. | Non-IBM Drives | 21.0 | 23.6 | 25.4 | 30.9 | | 40 | 6/70 |
| 11. | Total | | | 82.6 | 93.5 | | | |
| 12. | IBM Drives | | 48.8 | 50.6 | 52.7 | | 40 | 6/70 |
| 13. | Plug-Compat. 7xx | | 2.8 | 5.7 | 8.6 | | 40 | 6/70 |
| 14. | Total | | 75.2 | 81.7 | 92.2 | | 40 | 6/70 |
| | **Moving-Head Files** | | | | | | | |
| 15. | IBM 2311 Spindles | | | 18.6 | 14.5 | 12.4 | 1* | |
| 16. | IBM 2311 Spindles | | | (19.5) | (17.4) | | 65 | 9/70 |
| 17. | Plug-Compat. 2311 | | | 2.2 | 2.6 | 2.5 | 1* | |
| 18. | Plug-Compat. 2311 | | | (2.4) | (3.0) | | 65 | 9/70 |
| 19. | IBM 2314/19 | | | 47.1 | 49.1 | 43.0 | 1* | |
| 20. | IBM 2314/19 | | | (49.7) | (61.4) | | 65 | 9/70 |
| 21. | Plug-Compat. 2314/19 | | | 2.6 | 9.8 | 11.8 | 1* | |
| 22. | Plug-Compat 2314/19 | | | (.7) | (2.8) | | 65 | 9/70 |
| 23. | IBM 3330 | | | 0 | 2.8 | 12.7 | 1* | |
| 24. | IBM 3330 | | | (0) | (2.9) | | 65 | 9/70 |
| 25. | Subtotal | | | 70.5 | 78.8 | 82.4 | | |
| 26. | Non-IBM Spindles | | 10.2 | 11.5 | 17.6 | | 40 | 6/70 |
| 27. | Total | | | 82.0 | 96.4 | | | |

1* These entries are from EDP/IR Nov. 20, 1973, and are based on "Amendments to Findings of Fact" in Telex vs. IBM.

**Magnetic Tape Units.** One source of confusion in connection with tape equipment is the question of what is being counted, model numbers or tape drives. An IBM 2401, 2403, or 2404 each includes a single drive; a 2402 contains two drives; and a 2415 contains two, four, or six (according to Exhibit 225, 2577 2415's contained 7260 drives). As nearly as I can tell, all entries on lines 1-7 are *drives* in use.

1-2. These lines show drives in use on IBM 360/370 systems in 2401, 2402, 2403, 2404, 2415, and 2420 tape systems. Exhibit 225 is part of a comprehensive financial analysis of tapes and controls, and is probably more accurate than other reports. Specifically, it provides a very detailed analysis of units and controllers in use on each 360 model number as of 12/67 and 12/68. From the data given there, one can estimate the percentage of 360 systems having tapes, and the number of drives on those which have them. To make the estimate, I count the number of controllers attached to each CPU model number, including the 2803 and 2804, remembering that the 2403, 2404, and 2415 all contain controllers. If there are more controllers than CPU's, I assume *every* CPU includes tapes. If there are fewer controllers than CPU's, I assume there are as many CPU's with tapes as there are controllers. These assumptions lead to the conclusions that at the end of 1968, all 360 systems as expensive as or more expensive than the 360/40 contained tapes, and that 57.0% of all 360's had tape units at the end of 1968. It further leads to the conclusion that the CPU's with tapes averaged 4.44 drives per CPU.

For the years 1965, 1966, and 1967, exhibit 225 shows 2200, 12,600 and 29,900 IBM 24xx drives in use.

Line 2 contains a forecast only, and no historical data. Ostensibly exhibit 65 counted the same things as were counted in line 1. However, note that it records a drop in 24xx drives in use between end-1969 and end-1970 (from 48,900 to 45,100 drives.)

3-5. These lines estimate the number of plug-compatible drives installed on IBM 360 systems at year-end, from three different sources. It should be mentioned that reference (1) independently sampled the plug-compatible tape manufacturers, and counted 6500 tapes in use at the end of 1972, compared with the 4900 derived from IBM/Telex documents. I conclude that the data from exhibit 65 is probably most nearly correct, and include it in the sum, below. The entries not summed are shown in parenthesis.

6-7. Exhibit 65 also forecast the number of 700 series tape drives expected to be installed on first and second generation IBM systems. Both leased and purchased IBM drives are reportedly included in the IBM figure.

8. The IBM 3420 was first shipped in 1971.

9. This subtotal of IBM drives in use is the sum of lines 2, 6, and 8.

10. This estimate of non-IBM tape drives in use (by Burroughs, CDC, GE, HIS, NCR, RCA, Univac, and "Misc.") was put together by the IBM "OEM Peripherals Task Force".

11. This line is the sum of lines 9 and 10. Totals are shown only for 1970 and 1971 because the data for other years is incomplete.

12-14. The OEM Task Force also estimated total tape unit installations in the U.S., and these lines (together with line 8) show the breakdown and the total. Line 14 should be compared with line 11, and line 12 with line 9.

**Moving-Head Files.** 15-24. These paired entries in the table compare enumerations from the "Amendments to Findings of Fact" with those in exhibit 65, a forecast prepared in September, 1970. Other exhibits show similar disparities. For example, exhibit 283, prepared in April, 1971, indicates that 36,961 IBM 2314 spindles were in use on December 31, 1970; but exhibit 142 (page 9) shows 47,298 spindles in use on that same date.

25. This line is the sum of lines 15, 17, 19, 21, and 23.

26-27. Line 26 is an estimate of non-IBM, 2311-2314 type spindles in use on non-IBM systems. See the note on line 10 for a list of manufacturers. Line 27 is the sum of lines 25 and 26.

## TABLE II.1.22.3 TAPE AND DISK UNITS IN THE FEDERAL INVENTORY—NOTES

The data in this table is from NBS72, which lists the magnetic tape and disk units in the Federal Inventory, by Manufacturer, as of March 31, 1972; and from GSAInv72, which lists the number of computers in the inventory as of June 30, 1972. The average tape and disk units per computer are calculated by dividing the respective number of units by the number of computers. One subtotal is shown for non-IBM systems, another for IBM systems including three manufacturers of plug-compatible peripherals. Comments:

1. I assume that all Burroughs tape units are on Burroughs computers, etc., and all Calcomp tape units are on IBM systems. The source documents are silent on the question of which peripherals are connected to which systems.

2. "Disk Units" are not the same as "moving-head-file spindles", which is what we would like to count. In the first place, disk units include some head-per-track memories, notably Burroughs', where the data is recorded on disk surfaces. In addition, multiple-spindle units such as the IBM 2314 are counted as single units.

3. There are a total of 14,952 tape units and 4960 disk units listed in NBS72 compared with the 12,069 and 4139 shown in the table. Some of these units, manufactured by firms such as Ampex, DEC, and Potter (but not by the manufacturers listed in the table), may be attached to the 4436 computers included in the table.

## TABLE II.1.22.4 MAJOR EQUIPMENT CATEGORIES IN THE FEDERAL INVENTORY—NOTES

CPU's include both GP and mini- (or "Special Management Classification") processors. Terminals include units with punched card, punched tape, and magnetic tape devices, and also include communications controls, multiplexors, buffers, etc. "Other" includes OCR, MICR, plotters, operator consoles, analog-digital I/O equipment, and apparently keyboard data entry equipment—though this point is not clear in the source reports.

## TABLE II.1.22.5 COMPUTER SHIPMENTS BY U.S. MANUFACTURERS—NOTES

This data, from CenCenMan72, represents the Census Bureau's first attempt to collect and publish figures breaking down shipments of computing equipment. Though reported in the census of industry SIC 3573 (Electronic Computing Equipment), this is a census of shipments of this type of product by all manufacturers, including some whose SIC code is other than 3573.

Some explanatory comments: Digital computers include both general- and special-purpose systems; "magnetic tape units" include all serial-access storage devices; "other" peripherals include graphic displays ($15.4M), industrial control interfaces ($29.1M), plotters, paper tape readers, paper tape punches, and also off-line punched-card equipment like tabulators, collators, sorters, and interpreters; and CRT displays may include serial printers or cassettes. The data represents 1972 shipments.

**TABLE II.1.22.3 TAPE AND DISK UNITS IN USE IN THE FEDERAL INVENTORY**

| Manufacturer | Computers | Magnetic Tape Units | | Disk Units | |
|---|---|---|---|---|---|
| | | Total | Average | Total | Average |
| Burroughs | 271 | 681 | 2.51 | 897 | 3.31 |
| CDC | 482 | 1657 | 3.44 | 548 | 1.14 |
| HIS (with GE) | 550 | 1460 | 2.65 | 252 | .46 |
| NCR | 239 | 60 | .25 | 7 | .03 |
| RCA | 199 | 974 | 4.89 | 78 | .39 |
| Univac | 1266 | 1858 | 1.47 | 40 | .03 |
| Subtotal | 3007 | 6690 | 2.22 | 1822 | .61 |
| IBM | 1429 | 5261 | 3.68 | 1842 | 1.29 |
| Calcomp | - | 35 | - | 196 | - |
| Memorex | - | - | - | 279 | - |
| Storage Tech. | - | 83 | - | - | - |
| Subtotal | 1429 | 5379 | 3.76 | 2317 | 1.62 |
| Totals | 4436 | 12069 | 2.72 | 4139 | .93 |

**TABLE II.1.22.4 MAJOR EQUIPMENT CATEGORIES IN THE FEDERAL INVENTORY**

| Components | Number in Use | Ratio* | Value in Use ($M) | Percent | Average Value ($k) |
|---|---|---|---|---|---|
| CPU's | +6731 | | 985 | 32.3 | 146.3 |
| Memory (Core) | | | 360 | 11.8 | |
| I/O Channels and Controllers | | | 409 | 13.4 | |
| Terminals | +14589 | | 104 | 3.4 | 7.1 |
| Peripheral Units—Total | 32284 | 2.16 | 958 | 31.4 | 29.7 |
| Magnetic Tape Units | 14952 | 1.00 | 402 | 13.2 | 26.9 |
| Disk Units | 4960 | .33 | 234 | 7.7 | 47.2 |
| Drum Units | 1099 | .07 | 80 | 2.6 | 72.8 |
| Card Readers—Punches | 6047 | .40 | 102 | 3.3 | 16.9 |
| Printers | 5226 | .35 | 140 | 4.6 | 26.8 |
| Other | | | 238 | 7.8 | |
| Total Systems | +6731 | | 3054 | | 453.7 |

* Ratio of number of peripherals to number of tape units

+ Items marked + are from GSAInv72, and represent totals as of June 30, 1972. Other data is from NBS72, as of March 31, 1972.

**TABLE II.1.22.5 COMPUTER SHIPMENTS BY U.S. MANUFACTURERS**

| Product | Receipts ($B) | Percent |
|---|---|---|
| SIC 3573 | | |
| Electronic Digital Computers | 1.790 | 41.6 |
| Peripheral Equipment—Total | 2.148 | 49.9 |
| Memory—Total | 1.518 | 35.3 |
| MHF, HPT Files, Bulk Core | 1.005 | 23.4 |
| Magnetic Tape Units | .513 | 11.9 |
| Punched Card I/O | .068 | 1.6 |
| Printers | .296 | 6.9 |
| Other | .266 | 6.2 |
| Terminals—Total | .310 | 7.2 |
| CRT Displays | .196 | 4.6 |
| Other | .114 | 2.6 |
| OCR/MICR Equipment | .055 | 1.3 |
| Digital System Total | 4.303 | 100 |

| Product | Receipts ($B) | Percent |
|---|---|---|
| Data Entry Keyboard Equip. | .064 | |
| Communications Modems/M'xers | .109 | |
| Analog and Hybrid Computers | .047 | |
| Parts and Attachments | 1.403 | |
| Not Specified | .075 | |
| Electronic Computing Eq. Total | 6.001 | |
| SIC 3574 | | |
| Non-Electronic Calculators | .426 | |
| Electronic Calculators—Total | .221 | |
| Commercial—Display | .057 | |
| Printing | .061 | |
| Technical/Scientific | .103 | |
| Other | .024 | |
| Calc. & Accounting Machines— Total | .671 | |

## TABLE II.1.23 DATA ENTRY EQUIPMENT—NOTES

Increasingly over the past few years, new data is being entered into computer systems via on-line terminals. However, special off-line data entry equipment has been and continues to be used for this purpose, and that equipment will be discussed here.

1-5. We begin with keypunchs and verifiers, which are used to punch cards for later input of data into a computer system via a card reader. The 1968 figure is an extrapolation from *DP Focus* of January, 1970, which states that 212.3k IBM punches and 77.6k verifiers were in use on October 1, 1968. Regarding these numbers, *DP Focus* says "These figures are not estimates, nor are they based on hunches, rumors, or pulling figures from the air but are based on specific equipment entries in equipment files and other information which has been verified as to its authenticity and probable accuracy." Other entries on line 1 are from *EDP/IR* of October 19, 1971, and December 19, 1972 or (for 1973 and 1974) were derived from data from USSen74, as shown in lines 6-8 below. The 1969 figure for verifiers is an average of *EDP/IR's* figure of 93k, and *DP Focus's* figure of 80. The other figures on line 2 are my own extrapolations. My estimate that the verifier population has stopped growing is based on the fact that buffered keypunchs are an increasing proportion of the total population (see line 10 below) and can be used as verifiers. The verifier estimates for 1966 and 1967 maintain the 1968 ratio of verifiers to keypunchs. Line 3 is the sum of lines 1 and 2.

It should be noted that some sources estimate a substantially greater number of keypunch units installed in the United States. For example, an article in the June 1970 issue of *Datamation* magazine (StenR70) quotes Creative Strategies Inc. as estimating that 541k keypunchs and verifiers were in use at the end of 1969. I adopt the *DP Focus* and *EDP/IR* figures rather than the larger ones for two reasons: because of the authoritative nature of the *DP Focus* source; and because the independent estimate of keypunch operators in Table II.1.4.2 give a reasonable ratio of 1.2 operators per keyboard for the lower keyboard population, but would result in less than one operator per keyboard for the larger population.

4-5. Some keypunch equipment is used in conjunction with tabulating machines rather than with computer systems. Line 4 comes from Table II.1.4.2, line 31a, and represents an estimate of the proportion of keypunch operators who prepare data for computer systems. Assuming that this same proportion applies to the keypunch and verify equipment, we multiply lines 3 and 4 and arrive at line 5—the number of keypunch and verify units which are used to prepare data for computer systems.

6-7. These figures are from the previously mentioned *EDP/IR* issues of October 19, 1971 and December 19, 1972, and from IDC testimony given to the U.S. Senate in its antitrust investigations (USSen74, p. 5003).

8-9. The entries on line 8 for the years 1966 to 1972 were found by adding together lines 5, 6 and 7. The entries on line 9 for those same years are the result of dividing line 8 by the number of GP computers in use from Table II.1.21. Line 9 for those years implies the number of keyboards per computer increased slightly between 1966 and 1972. The earlier entries on line 9 are my guesses that the number of keyboards per computer have increased slightly since 1965; and line 8 for the years 1955 through 1965 is computed from line 9 by multiplying line 9 by the number of GP computers in use. The 1973-1974 entries on line 8 are from USSen74, except that they include verifiers, assumed to exist in the ratio of about one verifier for every two unbuffered keypunches.

10-15. Most keypunches and verifiers are leased by the users. However, we will compute the equipment value in use based on purchase prices. Line 11 estimates the average price of keypunch and verifier equipment. The increase in 1970 and later is based on the fact that buffered keypunchs have an average purchase price of about $7k, and represent an increasing proportion of total keypunches. Lines 10 and 10a, from *EDP/IR* December 19, 1972, and from USSen74, show the proportions upon which this average value is based. Line 12 is the product of lines 11 and 8. Lines 13 and 14 are computed from lines 6 and 7 assuming average prices per keyboard of $8k. Line 15 is the sum of lines 12, 13, and 14.

16-19. An estimate of the installed base of OCR systems starts with the July 1969 issue of *Datamation*, which was devoted to a review of OCR equipment and applications. In it, on facing pages, J.C. Rabinow wrote, "The world population of OCR today is something of the order of 600 machines", and T.L. Andersson said, "The best estimates of OCR installations are only of the order 1,000 or so." Since Mr. Rabinow was and is a pioneer and leader in the field, I have no trouble in accepting his figure for the number of systems in use at the end of 1968. *EDP/IR*, in its January 15, 1971, issue, states that 2200 OCR units were installed at the end of 1969. I find it impossible to accept *EDP/IR*'s figure, once having adopted Rabinow's, and look elsewhere for data. The June 23, 1971 issue of *Computerworld* quotes a private study as estimating 1500 units installed at the end of 1970, and 1200 at the end of 1969. The 1972-1974 figures on OCR systems are from USSen74. The value in use figures on line 17 are based on an average OCR system price of $150k.

Estimates of the number of MICR systems in use are even less easy to locate. In fact, the only estimate I found was published by *EDP/IR* in the January 15, 1971 issue, along with the OCR figure which I rejected in the paragraph above. The population is given at 3.5k units at the end of 1969. All the other figures on line 18 are estimates on my part, based on the estimated number of computers in banking applications (BanK66, 69) and assuming that about half the banks using computers or computer services were served by MICR units. The value in use on line 19 is based on *EDP/IR's* figure for 1970, and my estimate that system prices have dropped from an initial $100k to under $75k in 1972 and later.

20. The grand total value of data entry equipment in use is the sum of lines 15, 17, and 19. Note that the very tenuous figures for character reading systems account for more than a fifth of the total.

21-23. These entries are the ratios of lines 12, 13, and 14 to line 15.

24-26. These percentages are the ratios of lines 15, 17, and 19 to line 20.

## TABLE II.1.23 DATA ENTRY EQUIPMENT ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Keypunches–Total in Use | | k | | | | | | | | | | | | 175 | 198 | 214 | 225 | 235 | 250 | 255 | 280 | 285 |
| 2. | Verifiers–Total in Use | | k | | | | | | | | | | | | 65 | 73 | 78 | 83 | 85 | 85 | 85 | 85 | 70 |
| 3. | Keyp. & Ver.–Total in Use | | k | | | | | | | | | | | | 240 | 271 | 292 | 308 | 320 | 335 | 340 | 365 | 355 |
| 4. | Comp Keyp. Opr–% of Total | | % | | | | | | | | | | | | 76 | 80 | 83 | 88 | 91 | 93 | 95 | 97 | 98 |
| 5. | Keyp. & Ver. With Comp. | | k | | | | | | | | | | | | 182 | 217 | 242 | 271 | 291 | 312 | 323 | 355 | 347 |
| 6. | Key-to-Tape Kbds. in Use | 1.23.1 | k | | | | | | | | | | | | 2.0 | 6.4 | 16.0 | 30.0 | 42.5 | 52.5 | 60.5 | 52.3 | 51.3 |
| 7. | Key-to-Disk Kbds. in Use | 1.23.1 | k | | | | | | | | | | | | | | | .5 | 3.5 | 9.5 | 17.5 | 28.6 | 36.1 |
| 8. | Total Keyboards in Use | 1.23.3 | k | 1.5 | 4.3 | 7.7 | 13.0 | 19.3 | 27.3 | 39 | 51 | 74 | 107 | 138 | 184 | 233 | 258 | 302 | 337 | 374 | 401 | 436 | 434 |
| 9. | Per GP Computer | | | 6.1 | 6.1 | 6.1 | 6.2 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 | 6.4 | 6.4 | 6.5 | 6.5 | 6.3 | 6.6 | 6.9 | 6.9 | 6.9 | 7.0 | 6.7 |
| 10. | Buff. Keyp. & Ver. in Use | 1.23.1 | k | | | | | | | | | | | | | | | 0 | 20 | 50 | 85 | 115 | 142 |
| 10a. | Unbuff. Keyp. & Ver. in Use | 1.23.1 | k | 1.5 | 4.3 | 7.7 | 13.0 | 19.3 | 27.3 | 39 | 51 | 74 | 107 | 138 | 182 | 217 | 242 | 271 | 271 | 262 | 238 | 240 | 205 |
| 11. | Keyp. & Ver.–Av. Value | $k | | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.7 | 4.1 | 4.4 | 5.0 | 5.3 |
| 12. | Keyp. & Ver.–Value in Use | | $B | .005 | .015 | .027 | .046 | .067 | .095 | .136 | .179 | .258 | .374 | .483 | .637 | .760 | .847 | .949 | 1.077 | 1.279 | 1.421 | 1.775 | 1.839 |
| 13. | Key-to-Tape–Value in Use | | $B | | | | | | | | | | | | | .051 | .128 | .240 | .340 | .420 | .484 | .418 | .410 |
| 14. | Key-to-Disk–Value in Use | | $B | | | | | | | | | | | | | | | .004 | .028 | .076 | .140 | .229 | .289 |
| 15. | Tot. Kbd. Val. in Use | 1.23.2 | $B | .005 | .015 | .027 | .046 | .067 | .095 | .136 | .179 | .258 | .374 | .483 | .637 | .811 | .975 | 1.193 | 1.445 | 1.775 | 2.045 | 2.422 | 2.538 |
| 16. | OCR Systems–No. in Use | 1.23.3 | k | | | | | | | | | | | .1 | .2 | .3 | .6 | 1.0 | 1.4 | 1.8 | 2.2 | 2.6 | 3.2 |
| 17. | Value in Use | | $B | | | | | | | | | | | .020 | .030 | .050 | .090 | .150 | .210 | .270 | .330 | .390 | .480 |
| 18. | MICR Systems–No. in Use | 1.23.3 | k | | | | | | | 0.1 | 0.3 | 0.5 | 0.7 | 1.0 | 1.5 | 2.2 | 2.9 | 3.5 | 3.8 | 4.1 | 4.4 | 4.6 | 4.8 |
| 19. | Value in Use | | $B | | | | | | | .010 | .030 | .050 | .070 | .090 | .120 | .165 | .218 | .260 | .280 | .300 | .320 | .330 | .345 |
| 20. | Grand Tot. Val. in Use | 1.23.4 | $B | .005 | .015 | .027 | .046 | .067 | .095 | .146 | .209 | .308 | .444 | .593 | .787 | 1.026 | 1.273 | 1.603 | 1.935 | 2.345 | 2.695 | 3.142 | 3.363 |
| | Percent of Tot. Keyboard Value | | | | | | | | | | | | | | | | | | | | | | |
| 21. | Keyp. & Ver. | 1.23.2 | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 94 | 87 | 80 | 74 | 72 | 69 | 73 | 72 |
| 22. | Key-to-Tape Keyboards | 1.23.2 | % | | | | | | | | | | | | | 6 | 13 | 20 | 24 | 24 | 24 | 17 | 16 |
| 23. | Key-to-Disk Keyboards | 1.23.2 | % | | | | | | | | | | | | | | | | 2 | 4 | 7 | 9 | 11 |
| | Percent of Tot. Data Entry Val | | | | | | | | | | | | | | | | | | | | | | |
| 24. | Keyboards | 1.23.4 | % | 100 | 100 | 100 | 100 | 100 | 100 | 93 | 86 | 84 | 84 | 81 | 81 | 79 | 77 | 74 | 75 | 76 | 76 | 77 | 75 |
| 25. | OCR | 1.23.4 | % | | | | | | | | | | | 3 | 4 | 5 | 7 | 9 | 11 | 12 | 12 | 12 | 14 |
| 26. | MICR | 1.23.4 | % | | | | | | 0 | 7 | 14 | 16 | 16 | 15 | 15 | 16 | 17 | 16 | 14 | 13 | 12 | 11 | 10 |

## TABLE II.1.24 COMMUNICATIONS AND TERMINALS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Communications** | | | | | | | | | | | | | | | | | | | | | | |
| | Data Sets in Use | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Bell System–Series 100–DD | | k | | | | | | | | 2.10 | 3.40 | 5.30 | 8.15 | 13.53 | 25.07 | 40.30 | | | | | | |
| 2. | Series 100–Private Line | | k | | | | | | | | .05 | .20 | .70 | 1.55 | 2.78 | 5.13 | 9.50 | | | | | | |
| 3. | Series 100–Total | | k | | | | | | | | 2.15 | 3.60 | 6.00 | 9.70 | 16.30 | 30.20 | 49.80 | | | | | | |
| 4. | Series 200–Direct Dial | | k | | | | | | | | 1.15 | 1.78 | 2.30 | 3.15 | 4.42 | 5.58 | 7.90 | | | | | | |
| 5. | Series 200–PL | | k | | | | | | | | .75 | 1.03 | 1.60 | 2.55 | 4.08 | 6.42 | 9.40 | | | | | | |
| 6. | Series 200–Total | | k | | | | | | | | 1.90 | 2.80 | 3.90 | 5.70 | 8.50 | 12.00 | 17.30 | | | | | | |
| 7. | Series 300–Private Line | | k | | | | | | | | | .02 | .09 | .25 | .40 | .65 | .90 | | | | | | |
| 8. | Series 400–DD | | k | | | | | | | | 2.38 | 3.86 | 6.14 | 8.71 | 11.09 | 12.77 | 15.25 | | | | | | |
| 9. | Series 400–PL | | k | | | | | | | | .03 | .04 | .07 | .09 | .12 | .13 | .16 | | | | | | |
| 10. | Series 400–Total | | k | | | | | | | | 2.40 | 3.90 | 6.20 | 8.80 | 11.20 | 12.90 | 15.40 | | | | | | |
| 11. | Subtotal–DD | | k | | | | | | | | 5.63 | 9.04 | 13.74 | 20.01 | 29.04 | 43.42 | 63.45 | | | | | | |
| 12. | Subtotal–PL | | k | | | | | | | | .83 | 1.29 | 2.45 | 4.44 | 7.38 | 12.33 | 19.96 | | | | | | |
| 13. | Subtotal–Bell System | | k | | | | | 1. | 2. | 3. | 6.45 | 10.32 | 16.19 | 24.45 | 36.40 | 55.75 | 83.40 | 125 | 180 | 250 | 300 | 350 | 400 |
| 14. | Other Telephone Companies | | k | | | | | | | | | | | 1 | 2 | 3 | 5 | 7 | 12 | 20 | 30 | 40 | 50 |
| 15. | Independent Modems | | k | | | | | | | | | | | | | 2 | 7 | 12 | 20 | 30 | 42 | 55 | 65 |

## TABLE II.1.24 COMMUNICATION AND TERMINALS—NOTES

A *terminal* is a system component which can transmit and/or receive data to or from a CPU over a communication line. A *communication line* is a data transmitting and receiving facility provided by a communication company. Such facilities have the properties that: they can interconnect any two points in the U.S.; they can be used with the direct dial (DD) switched network to provide great interconnection flexibility; they provide connections via the equivalent of a single wire; and they are limited in the rate at which they can transfer information. As has been stated previously, computer peripherals are located adjacent to a CPU, and are connected to it via cables which generally provide a number of wires in parallel, each operating at high data rates—in contrast to the single-wire, low-data-rate communications lines. Note that an electromechanical device which serves as a terminal in one application may serve as a peripheral in another. For example, a keyboard-printer may be connected to a communication line to act as a terminal in a time-sharing application; the same device may serve as an operator's console in the computer room, connected to the computer through a sophisticated buffer of some kind. As another example, a line printer and card reader, normally used as system peripherals, may also be components of a Remote Batch Terminal, supplying and receiving data to and from a CPU at some distant location over a communication line.

As the importance of data communication has grown, and as electronic costs have dropped, minicomputers have increasingly been used as components in "intelligent terminal" systems. In the discussion which follows, I will count such systems as terminals, and in general will relate terminal installations to the number of GP systems installed—making the assumption that terminals are subservient to and components of GP systems. In many cases, a "minicomputer" or dedicated-application CPU is the heart of a store-and-forward communication system, or of a data retrieval system, and has a number of terminals (perhaps including intelligent terminals which themselves contain other minis) connected to it. To the extent that such installations are numerous or large, some of my data may be misleading.

**Data Sets.** 1-13. The data shown here for the periods 1962 through 1968 is from a Stanford Research Institute report (ZeidH69) prepared in connection with an FCC inquiry into the communications/data processing industries. The source was AT & T. The data on line 13 for the years 1959-1961 is my own extrapolation. The data for the years 1969 through 1974 is computed by dividing line 28 by line 29—making the assumption that the average revenue per data set has remained constant.

14-16. Lines 14 and 15 are my own estimates, based in part on General Telephone and Electronics Corporation's 1968 reply to the above mentioned FCC inquiry; and in part on a variety of public and private reports, most of which conflict with one another. For example, an article in the September, 1971, issue of *Telecommunications* magazine ("Nationwide Digital Transmission Network For Data", by R.G. DeWitt, of Western Union Telegraph Company) estimated that the Bell System shipped 140,000 data sets in 1970. In a special report on modems, *Electronic News* on September 6, 1971 published a report by Dittenberner Associates estimating that a total of 56,000 data sets were shipped in 1970, including both Bell System and independents. The same *Electronic News* article quotes Auerbach Associates as saying that there would be 298,000 data sets installed at the end of 1971. And an article in the June, 1973 issue of *Telecommunications* magazine stated that 500,000 modems were in use at the end of 1971—though we have seen (line 13) that the official AT & T figure for 1968 was only 13,400 in use. Line 16 is the sum of lines 13, 14 and 15.

17-23. Lines 17 through 20 are computed by dividing lines 3, 6, 7, and 10, respectively, by line 13; lines 21 and 22 are computed by dividing lines 11 and 12 by line 13. Line 23 is the quotient of line 13 and line 16.

24-29. The data shown for the years 1962 through 1968 is based on the estimated average Bell System tariff per year for each class of data set, as shown in the headings for those lines; and on the population of each data set type from lines 3, 6, 7, and 10. For example, the 1962 entry on line 24 is the product of $240 per year and the 2,150 data sets on line 3 for that year. Line 28 is the sums of lines 24 through line 27. The AT & T revenues on line 28 for the years 1969-1971 are from an article 'Minis in DataCom—A Windfall for Modems,' by Ron Schneiderman, in *Electronic News.* The 1972-1974 figures are an extrapolation on my part. Line 29 for the years 1962-1968 is found by dividing the entries on line 28 by those on line 13. Since the average revenue per data set is so nearly constant at $420 per year, I extended that average for the years 1959-1961 and 1969-1972.

30-33. The proportion of revenue which comes from each data set type is found by dividing lines 24 through 27 by line 28.

34. The independent data sets, which are an increasing proportion of all those installed, as shown in line 15, are sold rather than leased. However, to provide an estimate of the annual cost to users of data sets, line 34 is computed by multiplying $420 by the total number of data sets on line 16.

**Carriage of Data.** 35-43. "Carriage of Data" is the revenue to communication companies for transmission of data on leased private lines. (It does not include revenues from data transmission on the dialed-up network, since those revenues are a very complicated function of the number of terminals in use, and are impossible for the communication companies to measure. Many telephone lines, for example, are sometimes used for data and sometimes for voice transmission; and many of the calls are made under a flat rate tariff, which provides no incremental revenue.) The figures shown on line 35 for the years 1968-1971 are from *EDP/IR* dated October 19, 1971. The ratios on line 36 for those four years are found by dividing the entries on line 35 by those on line 16. The other entries on line 35 were computed from the assumed communication costs per data set shown on line 36 for those years, and the number of data sets on line 16. AT & T's "data service revenue" shown on line 37 is from the AT & T 1971 and 1972 Annual Reports. Those revenues are said to include revenues from data sets, from sales and leases of teletype equipment and other terminals, and from AT & T's Telex service, which was handed over to Western Union in 1971. The figures for AT & T's "carriage of data" shown on line 38 were computed using the ratios on line 36 multiplied by the number of Bell System data sets on line 13, and an assumed number of the data sets on line 15 which provide a revenue to AT & T. Line 39, then, is the difference between line 37,

## TABLE II.1.24 COMMUNICATIONS AND TERMINALS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16. | Grand Total Data Sets | 1.24.3 | k | | | | | 1. | 2. | 3. | 6.5 | 10.3 | 16.2 | 25. | 38. | 61. | 95. | 144 | 212 | 300 | 372 | 445 | 515 |
| | Bell Data Set Distribution | | | | | | | | | | | | | | | | | | | | | | |
| 17. | Series 100 | 1.24.3 | % | | | | | | | | 33.3 | 34.9 | 37.1 | 39.7 | 44.7 | 54.1 | 59.7 | | | | | | |
| 18. | Series 200 | 1.24.3 | % | | | | | | | | 29.5 | 27.1 | 24.1 | 23.3 | 23.3 | 21.5 | 20.7 | | | | | | |
| 19. | Series 300 | 1.24.3 | % | | | | | | | | | .2 | .6 | 1.0 | 1.0 | 1.2 | 1.1 | | | | | | |
| 20. | Series 400 | 1.24.3 | % | | | | | | | | 37.2 | 37.8 | 38.3 | 36.0 | 30.7 | 23.1 | 18.4 | | | | | | |
| 21. | Direct Dial | 1.24.3 | % | | | | | | | | 87.3 | 87.6 | 84.9 | 81.8 | 79.7 | 77.8 | 76.0 | | | | | | |
| 22. | Private Line | | % | | | | | | | | 12.9 | 12.5 | 15.1 | 18.1 | 20.2 | 22.1 | 23.9 | | | | | | |
| 23. | Percent of All Data Sets | | % | | | | | 100 | 100 | 100 | 100 | 100 | 100 | 96.0 | 94.7 | 91.7 | 87.4 | 86.8 | 84.9 | 83.3 | 80.6 | 78.7 | 77.7 |
| | Bell Data Set Revenue | | | | | | | | | | | | | | | | | | | | | | |
| 24. | Series 100 at $240/yr. | | $M/yr | | | | | | | | .52 | .86 | 1.44 | 2.33 | 3.91 | 7.25 | 11.95 | | | | | | |
| 25. | Series 200 at $1000/yr. | | $M/yr | | | | | | | | 1.90 | 2.80 | 3.90 | 5.70 | 8.50 | 12.00 | 17.30 | | | | | | |
| 26. | Series 300 at $4200/yr. | | $M/yr | | | | | | | | | .08 | .38 | 1.05 | 1.68 | 2.73 | 3.78 | | | | | | |
| 27. | Series 400 at $120/yr. | | $M/yr | | | | | | | | .29 | .47 | .74 | 1.06 | 1.34 | 1.55 | 1.85 | | | | | | |
| 28. | Total Revenue | | $M/yr | | | | | .42 | .84 | 1.26 | 2.71 | 4.21 | 6.46 | 10.14 | 15.43 | 23.53 | 34.88 | 51. | 76. | 103. | 126. | 147. | 168. |
| 29. | Average Rev. Per Data Set | | $k/yr | | | | | .42 | .42 | .42 | .42 | .41 | .40 | .42 | .42 | .42 | .42 | .42 | .42 | .42 | .42 | .42 | .42 |
| | Bell Data Set Rev. Distrib. | | | | | | | | | | | | | | | | | | | | | | |
| 30. | Series 100 | 1.24.4 | % | | | | | | | | 19.1 | 20.4 | 22.2 | 23.0 | 25.3 | 30.8 | 34.2 | | | | | | |
| 31. | Series 200 | 1.24.4 | % | | | | | | | | 70.1 | 66.5 | 60.3 | 56.2 | 55.0 | 50.9 | 49.6 | | | | | | |
| 32. | Series 300 | 1.24.4 | % | | | | | | | | | 1.9 | 5.8 | 10.3 | 10.8 | 11.60 | 10.8 | | | | | | |
| 33. | Series 400 | 1.24.4 | % | | | | | | | | 10.7 | 11.1 | 11.4 | 10.4 | 8.6 | 6.5 | 5.3 | | | | | | |
| 34. | Total D.S. Lease Rev. | 1.24.4 | $B/yr | | | | | | .001 | .001 | .003 | .004 | .006 | .011 | .016 | .026 | .040 | .061 | .089 | .126 | .156 | .187 | .216 |
| | Carriage of Data Per Year | | | | | | | | | | | | | | | | | | | | | | |
| 35. | Total Carriage of Data | | $B/yr | | | | | | | .004 | .009 | .014 | .023 | .035 | .053 | .085 | .135 | .200 | .280 | .405 | .500 | .590 | .675 |
| 36. | Carriage of Data per D.S. | | $k/yr | | | | | | | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.42 | 1.39 | 1.32 | 1.35 | 1.35 | 1.33 | 1.31 |
| 37. | AT & T 'Data Serv. Rev.' | 1.24.2 | $B/yr | | | | | | | | .16 | .18 | .20 | .23 | .26 | .30 | .36 | .45 | .55 | .65 | .75 | | |
| 38. | Carriage of Data | | $B/yr | | | | | | | .004 | .009 | .014 | .023 | .034 | .050 | .082 | .125 | .190 | .263 | .377 | .457 | | |
| 39. | Other Revenues | | $B/yr | | | | | | | | .14 | .16 | .17 | .18 | .20 | .20 | .20 | .21 | .21 | .17 | .17 | | |
| | Fract. of ATT Data Serv. Rev. | | | | | | | | | | | | | | | | | | | | | | |
| 41. | Carriage of Data | | % | | | | | | | | 6 | 8 | 12 | 15 | 19 | 27 | 35 | 42 | 48 | 58 | 61 | | |
| 42. | Data Sets | | % | | | | | | | | 2 | 2 | 3 | 4 | 6 | 8 | 10 | 11 | 14 | 16 | 17 | | |
| 43. | Other | | % | | | | | | | | 92 | 90 | 85 | 81 | 75 | 65 | 55 | 47 | 38 | 26 | 22 | | |
| | **Terminals** | | | | | | | | | | | | | | | | | | | | | | |
| | General-Purpose–In Use | | | | | | | | | | | | | | | | | | | | | | |
| 44. | Keyboard-Printers–No. | | k | | | | | | | | | | 2 | | 20 | | 70 | | 127 | | 180 | | 240 |
| 45. | Value at $4k | | $B | | | | | | | | | | .01 | | .08 | | .28 | | .50 | | .72 | | .96 |
| 46. | Cathode-Ray-Tube–No. | | k | | | | | | | | | | | | 3 | | 15 | | 35 | | 90 | | 215 |
| 47. | Value at $4k | | $B | | | | | | | | | | | | .01 | | .06 | | .14 | | .36 | | .86 |
| | Application-Oriented–In Use | | | | | | | | | | | | | | | | | | | | | | |
| 48. | Airline Reservation–No. | | k | | | | .55 | .69 | .69 | 2.69 | 5.19 | 6.07 | 7.72 | 8.12 | 8.32 | 8.32 | 8.62 | | 10 | | 10 | | 10 |
| 49. | Value at $5k | | $B | | | | | | | | .03 | | .04 | | .04 | | .04 | | .05 | | .05 | | .05 |
| 50. | Banking–No. | | k | | | | | | | | | | | | | | 1 | | 2 | | 20 | | 50 |
| 51. | Value at $8k | | $B | | | | | | | | | | | | | | .01 | | .02 | | .16 | | .40 |
| 52. | Point-of-Sale–No. | | k | | | | | | | | | | | | | | | | | | 15 | | 110 |
| 53. | Value at $4k | | $B | | | | | | | | | | | | | | | | | | .06 | | .44 |
| 54. | Stock Quotation–No. | | k | | | | | | | | 2 | | 5 | | 13 | | 25 | | 30 | | 40 | | 50 |
| 55. | Value at $4k | | $B | | | | | | | | .01 | | .02 | | .05 | | .10 | | .12 | | .16 | | .20 |
| 56. | Credit Authorization–No. | | k | | | | | | | | | | | | | | | | 10 | | 30 | | 50 |
| 57. | Value at $2k | | $B | | | | | | | | | | | | | | | | .02 | | .06 | | .10 |
| 58. | Data Collection–No. | | k | | | | | | | | | | 2 | | 8 | | 15 | | 28 | | 40 | | 65 |
| 59. | Value at $3k-$6k | | $B | | | | | | | | | | .01 | | .05 | | .09 | | .17 | | .18 | | .19 |

and the sum of lines 38 and 28. As a check to the "carriage of data" figures, it indicates that the Bell System revenues from Telex, and from the sale and leases of terminals increased only moderately over this ten year period; and dropped substantially in 1971 and 1972 when the Telex revenue disappeared.

Lines 41 through 43 are computed by dividing lines 38, 28, and 39 by line 37.

**Terminals.** Reliable data on the number of terminals of various kinds in use is notoriously difficult to come by. One reason for the large variability in published figures is probably the problem of definition. Distressingly often, firms which publish terminal censuses fail to define what they mean by terminals. Do they include keyboard printers on the Telex or TWX networks? Typewriters or CRT's used as operators' consoles in the computer room? Where no definition is provided, these questions can't be answered. Neither category is included in my definition.

IDC (in *EDP/IR*, May 31, 1973), distinguished three classes of terminals: general purpose keyboard-printers and keyboard-CRT's, which permit an operator to perform an unlimited variety of functions, depending only on the program of the central computer; application-oriented units, designed specifically for some limited application; and machine-to-machine terminals whose primary function is the transmission of data in quantity to one location from another—exemplified by special purpose systems such as UNIVAC's DCT-2000, as well as small GP and minicomputer systems whose CPU's act as interface between a communication line and a collection of peripherals.

As usual, my primary source of data is IDC, in the following issues of *EDP/IR*: June 30, 1971; January 17, 1972; November 6, 1972; May 31, 1973; August 23, 1973; and February 13, 1974. However, although these issues and some accessible private reports provide recent estimates of terminal installations, most of the earlier figures represent educated guesses on my part. Two exceptions: the number of airline reservation terminals installed for the years 1958 through 1968 come from BoozA68, a report prepared for the Business Equipment Manufacturers Association in connection with the previously-mentioned FCC study. And the estimated number of stock quotation terminals on line 54 comes in part from my personal experience in that field, and in part from an article in the July 1973 issue of *Datamation* which indicated that Bunker Ramo had over 20,000 terminals installed in the U.S. and Canada.

The installed values of individual terminals shown in the table are found by multiplying the assumed number of terminals by the assumed average price, as shown in the table headings. The average prices of keyboard printers, CRT's, banking terminals, and data collection terminals are based on estimated average selling prices for IBM and Teletype equipment. The point-of-sale average value is based on IBM and NCR product prices; the stock quotation and credit authorization averages are my own personal estimates; and the remote batch terminal average price is based on a *Datamation* survey (TheiD71), and a rash assumption about the distribution of terminal types. For data collection and remote batch terminals, I have assumed a reduction in average prices starting in about 1972.

Lines 62 and 63 are the sums of the individual terminal counts and terminal values, and line 64 is the quotient of line 63 and 62.

**Summary.** 65-66. The previously-mentioned BEMA Report (BoozA68) estimated the total number of on-line systems for 1955, 1960, 1963, and 1966 as 2, 31, 418, and 2,330, respectively. These installations, however, included military as well as commercial computer systems. The 1972 number of 15,000 systems comes from *EDP/IR* of May 31, 1973. The other figures represent a straightforward extrapolation of the percentage of GP systems having terminals (line 66) between 1966 and 1972. (As usual, there are wide variations in estimates from various sources—though many of them probably arise because minicomputer systems tied to communication lines are included. *EDP/IR* data explicitly includes only GP systems. However, some measure of the uncertainty involved can be gained by noting that, in their January 17, 1972, issue, *EDP/IR* estimated that 32% of GP systems had terminals at year-end 1971. Sixteen months later their estimate for year-end 1972 had dropped to 26%, though they did not claim, and I do not believe, the percentage actually dropped.)

67-69. Data sets per system having communication lines is the quotient of line 16 and line 65; terminals per system the quotient of lines 62 and 65; and terminals per data set the quotient of lines 62 and 16.

70-72. The data set annual cost per system on line 70 is the quotient of lines 34 and 65; the Annual Carriage of Data cost the quotient of lines 35 and 65; and the terminal investment per system having communication lines is the quotient of lines 63 and 65.

73. Total data revenues includes data sets and carriage of data, and is the sum of lines 34 and 35.

74. The value of terminals in use as a percent of the total value of GP systems installed in the United States is the quotient of line 63 of this table and the total value in use from Table 1.22.1.

75-82. These figures are the ratio of the various terminal populations from the even-numbered lines between 44 and 60, to total terminals on line 62.

83-90. Similarly, these lines are the ratio of terminal values from the odd-numbered lines between 45 and 61 to total value on line 63.

## TABLE II.1.24 COMMUNICATIONS AND TERMINALS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Machine-to-Machine—In Use | | | | | | | | | | | | | | | | | | | | | | |
| 60. | Remote Batch | | k | | | | | | | | | | | | | | 2 | | 8 | | 11 | | 17 |
| 61. | Value at $16k-$25k | | $B | | | | | | | | | | | | | | .05 | | .20 | | .22 | | .27 |
| 62. | Total Terminals in Use | 1.24.5 | k | | | | | | 1 | | 7 | | 17 | | 52 | | 137 | | 250 | | 435 | | 808 |
| 63. | Total Value in Use | 1.24.6 | $B | | | | | | | | .04 | | .08 | | .23 | | .63 | | 1.22 | | 1.97 | | 3.47 |
| 64. | Average Value in Use | | $k | | | | | | | | 5 | | 5 | | 4.4 | | 4.6 | | 4.9 | | 4.5 | | 4.3 |
| | **Summary** | | | | | | | | | | | | | | | | | | | | | | |
| 65. | Comp. Systs. with Comm. | 1.24.1 | k | .002 | | | | | .03 | .08 | .2 | .3 | .8 | 1.4 | 2.3 | 4.0 | 5.8 | 8.0 | 9.7 | 12.5 | 15.0 | 16.8 | 18.2 |
| 66. | % of U.S. GP Systs. | 1.24.1 | % | 1 | | | | | 1 | 1 | 2 | 3 | 5 | 6 | 8 | 11 | 14 | 17 | 20 | 23 | 26 | 27 | 28 |
| 67. | Data Sets Per System | 1.24.7. | | | | | | | 66 | 38 | 33 | 34 | 20 | 18 | 17 | 15 | 16 | 18 | 22 | 24 | 25 | 26 | 28 |
| 68. | Terminals Per System | 1.24.7 | | | | | | | 33 | | 35 | | 21 | | 22 | | 24 | | 26 | | 29 | | 44 |
| 69. | Terminals Per Data Set | 1.24.7 | | | | | | | .5 | | 1.1 | | 1.0 | | 1.4 | | 1.4 | | 1.2 | | 1.2 | | 1.6 |
| 70. | Cost Per System—Data Sets | 1.24.8 | $k/yr | | | | | | 28 | 16 | 14 | 14 | 8 | 7.5 | 7.0 | 6.4 | 6.9 | 7.6 | 9.2 | 10.0 | 10.4 | 11.1 | 11.9 |
| 71. | Carriage of Data | 1.24.8 | $k/yr | | | | | | | 50 | 45 | 47 | 29 | 25 | 23 | 21 | 23 | 25 | 29 | 32 | 33 | 35 | 37 |
| 72. | Terminal Investment | 1.24.8 | $k | | | | | | 116 | | 170 | | 100 | | 100 | | 109 | | 126 | | 131 | | 191 |
| 73. | Total Data Revenues | 1.24.2 | $B/yr | | | | | | .001 | .005 | .012 | .018 | .029 | .046 | .069 | .111 | .175 | .261 | .369 | .531 | .656 | .777 | .891 |
| | Terminals | | | | | | | | | | | | | | | | | | | | | | |
| 74. | Percent of GP Value | | % | | | | | | | | 1.1 | | 1.3 | | 2.1 | | 3.6 | | 5.2 | | 7.4 | | 11.5 |
| 75. | Percent of Total No.—GP | 1.24.5 | % | | | | | | | | | | 12 | | 44 | | 62 | | 65 | | 62 | | 56 |
| 76. | Keyboard—Printers | | % | | | | | | | | | | 12 | | 38 | | 51 | | 51 | | 41 | | 30 |
| 77. | CRT's | | % | | | | | | | | | | | | 6 | | 11 | | 14 | | 21 | | 27 |
| 78. | Application-Oriented | 1.24.5 | % | | | | 100 | | 100 | | 100 | | 88 | | 56 | | 36 | | 32 | | 36 | | 41 |
| 79. | Airline Reservation | | % | | | | 100 | | 100 | | 71 | | 47 | | 15 | | 7 | | 4 | | 2 | | 1 |
| 80. | Stock Quotation | | % | | | | | | | | 29 | | 29 | | 25 | | 18 | | 12 | | 9 | | 6 |
| 81. | Data Collection | | % | | | | | | | | | | 12 | | 15 | | 11 | | 11 | | 9 | | 8 |
| 81a. | Point-of-Sale | | % | | | | | | | | | | | | 0 | | 0 | | 0 | | 3 | | 14 |
| 82. | Machine-to-Machine | 1.24.5 | % | | | | | | | | | | | | 0 | | 1 | | 3 | | 3 | | 2 |
| 83. | Percent of Total Value—GP | 1.24.6 | % | | | | | | | | | | 13 | | 39 | | 54 | | 52 | | 55 | | 52 |
| 84. | Keyboard-Printers | | % | | | | | | | | | | 13 | | 35 | | 44 | | 41 | | 37 | | 28 |
| 85. | CRT's | | % | | | | | | | | | | | | 4 | | 10 | | 11 | | 18 | | 25 |
| 86. | Application-Oriented | 1.24.6 | % | | | | 100 | | 100 | | 100 | | 87 | | 61 | | 38 | | 32 | | 34 | | 40 |
| 87. | Airline Reservation | | % | | | | 100 | | 100 | | 75 | | 50 | | 17 | | 6 | | 4 | | 3 | | 1 |
| 88. | Stock Quotation | | % | | | | | | | | 25 | | 25 | | 22 | | 16 | | 10 | | 8 | | 6 |
| 89. | Data Collection | | % | | | | | | | | | | 12 | | 22 | | 14 | | 14 | | 9 | | 5 |
| 89a. | Point-of-Sale | | % | | | | | | | | | | | | 0 | | 0 | | 0 | | 3 | | 13 |
| 89b. | Banking | | % | | | | | | | | | | | | 0 | | 2 | | 2 | | 8 | | 12 |
| 90. | Machine-to-Machine | 1.24.6 | % | | | | | | | | | | | | | | 8 | | 16 | | 11 | | 8 |

## TABLE II.1.25—SOFTWARE

**User Costs.** 1-5. Annual salaries, on lines 1 and 2, were computed from the salary data in Table II.1.4.3 and the user personnel summary in Table II.1.4.2. The personnel counts were as of year-end, and I computed annual salaries by computing the average of two end-year counts and multiplying by salary, assuming a 52-week year. Line 3 is the sum of lines 1 and 2. The overhead rate on line 4 is based on the assumptions that one secretary and two managers are required for every ten programmers and systems analysts. It assumes the managers' salaries are 50% higher than the programmers' or systems analysts' and includes an allowance for fringe benefits, but not for computer time. The overhead rate is lower than the corresponding one for development programming because it includes no allowance for documentation labor—I assume the user's personnel do their own documentation, whereas development programmers are provided with documentation support. Line 5 is computed from lines 3 and 4. Line 5a is the quotient of line 5 and the value of U.S. GP computers in use, from Table II.1.21. Note, however, that the significance of this percentage is tied directly to the assumption made in connection with Table II.1.4.2 that the number of system analysts and programmers per $100k of system value has increased modestly over the years. The result is that my figures for salaries as a percent of computer value in use vary fairly directly with salary rates.

**Software Industry.** 6-8. These figures come directly from Table II.1.26, and their source is discussed in connection with that table.

**Suppliers' Development Costs.** 9. Supplier software development cost is derived in connection with Table II.1.4.2, where we discuss the number of software personnel working for system manufacturers. Line 9 is copied from line 110 of that table, and its derivation is discussed there. The total cost includes an overhead factor similar to that shown on line 4 above. However, once again the cost shown here does not include the cost of computer time required for software development. Line 9a is the quotient of lines 110 (software development costs) and 111 (total hardware plus software development costs) of Table II.1.4.2.

**Summary.** 10-13. Line 10 is the sum of lines 5, 8, and 9; and lines 11 through 13 are computed by dividing those three lines by line 10.

**Standard Programming Support.** 14-15. The number of lines of code of "standard program support" (assemblers, compilers, operating systems, etc.) supplied by the manufacturers, is based on a chart by R. M. McClure, in NaurP69. McClure's data is shown in Figure 1.25.5. It shows the amount of code provided by computer manufacturers in various specific years for certain specified computers and computer families. The dotted lines on the chart, representing the data on lines 14 and 15, are my own interpretation of McClure's data. My curve is intended to show the amount of independently-derived software required for each computer model. Since the 360 family of machines presumably share a good deal of common software, I presume that software per CPU for IBM machines has increased in recent years in something less than an exponential fashion. My assumption about the growth rate of non-IBM software is pure speculation my part. Note it seems a reasonably approximation in connection with the 1604 shown in the figure, but not with regard to the Datatron machine. Note also the approximation is intended to apply to GP machines only. I have not tried to estimate the amount of software and the number of programmers required for minicomputer systems.

16-18. These figures are derived from those on lines 14 and 15 by making various assumptions about the rate of software development. The assumptions are documented, and the calculations described in connection with Table II.1.4.2; and lines 16 and 17 are copied from lines 68 and 93 of that table. Line 18 is the sum of lines 16 and 17.

## TABLE II.1.26 SERVICE INDUSTRIES—NOTES

1. *EDP/IR* issues of March 30, 1973, and March 12, 1970, are the source for the years 1955 to 1965, inclusive. The Sixth Annual Industry Survey, commissioned by the Association of Data Processing Service Organizations and published in 1972 (IDCServ72), is the source for the 1966-1971 figures, and various issues of *EDP/IR* are the source for the later data. Since IDC, the publisher of *EDP/IR*, also carried out the ADAPSO study, the two sets of figures should be compatible with one another. Lines 2 through 9, described below, identify the various components of total revenue, and the descriptions which follow will therefore establish a definition of the service industries.
2. Batch data processing services are those in which a customer supplies data punched on cards or written on paper to a service company which processes the data on a GP computer and returns printed results to the customer. "Periodically" generally means weekly or monthly. Initially, all data processing services were performed in this fashion. The source of data for this line is the same as that for line 1 above.

3-5. On-line processing is defined exactly as is batch data processing, except that input and output data is transferred between the customer and the service company over communication lines, instead of on pieces of paper. Two kinds of on-line processing are distinguished. In the first, called "remote batch", the customer's communication station contains unit record equipment (often a card reader, card punch, and line printer), and the customer receives service very similar to a batch data processing service, except that his input cards and output data are handled on his premises, and do not have to be transported between his office and that of a service company. Interactive services, on the other hand, are carried via a keyboard terminal of some kind, from which an operator enters data and to which the serving computer supplies replies. The name "interactive" comes about because the computer must from time to time respond to the operator. (*EDP/IR* calls this the "rair" market, meaning "remote access/immediate response" interaction with computers.) The figures on lines 3-5 for 1966-1972 are from IDCServ72 and the March 30, 1973, *EDP/IR*. Earlier figures are my own extrapolations; the later figures are from other issues of *EDP/IR*.

The data processing services identified by lines 2 through 5 supply computer power to the customer in three ways. If raw power is sold, the customer must supply his own software and operating instructions to the supplier. Timesharing services, and the sale of batch computer time by the hour are examples. In the second alternative, vendor and customer agree on the algorithms which will be used to transform the customer's raw data, update his

## TABLE II.1.25 SOFTWARE ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **User Costs** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Salaries–System Analysts | 1.25.2 | $B | .005 | .010 | .017 | .030 | .048 | .072 | .107 | .152 | .214 | .299 | .411 | .581 | .831 | 1.114 | 1.475 | 1.794 | 1.968 | 2.180 | 2.434 | 2.712 |
| 2. | Programmers | 1.25.2 | $B | .006 | .011 | .019 | .032 | .051 | .076 | .111 | .160 | .217 | .299 | .422 | .609 | .846 | 1.150 | 1.537 | 1.860 | 2.096 | 2.345 | 2.520 | 2.847 |
| 3. | Total | | $B | .011 | .021 | .036 | .062 | .099 | .148 | .218 | .312 | .431 | .598 | .833 | 1.190 | 1.677 | 2.264 | 3.012 | 3.654 | 4.064 | 4.525 | 4.954 | 5.559 |
| 4. | Overhead Ratio | | % | 46 | 47 | 48 | 49 | 50 | 50 | 51 | 51 | 51 | 52 | 52 | 52 | 53 | 53 | 53 | 54 | 54 | 54 | 55 | 56 |
| 5. | Total User Software Costs | 1.25.2 | $B | .016 | .031 | .053 | .092 | .149 | .222 | .329 | .471 | .651 | .909 | 1.266 | 1.809 | 2.566 | 3.464 | 4.608 | 5.627 | 6.259 | 6.969 | 7.679 | 8.672 |
| 5a. | % of U.S. GP Value in Use | | % | 8.9 | 9.6 | 9.9 | 10.3 | 11.1 | 11.9 | 12.6 | 13.5 | 14.3 | 15.1 | 16.2 | 16.9 | 18.6 | 19.8 | 21.5 | 23.8 | 24.8 | 26.2 | 28.1 | 28.7 |
| | **Software Industry** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Custom Software | 1.25.3 | $B | | | | | | | | | .005 | .020 | .050 | .100 | .165 | .245 | .315 | .365 | .350 | .436 | .473 | |
| 7. | Standard Packages | 1.25.3 | $B | | | | | | | | | | | | | .010 | .025 | .045 | .075 | .100 | .281 | .395 | |
| 8. | Total Revenue | 1.25.3 | $B | | | | | | | | | .005 | .020 | .050 | .100 | .175 | .270 | .360 | .440 | .450 | .717 | .868 | 1.000 |
| | **Suppliers' Devel. Costs** | | | | | | | | | | | | | | | | | | | | | | |
| 9. | Total Software Dev. Cost | 1.25.4 | $B | .001 | .002 | .002 | .004 | .008 | .015 | .019 | .032 | .047 | .071 | .097 | .115 | .129 | .150 | .160 | .184 | .208 | .235 | .256 | .297 |
| 9a. | % of Total Dev. Costs | 1.25.4 | % | 6.8 | 4.3 | 3.7 | 3.9 | 7.1 | 11.8 | 13.4 | 21.5 | 26.6 | 34.3 | 39.3 | 40.8 | 37.3 | 35.8 | 33.1 | 33.9 | 34.4 | 35.1 | 35.2 | 36.7 |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| 10. | Total Software Costs | 1.25.1 | $B | .017 | .033 | .055 | .096 | .157 | .237 | .348 | .503 | .703 | 1.000 | 1.413 | 2.024 | 2.870 | 3.884 | 5.128 | 6.251 | 6.917 | 7.921 | 8.803 | 9.969 |
| 11. | Percent of Tot.–Users | | % | 94. | 94. | 96. | 96. | 95. | 93.7 | 94.5 | 93.6 | 92.6 | 90.9 | 89.6 | 89.4 | 89.4 | 89.2 | 89.9 | 90.0 | 90.5 | 88.0 | 87.2 | 87.0 |
| 12. | Software Industry | 1.25.1 | % | | | | | | | | | 0.7 | 2.0 | 3.5 | 4.9 | 6.1 | 7.0 | 7.0 | 7.0 | 6.5 | 9.1 | 9.9 | 10.0 |
| 13. | Suppliers | 1.25.1 | % | 6. | 6. | 4. | 4. | 5. | 6.3 | 5.5 | 6.4 | 6.7 | 7.1 | 6.9 | 5.7 | 4.5 | 3.9 | 3.1 | 2.9 | 3.0 | 3.0 | 2.9 | 3.0 |
| | **Std. Programming Support** | | | | | | | | | | | | | | | | | | | | | | |
| 14. | Lines of Code/CPU–IBM | 1.25.5 | kli | 11 | 16 | 25 | 37 | 57 | 86 | 130 | 200 | 300 | 460 | 660 | 850 | 1040 | 1220 | 1400 | 1575 | 1750 | 1920 | 2090 | 2260 |
| 15. | Other GP Manufacturers | 1.25.5 | kli | 3 | 4 | 6 | 9 | 14 | 22 | 33 | 50 | 75 | 115 | 165 | 212 | 260 | 305 | 350 | 394 | 437 | 480 | 523 | 565 |
| | Cumulative Software Completed | | | | | | | | | | | | | | | | | | | | | | |
| 16. | By IBM | 1.25.6 | Mli | .09 | .15 | .24 | .38 | .75 | 1.4 | 2.2 | 3.9 | 5.9 | 9.0 | 13.3 | 17.7 | 22.4 | 26.5 | 31.0 | 36.4 | 40.8 | 46.0 | 51.9 | 58.4 |
| 17. | By Other GP M'fctrs. | 1.25.6 | Mli | .10 | .18 | .31 | .52 | .93 | 1.6 | 2.6 | 3.9 | 6.0 | 8.8 | 12.0 | 15.7 | 19.8 | 24.9 | 30.0 | 36.4 | 44.0 | 52.0 | 60.2 | 70.0 |
| 18. | Total | 1.25.6 | Mli | .19 | .33 | .55 | .90 | 1.68 | 3.0 | 4.8 | 7.8 | 11.9 | 17.8 | 25.3 | 33.4 | 42.2 | 51.4 | 61.0 | 72.8 | 84.8 | 98.0 | 112.1 | 128.4 |

## TABLE II.1.26 SERVICE INDUSTRIES

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Total Service Revenue | 1.26.1 | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .270 | .317 | .410 | .540 | .735 | 1.040 | 1.460 | 1.900 | 2.350 | 3.037 | 3.618 | 4.385 |
| 2. | Batch Data Processing | 1.26.1 | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .260 | .285 | .340 | .410 | .480 | .600 | .740 | .930 | 1.060 | 1.230 | 1.400 | 1.580 |
| 3. | On-Line Proc'sng–Tot. | 1.26.1 | $B | | | | | | | | | .005 | .010 | .015 | .020 | .050 | .120 | .210 | .330 | .440 | .590 | .750 | 1.105 |
| 4. | Remote Batch | | $B | | | | | | | | | | | | | | .010 | .050 | .090 | .130 | .180 | | |
| 5. | Interactive | | $B | | | | | | | | | .005 | .010 | .015 | .020 | .050 | .110 | .160 | .240 | .310 | .410 | | |
| 6. | Software–Total | 1.26.1 | $B | | | | | | | | | .005 | .020 | .050 | .100 | .175 | .270 | .360 | .440 | .450 | .717 | .868 | 1.000 |
| 7. | Custom | | $B | | | | | | | | | .005 | .020 | .050 | .100 | .165 | .245 | .315 | .365 | .350 | .436 | .473 | |
| 8. | Std. Packages | | $B | | | | | | | | | | | | | .010 | .025 | .045 | .075 | .100 | .281 | .395 | |
| 9. | Other | 1.26.1 | $B | | | | | | | | | | .002 | .005 | .010 | .030 | .050 | .150 | .200 | .400 | .500 | .600 | .700 |
| 10. | Number of Firms–Total | | | 24 | 31 | 31 | 70 | 150 | 210 | 310 | 370 | 440 | 520 | 665 | 750 | 900 | 1300 | 1300 | 1400 | 1500 | 1600 | 1700 | |
| 11. | Batch and On-Line | 1.26.4 | | 24 | 31 | 31 | 70 | 150 | 210 | 310 | 370 | 420 | 490 | 620 | 700 | 840 | 1000 | 1000 | 1050 | 1300 | | | |
| 12. | Revenue Per Firm–Total | | $k | 625 | 645 | 806 | 600 | 600 | 600 | 581 | 595 | 614 | 610 | 617 | 720 | 817 | 800 | 1123 | 1357 | 1567 | 1722 | 1900 | |
| 13. | Batch and On-Line | 1.26.4 | $k | 625 | 645 | 806 | 600 | 600 | 600 | 581 | 595 | 631 | 602 | 572 | 614 | 631 | 720 | 950 | 1200 | 1154 | | | |

files, and compute output data. The supplier then provides programs and operating procedures as well as computer power. Most service bureaus provide this kind of service, as do the newer business data processing timesharing services. Finally, a service may provide access to, and answer inquiries about, a file of general interest which is maintained by the supplier. Entertainment ticket services, stock market quotation systems, credit inquiry systems, and U.S. census data inquiry systems are examples.

6-8. The software industry has two parts. Some companies accept contracts to write special programs, uniquely designed to meet the requirements of a particular customer. The customer may be a user for whom an application program is written; or a system or peripheral manufacturer for whom an operating system, compiler, assembler, or peripheral handler is designed. Alternatively, the supplier can develop, with his own funds and at his own risk, a standard software package of some kind, and then offer it for sale in the marketplace. This "standard package" business came into its own after 1968. At that time IBM, which had previously offered a variety of software systems to its customer at no charge when they purchased IBM equipment, "unbundled" and began to charge for many programs which had previously been "free". Standard packages are perhaps better classified as products than as services, and it can be argued they should be summarized along with independent peripheral sales, not here in the "service" category.

The data on line 6 for the years up to 1971 comes from *EDP/IR* March 30, 1973. For 1969 to 1971, the data for lines 7 and 8 comes from *EDP/IR* November 30, 1972. Earlier data is my own extrapolation. (Incidentally, the October 11, 1973, *EDP/IR* shows 1969 software revenue at $.45B compared with the $.36B carried previously. I have stuck to the earlier version.) Data for 1972 and 1973 is from lines 26-28 below, and the 1974 data is an extrapolation therefrom.

A letter to the Editor of *Datamation* (April 1973, page 21) from Frank Wagner, Vice-President of Informatics, estimated 1972 programming revenue as follows. Custom Programming: Computer Science Corp. $60M; Systems Development Corp. $30M; five top software companies $40M; 100 small software firms $50M; ADAPSO members $80M; IBM $100M; total $360M. Software Packages: IBM (mostly System/3) $40M; other manufacturers $5M; Informatics $6M; ADR $4M; 50 other software firms $50M; banks selling to other banks $5M; total $110M.

9. "Other" services include facilities management (operating, and often designing, a customer's data processing system for him), education (of computer programmers, operators, maintenance men, etc. by special trade schools), and input/output services (keypunching of data, conversion of data to computer form by optical character readers, and the conversion of computer data to microfilm or to printed copy.) IDCServ72 and *EDP/IR* Oct. 11, 1973, are the sources of the data for 1966 to 1973; other data are my own extrapolations.

One final comment should be made about the 1971 figures. The AFIPS industry study previously referred to (GilcB73), which provided figures reportedly a concensus of several industry sources including IDC, gave the following figures for 1971: batch services, $950M; on-line services, $500M; software, $450M (not including $300M of government contract work); and education, $160M.

10-13. For 1966 and later, lines 10 and 11 are my own interpretations of data from IDCServ72 and DesJServ70 (the third annual industry study). For the years 1961 to 1965, my estimate of the number of firms was based on the estimated age of then existing firms, as given in those two reports. For 1958 through 1960, my estimate was based on the assumption that the average revenue per firm was $600k per year. For 1955 through 1957, my source was an article in *Computers and Automation* (MacDN58). Line 12 is the quotient of lines 1 and 10; line 13 is the quotient of lines 2 and 11. Note that, since the sources of 1955-1957 data for lines 10 and 11 are completely different from those of lines 1 and 2, the quotients on lines 12 and 13 may be misleading. Specifically, the 31 firms on line 11 which were providing services in 1957 were using 71 GP and minicomputers. (Two Bendix G-15's and two LGP-30's, in addition to 26 IBM 650's, four Electrodata Datatrons, three UNIVAC I's, etc.) The batch service revenue shown on line 2 may include income from a number of tabulating machine service companies–in which case the revenue per firm figures on lines 12 and 13 are meaningless.

14-21. These figures represent the ratios of lines 2 through 9 to line 1.

23-31. The eighth annual survey of the Service Industry (QSServ74) was prepared by Quantum Sciences Corp., and a summary of data from that report is presented here. As can be seen by comparing it with lines 1-9, there are large differences in many categories, and no published explanations (or even mentions) of the differences. Note that in general I have adopted IDC's figures, except for software expenditures where IDC stopped making estimates and the Quantum Science figures for earlier years are comparable to IDC's.

## TABLE 1.26.2 BATCH AND ON-LINE DATA PROCESSING FIRMS—NOTES

The source of data for this table is IDCServ71,72. The data for the 1230 smallest firms comes from the 1972 report, though some arithmetic errors in that report have been corrected in my table. The 1972 report provided some minimal information on the total population of firms, including the fact that there were 1300 firms in total with a total revenue of $1.481B (page 9), and that personnel costs and the cost of rental, depreciation, and maintenance of equipment accounted for 36.8% and 28.2% of the total costs of a sample 85 firms (page 13).

However, the later study gave no information on the structure of the 70 largest firms. The 1971 study, on the other hand, included a profile of all firms. In particular, it estimated the number of offices, employees, customers, and computers per firm for all the firms lumped together. I assumed that those ratios did not change from 1971 to 1972, and therefore adopted those four numbers as a starting point for further calculations. From those ratios, I computed how many offices, employees, customers, and computers all 1300 firms must have had in 1971. Knowing those numbers for the 1300 total firms and the 1320 smallest ones, I could compute corresponding figures for the 70 largest firms—and from that point all the ratios shown could easily be computed. For example: at an average of 81 employees per firm, the 1300 firms must have 105,300 total employees. The 1972 report indicates that the 1230 smallest firms had 47,720 employees; therefore the 70 largest firms must have had approximately 57,580 employees, for an average of 823 employees per firm.

One critical and unexplained anomaly occurs in the 1971 report: the ratios per firm are based on a total of 1050 firms having total revenues of $1.98B. The 1972 study shows the same total revenue generated by 1400 total firms. Thus the averages which I use as a basis for batch and on-line firms only may somehow have included other firms as well. The 1972 report supplies no information as to the reason for the change in the number of firms, and no comment on the ratios calculated in the previous report.

## TABLE II.1.26 SERVICE INDUSTRIES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Proportion of Total Revenue | | | | | | | | | | | | | | | | | | | | | | |
| 14. | Batch Data Processing | 1.26.2 | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 96 | 90 | 83 | 76 | 65 | 58 | 51 | 49 | 45 | 41 | 39 | 36 |
| 15. | On-Line Processing–Tot. | 1.26.3 | % | | | | | | | | | 2 | 3 | 4 | 4 | 7 | 12 | 14 | 17 | 19 | 19 | 21 | 25 |
| 16. | Remote Batch | 1.26.3 | % | | | | | | | | | | | | | | 1 | 3 | 5 | 6 | 6 | | |
| 17. | Interactive | 1.26.3 | % | | | | | | | | | 2 | 3 | 4 | 4 | 7 | 11 | 11 | 13 | 13 | 14 | | |
| 18. | Software–Total | 1.26.2 | % | | | | | | | | | 2 | 6 | 12 | 19 | 24 | 26 | 25 | 23 | 19 | 24 | 24 | 23 |
| 19. | Custom | | % | | | | | | | | | 2 | 6 | 12 | 19 | 22 | 24 | 22 | 19 | 15 | 14 | 13 | |
| 20. | Std. Packages | | % | | | | | | | | | | | | | 1 | 2 | 3 | 4 | 4 | 9 | 11 | |
| 21. | Other | 1.26.2 | % | | | | | | | | | | 1 | 1 | 2 | 4 | 5 | 10 | 11 | 17 | 16 | 17 | 16 |
| 22. | Tot. Rev., Excl. Software | 1.20.5 | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .265 | .297 | .360 | .440 | .560 | .770 | 1.100 | 1.460 | 1.900 | 2.320 | 2.750 | 3.385 |
| | 8th ADAPSO Report | | | | | | | | | | | | | | | | | | | | | | |
| 23. | Total Service Revenue | | $B | | | | | | .115 | | | | | .555 | | .918 | | | 1.930 | 2.287 | 2.956 | 3.769 | |
| 24. | Batch Data Processing | | $B | | | | | | .050 | | | | | .300 | | .500 | | | .610 | .650 | .749 | 1.020 | |
| 25. | On-Line Proc'sng | | $B | | | | | | | | | | | .005 | | .045 | | | .345 | .430 | .577 | .766 | |
| 26. | Software–Total | | $B | | | | | | .050 | | | | | .160 | | .200 | | | .400 | .467 | .717 | .868 | |
| 27. | Products | | $B | | | | | | | | | | | | | | | | | | .281 | .395 | |
| 28. | Services | | $B | | | | | | | | | | | | | | | | | | .436 | .473 | |
| 29. | Facilities Management | | $B | | | | | | .010 | | | | | .050 | | .110 | | | .500 | .645 | .799 | .977 | |
| 30. | Education | | $B | | | | | | .005 | | | | | .040 | | .060 | | | .055 | .050 | .058 | .070 | |
| 31. | Maintenance | | $B | | | | | | | | | | | | | .003 | | | .020 | .045 | .056 | .068 | |

## TABLE II.1.27 SUPPLIES—NOTES

Supplies includes the various materials required to operate a computer system. Categories normally included and discussed here are continuous forms, punched cards, magnetic tape, disk packs, and printer ribbons.

**Continuous Forms**. 1-3. The U.S. Department of Commerce collects data on the Manifold Business Forms industry under SIC Code 2761. The figures in line 1 are from ComIndOut and CenCenMan, and give the estimated shipment value of all Manifold Business Form products. Line 2 is from an analysis of U.S. Department of Commerce figures in CenCenMan. It represents the percentage of total continuous business forms shipments described as "imprinted stock", "stock", and "specially printed". It is these categories of forms which I presume are used by computer printers. (Another category, "continuous tabulating cards", is obviously also associated with computer printers. However, I have assumed it is included in the figures for tabulating card shipments, given below. In 1967 continuous tabulating card shipments amounted to $19.4M, or 2.2% of total forms shipments. The shipment value in 1963 was negligible—less than 0.5%.) The entries on line 3 for 1958, 1963, 1967, and 1972, are computed from lines 2 and 1. The other entries for 1964 and later were computed from line 1, assuming that the percentage of printer continuous forms increased smoothly in accordance with line 2.

4-5. The forms described above are presumably used both by computer printers and by tabulating equipment. In line 4 I perform a correction, applying the factor on line 31a of Table II.1.4.2 to the shipment values on line 3. (This correction assumes that the proportion of continuous printer paper value used by EDP equipment to total paper value is the same as the proportion of EDP keypunch operators to total keypunch operators—an admittedly tenuous assumption, but the only one I have found available.) Line 5 for 1958 and for 1963 and later was found by dividing line 4 by the number of line printers from Table II.1.22, line 83. The entries on line 5 for the years 1955-1957 and 1959-1962 are my own extrapolations; and the figures on line 4 for those same years are the products of line 5 and the number of line printers from Table II.1.22. (By way of check, the *EDP/IR* issue of April 9, 1971, gives the cost of "paper forms" used for computer supplies as $630M for 1970.)

**Tabulating Cards**. 6. Card prices per thousand cards for the years 1956 and 1970 are from WilsJ70. They represent prices for "large quantity" purchases, and the 1970 figure is reportedly from a GSA contract. The other figures on this line are my own interpolation—I have found no other source of data. The 1972-1974 data was derived from telephone calls to IBM and to local card users.

7-8. The figures on line 7 are from CenCenMan. They represent the sum of the two categories "continuous tabulating cards" and "tabulating card sets". Line 8 is the quotient of line 7 and the number of punched card units from line 75 of Table II.1.22. (Note I assume every "unit" includes a punch.)

9. The number of cards per year punched by EDP keypunch operators is based on the number of EDP keypunches and verifiers in use from line 5 of Table II.1.23. For simplicity, I assume that 73% of the total "keypunches and verifiers" are keypunches, that there are an average of 1.2 operators per keypunch, and that an operator punches 100 cards per hour, or 208,000 cards per year. Note that line 9 is in billions of cards.

10. The shipment value of the cards on line 9 is computed by multiplying line 9 by line 6. Note that this computation assumes that all keypunch cards are purchased as individual cards. In fact, of course, some proportion of the cards used on keypunch machines were originally continuous tab cards (for example, bills printed by a line printer, separated and mailed to individual customers, and returned by the customers with their payment), or tabulating card sets (for example, charge account bills signed by the customer at the point of sale, where the tab card is detached and sent to the computer center so that bills can be prepared). These cards, whose total value is shown in line 7 above, have a much higher cost per card than that shown in line 6. However, I know no way of estimating what proportion of these card forms are actually keypunched.

11-14. There seems to be very little available data on total punched card sales, and the figures shown on these lines are based on some very shaky assumptions and some very sparse data. The "card sets" (i.e. carbon-paper forms which include a card as one element) and "continuous card forms" (i.e. cards supplied in sheets which can be printed by a line printer and then separated for further use) described on lines 7-8 above represent only a small fraction of total card revenues—most cards used are sold as individual units, by the thousand. To derive a history of card costs, I start with the *EDP/IR* estimate of April 9, 1971, that $310M was the value of punched cards shipped in 1970. I reduce that to the $282M figure shown on line 11 by applying the same correction factor to the $310M which was described in connection with line 4 above—thus eliminating punched card shipments associated with tabulating equipment. I then subtract the value of cards shipped for keypunch use ($42M, from line 10), thus obtaining the value of cards presumably punched by computer punches. I divide that number by the number of punched card units in use in 1970 (from Table II.1.22, line 75) to get the result on line 13—that $5,820 was spent in 1970 to supply cards to each computer card punch. I hope it is clear that, at this point, lines 11-13 contain only the three numbers in the 1970 column.

I now ask myself how the card cost per punch has changed over the years. The only evidence I have is that shown on line 8, for tab card forms; and that data is not really applicable because those forms are, it would seem, mostly fed to card readers, keypunch machines, and OCR units rather than computer punches. Nevertheless, I conclude there has been a slight increase with time in the dollar cost of cards per card punch unit; and I compute entries on line 13 for the period 1955-1972 starting with the 1970 entry and assuming a constant growth rate of 0.3% per year in card cost per punch. (Because of the large increase in unit card costs in 1973-1974, however, I assume usage per punch fixed at the 1970 value of 7.3 million per year (line 14) and compute dollar value from that figure for those two years.) I can then compute line 12 by multiplying line 13 by the number of card units in use each year, and line 11 by adding lines 10 and 12. Finally, the number of cards per punch on line 14 is computed by dividing line 13 by line 6.

**Magnetic Tape Reels**. 15. I have found no published source of data on computer tape prices. I found good agreement

## TABLE II.1.27 SUPPLIES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous Forms** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | US Dept of Comm–Tot Biz Forms | | $M | | | | 374.0 | | | | | 598.4 | 631.9 | 700.2 | 793.7 | 895.8 | 990.6 | 1113.5 | 1199.1 | 1242.3 | 1381.9 | 1551. | 1784. |
| 2. | Percent Printer Cont. Forms | | % | | | | 33.1 | | | | | 40.1 | | | | 46.0 | | | | | 49.7 | | |
| 3. | Shipments | | $M | | | | 123.9 | | | | | 239.7 | 262. | 301. | 353. | 412.1 | 475. | 557. | 609. | 625. | 686.5 | 775 | 900 |
| 4. | Cont. Forms for EDP | 1.27.2 | $M | 2 | 6 | 12 | 22 | 34 | 50 | 73 | 98 | 144 | 173 | 217 | 268 | 330 | 394 | 490 | 554 | 581 | 652 | 750 | 880 |
| 5. | Per Line Printer | 1.27.2 | $k/yr | 16.4 | 16.2 | 16.0 | 15.8 | 15.6 | 15.3 | 15.1 | 14.8 | 14.6 | 11.9 | 11.4 | 10.5 | 10.0 | 9.9 | 10.3 | 10.7 | 9.8 | 10.2 | 10.8 | 12.1 |
| | **Tabulating Cards** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Card Cost/1000–80 By. | 1.27.5 | $/k | 1.28 | 1.24 | 1.20 | 1.15 | 1.10 | 1.06 | 1.02 | .99 | .95 | .91 | .87 | .84 | .82 | .81 | .80 | .80 | .80 | .80 | 1.00 | 2.00 |
| 6a. | 96-Byte | | | | | | | | | | | | | | | | | | | | .55 | .75 | |
| 7. | Tab Card Forms | | $M | | | | | | | | | 17.3 | | | | 56.3 | | | | | 64.2 | | |
| 8. | Per EDP Punch | | $k/yr | | | | | | | | | 1.80 | | | | 1.82 | | | | | 1.34 | | |
| 9. | No. Cards for EDP Keyp. | | B | .3 | .8 | 1.4 | 2.3 | 3.5 | 4.9 | 7.0 | 9.1 | 13 | 19 | 25 | 33 | 39 | 44 | 49 | 52 | 56 | 58 | 65 | 63 |
| 10. | Ship Value of Cards | 1.27.3 | $M | .4 | 1.0 | 1.7 | 2.6 | 3.9 | 5.2 | 7.1 | 9.0 | 12 | 17 | 22 | 28 | 33 | 36 | 39 | 42 | 45 | 46 | 65 | 126 |
| 11. | Ship Value of All Cards | 1.27.3 | $M | 1.1 | 3.2 | 6.0 | 10.3 | 15.9 | 23.3 | 33.9 | 45.8 | 67 | 97 | 127 | 168 | 212 | 240 | 268 | 282 | 312 | 324 | 438 | 895 |
| 12. | Ship Value Comp Punched Cards | | $M | .7 | 2.2 | 4.3 | 7.7 | 12.0 | 18.1 | 26.8 | 36.8 | 55 | 80 | 105 | 140 | 179 | 204 | 229 | 240 | 267 | 278 | 373 | 769 |
| 13. | Per Card Punch | | $k/yr | 5.56 | 5.58 | 5.60 | 5.61 | 5.63 | 5.65 | 5.67 | 5.68 | 5.70 | 5.72 | 5.73 | 5.75 | 5.77 | 5.79 | 5.80 | 5.82 | 5.84 | 5.85 | 7.30 | 14.60 |
| 14. | No. Cards Per Card Punch | | M | 4.3 | 4.5 | 4.7 | 4.9 | 5.1 | 5.3 | 5.6 | 5.7 | 6.0 | 6.3 | 6.6 | 6.8 | 7.0 | 7.1 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 |
| | **Magnetic Tape Reels** | | | | | | | | | | | | | | | | | | | | | | |
| 15. | MT Cost Per Reel | 1.27.5 | $ | 50 | 50 | 50 | 50 | 50 | 50 | 47 | 44 | 40 | 36 | 32 | 28 | 24 | 15 | 12.5 | 11 | 10 | 9 | 9 | 9 |
| 16. | Tapes Per Drive In Use | 1.27.6 | | | 20 | 30 | 40 | 50 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 |
| 17. | Total Tapes In Use | 1.27.7 | M | | .004 | .021 | .060 | .145 | .372 | .912 | 1.720 | 3.048 | 5.208 | 7.95 | 11.99 | 16.98 | 20.75 | 23.16 | 25.90 | 28.56 | 30.78 | 33.41 | 37.23 |
| 18. | Net Tapes Shipped | | M | | .004 | .017 | .039 | .085 | .227 | .540 | .808 | 1.328 | 2.160 | 2.74 | 4.04 | 4.99 | 3.77 | 2.41 | 2.74 | 2.66 | 2.22 | 2.63 | 3.82 |
| 19. | Replacement Tapes Shipped | | M | | | | | | | .004 | .017 | .039 | .085 | .23 | .54 | .81 | 1.33 | 2.16 | 2.74 | 4.04 | 4.99 | 3.77 | 2.41 |
| 20. | Total Tapes Shipped | | M | | .004 | .017 | .039 | .085 | .227 | .544 | .825 | 1.367 | 2.245 | 2.97 | 4.58 | 5.80 | 5.10 | 4.57 | 5.48 | 6.70 | 7.21 | 6.40 | 6.23 |
| 21. | Shipment Value | 1.27.4 | $M | | .2 | .9 | 2.0 | 4.3 | 11.4 | 25.6 | 36.3 | 54.7 | 80.8 | 95 | 128 | 139 | 77 | 57 | 60 | 67 | 65 | 58 | 56 |
| 22. | Tot. Tape Capy.–Off-Line | 1.27.8 | MMBy | | .02 | .11 | .30 | .73 | 3.24 | 9.67 | 20.30 | 37.80 | 66.14 | 106 | 173 | 265 | 342 | 394 | 451 | 500 | 542 | 591 | 659 |
| | **Disk Packs**, Domestic | | | | | | | | | | | | | | | | | | | | | | |
| | Packs in Use, Per Spindle | | | | | | | | | | | | | | | | | | | | | | |
| 23. | For 2311-Type Spindles | 1.27.6 | | | | | | | | | | | | 1.7 | 2.6 | 3.9 | 6.6 | 8.3 | 10.4 | 11.2 | 9.7 | 9.3 | 9.1 |
| 24. | For 2314/2319 | 1.27.6 | | | | | | | | | | | | | | 2.0 | 3.8 | 4.4 | 4.8 | 4.3 | 4.3 | 4.4 | 4.4 |
| 25. | For 3330 | 1.27.6 | | | | | | | | | | | | | | | | | | 2.9 | 2.4 | 3.5 | 3.7 |
| 26. | For 2310/5444 | | | | | | | | | | | | | | 1 | 1.4 | 1.7 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| 27. | 2311–Total Spindles | | k | | | | | | | | | | | 1.2 | 7.8 | 15.8 | 21.2 | 26.6 | 25.0 | 21.4 | 19.3 | 16.2 | 15.7 |
| 28. | For 2311–Packs in Use | 1.27.7 | k | | | | | | | | | | | 2 | 20 | 61 | 140 | 222 | 260 | 241 | 188 | 150 | 143 |
| 29. | Packs Shipped | | k | | | | | | | | | | | 2 | 18 | 41 | 79 | 82 | 38 | | | | |
| 30. | Price Per Pack | 1.27.5 | $ | | | | | | | | | | | 490 | 450 | 400 | 350 | 300 | 300 | | | | |
| 31. | Shipped Value | | $M | | | | | | | | | | | 1.0 | 8.1 | 16.4 | 27.7 | 24.6 | 11.4 | | | | |
| 32. | 2314–Total Spindles | | | | | | | | | | | | | | | 5.5 | 17.6 | 36.1 | 58.4 | 73.9 | 71.0 | 61.8 | 52.8 |
| 33. | For 2314/9–Packs in Use | 1.27.7 | k | | | | | | | | | | | | | 11 | 67 | 160 | 278 | 318 | 301 | 272 | 232 |
| 34. | Packs Shipped | | k | | | | | | | | | | | | | 11 | 56 | 93 | 118 | 40 | - | | |
| 35. | Price Per Pack | 1.27.5 | $ | | | | | | | | | | | | | 650 | 600 | 500 | 400 | 350 | - | | |
| 36. | Shipped Value | | $M | | | | | | | | | | | | | 7.2 | 33.6 | 46.5 | 47.2 | 14.0 | - | | |
| 37. | 3330–Total Spindles | | | | | | | | | | | | | | | | | | | 3.5 | 16.6 | 20.1 | 29.7 |
| 38. | For 3330–Packs in Use | 1.27.7 | k | | | | | | | | | | | | | | | | | 10 | 40 | 70 | 110 |
| 39. | Packs Shipped | | k | | | | | | | | | | | | | | | | | 10 | 30 | 30 | 40 |
| 40. | Price Per Pack | 1.27.5 | $ | | | | | | | | | | | | | | | | | 1000 | 1000 | 850 | 700 |
| 41. | Shipped Value | | $M | | | | | | | | | | | | | | | | | 10.0 | 30.0 | 25.5 | 28.0 |
| 42. | For 2310/5444–Packs in Use | | k | | | | | | | | | | | | .3 | 1.4 | 2.7 | 3.6 | 5.0 | 9.2 | 14.4 | 21.2 | 23.6 |
| 43. | Packs Shipped | | k | | | | | | | | | | | | .3 | 1.1 | 1.3 | .9 | 1.4 | 4.2 | 5.2 | 6.8 | 2.4 |
| 44. | Price Per Pack | | $ | | | | | | | | | | | | 90 | 90 | 90 | 90 | 170 | 175 | 175 | 175 | 175 |
| 45. | Shipped Value | | $M | | | | | | | | | | | | | .1 | .1 | .1 | .2 | .7 | .9 | 1.2 | .4 |

between two completely independent private sources for large-quantity prices over the period 1966-1974, and for those years the table follows those sources. The earlier figures are based on my personal experience in the early sixties, and on the unsupported assumption that prices were a constant $50 during the fifties. Average prices of a 2400 foot reel of computer tape are assumed.

16. The figures on tape reels per drive for years 1968 to 1970 come from a private report of a survey of computer users. The other figures represent an unsupported extrapolation on my part.

17-21. Total tapes in use, on line 17, is the product of tapes per drive on line 16 and the number of tape units in use from line 25 of Table II.1.22. Line 18 is the difference between adjacent entries on line 17—for example, the net number of tape reels shipped in 1966 is the difference between the 11.99 million in use at the end of 1966 and the 7.95 million in use at the end of 1965. The numbers on line 18, however, do not include tapes shipped for replacement purposes. I have arbitrarily assumed that the tapes in use have an average useful life of five years; and therefore I enter in line 19, as replacement shipments, the total number of tapes shipped five years earlier from line 20. Thus the entry on line 19 for the year 1961 is the same as that on line 20 for 1956. Line 20 itself is the sum of lines 18 and 19—total tapes shipped is the sum of the new tapes required and the replacement tapes necessary. Note that this series of assumptions about the history of tape shipments leads to a satisfying coincidence: 1968 was the first year in the history of the tape business that the number of reels shipped represented a decrease from the previous years' shipments. It was also a year which saw an extraordinary 37% drop in tape prices—the implication being that a sudden drop in demand forced a price reduction. Finally, shipment value on line 21 is the product of lines 15 and 20.

22. Total capacity of off-line tapes was computed by multiplying the number of tapes in use (line 17 above) by the average capacity per tape in use (line 34 from Table II.1.22). Note that this storage capacity is based on the assumption that 2400 foot reels of tape are completely filled with 1,000-character blocks of data.

**Disk Packs.** 23-26. I found very little published data on disk pack sales or usage, and the information shown in the table comes primarily from two sources. The first source was a private survey of disk drive users. For the 2311-type packs, it indicated that the number of packs per drive increased from about 5.0 in 1965, 1966, and 1967 to 7.0 in 1969. It also reported that the number of disk packs per 2314-type spindle increased from about 2.0 in 1967 to 2.7 in 1969. These figures were derived from a survey of about 100 disk drive users. Incidentally, it was this same survey which provided data on the number of magnetic tape reels in inventory per tape drive.

My second source was a study carried out in late 1972 for an independent peripheral manufacturer. It estimated the number of disk packs of each type in use, both domestically and internationally. This latter analysis agreed moderately well with the first one with regards to the 2311-type drives, and not very well concerning the 2314-type. However, because it is a later and more comprehensive survey than the former, I have largely adopted its conclusions. Data after 1972 represents my own extrapolations.

The number of disk packs in use per spindle on lines 23 through 25 are actually derived from lines 28, 33, and 38, which were the estimates of disk packs in use from the second study. Line 23, for example, is the quotient of line 28 and line 27, the total number of spindles in use from Table II.1.22. (This estimate of total spindles includes both the IBM and IBM compatible 2311's, and a fraction of the non-IBM moving-head-files. To estimate this fraction, I assumed that the non-IBM equipment included 2311-type spindles in the same proportion as IBM's 2311's are to IBM's total moving-head-file inventory. I made the same kind of assumption about non-IBM moving-head-files in computing the total number of 2314-type and 3330-type spindles on lines 32 and 37.) The number of disk packs per spindle on the 2310 and 5444 files (line 26) is a completely unsupported estimate on my part. I could find no data, private or public, on these disk packs.

27-45. For each of the four spindle types, these lines contain a derivation of the value of disk packs shipped. I first list the total number of spindles in use, from Table II.1.22 (suitably modified to include the use of non-IBM spindles, as described above). I then list total packs in use, which is the product of total spindles and disk packs per spindle. (As was stated above in connection with lines 23-26, the packs per spindle were actually computed from total packs in use for the 2311's, 2314's, and 3330's. However, the packs in use for the 2310's/5444 were computed by multiplying the assumed number of packs per spindle on line 26 by the number of IBM spindles from Table II.1.22.) The number of packs shipped per year I then computed by difference between the total packs in use on successive years. For example, the 38,000 2311-type packs shipped in 1970 (line 29) is the difference between the 260k packs in use at the end of 1970 and the 222k packs in use at the end of 1969. Selling prices per pack for the 2311- and 2314-type packs (lines 30 and 35) start in each case with the initial IBM offering price. Subsequent prices I estimated by interpolation from these initial prices to the prices for independent (non-IBM) manufacturers as given in *EDP/IR* of April 9, 1971. That issue showed $500 and $350 as the 1969 and 1971 prices for 2314 packs; and $300 and $200 for the prices of 2311 packs for those same years. The price for the 3330 pack (line 40) was derived from conversations with a small sample of local users. The 2310/5444 prices on line 44 are IBM prices. The increase in price from 1969 to 1971 reflects my estimate of the change in mix between 2310 disk packs (at $90) and 5444 packs (at $175).

The value of packs shipped, on lines 31, 36, 41, and 45, is then computed by multiplying price per pack by number of packs shipped.

46-58. Moving-head-files are, of course, used on systems throughout the world—though I have not here attempted to estimate the number of spindles installed outside the United States. However, disk packs for those spindles are manufactured by American companies, and the private report described above estimated the number of packs in use for 2311's, 2314's and 3330's—as shown on lines 46, 50, and 54. From these numbers, I deduced the number of packs shipped; and computed the value of the packs shipped by multiplying by price per pack. The price per pack data I used assumes that pack prices abroad in the nth shipment year for a given pack are the same as domestic prices in the nth domestic shipping year. Since

## TABLE II.1.27 SUPPLIES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | International Business | | | | | | | | | | | | | | | | | | | | | | |
| 46. | For 2311–Tot. Packs in Use | | k | | | | | | | | | | | | | 10 | 30 | 60 | 100 | 130 | 150 | 130 | 120 |
| 47. | Packs Shipped | | k | | | | | | | | | | | | | 10 | 20 | 30 | 40 | 30 | 20 | | |
| 48. | Price Per Pack | | $ | | | | | | | | | | | | | 490 | 450 | 400 | 350 | 300 | 300 | | |
| 49. | Shipped Value | | $M | | | | | | | | | | | | | 4.9 | 9.0 | 12.0 | 14.0 | 9.0 | 6.0 | | |
| 50. | For 2314–Tot. Packs in Use | | k | | | | | | | | | | | | | | 10 | 30 | 80 | 160 | 210 | 250 | 210 |
| 51. | Packs Shipped | | k | | | | | | | | | | | | | | 10 | 20 | 50 | 80 | 50 | 40 | |
| 52. | Price Per Pack | | $ | | | | | | | | | | | | | | 650 | 600 | 500 | 400 | 350 | 350 | |
| 53. | Shipped Value | | $M | | | | | | | | | | | | | | 6.5 | 12.0 | 25.0 | 32.0 | 17.5 | 14.0 | |
| 54. | For 3330–Tot. Packs in Use | | k | | | | | | | | | | | | | | | | | 5 | 10 | 20 | 30 |
| 55. | Packs Shipped | | k | | | | | | | | | | | | | | | | | 5 | 5 | 10 | 10 |
| 56. | Price Per Pack | | $ | | | | | | | | | | | | | | | | | 1000 | 1000 | 850 | 700 |
| 57. | Shipped Value | | $M | | | | | | | | | | | | | | | | | 5.0 | 5.0 | 8.5 | 7.0 |
| 58. | For 2310/5444–Shipped Value | | $M | | | | | | | | | | | | | | .1 | .1 | .1 | .2 | .4 | .5 | .6 |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| | Domestic | | | | | | | | | | | | | | | | | | | | | | |
| 59. | Total Packs in Use | 1.27.6 | k | | | | | | | | | | | 2 | 20 | 73 | 210 | 386 | 543 | 578 | 543 | 513 | 509 |
| 60. | Total Packs Shipped | | k | | | | | | | | | | | 2 | 18 | 53 | 136 | 176 | 157 | 54 | 35 | 37 | 42 |
| 61. | Total Shipped Value | 1.27.4 | $M | | | | | | | | | | | 1.0 | 8.1 | 23.7 | 61.4 | 71.2 | 58.8 | 24.7 | 30.9 | 26.7 | 28.4 |
| | International | | | | | | | | | | | | | | | | | | | | | | |
| 62. | Total Packs in Use | | k | | | | | | | | | | | | | 10 | 40 | 90 | 180 | 295 | 370 | 400 | 360 |
| 63. | Total Packs Shipped | | k | | | | | | | | | | | | | 10 | 30 | 50 | 90 | 115 | 75 | 50 | 10 |
| 64. | Total Shipped Value | | $M | | | | | | | | | | | | | 4.9 | 15.6 | 24.1 | 39.1 | 46.2 | 28.9 | 23.0 | 7.6 |
| | Worldwide | | | | | | | | | | | | | | | | | | | | | | |
| 65. | Total Packs in Use | | k | | | | | | | | | | | 2 | 20 | 83 | 250 | 476 | 723 | 873 | 913 | 913 | 869 |
| 66. | Total Packs Shipped | | k | | | | | | | | | | | 2 | 18 | 63 | 166 | 226 | 247 | 169 | 110 | 87 | 52 |
| 67. | Total Shipped Value | | $M | | | | | | | | | | | 1.0 | 8.1 | 28.6 | 77.0 | 95.3 | 97.9 | 70.9 | 59.8 | 49.7 | 36.0 |
| | Off-Line Disk Pack Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 68. | 2311-Type at 7.5MBy | | MMBy | | | | | | | | | | | .02 | .15 | .46 | 1.05 | 1.67 | 1.95 | 1.81 | 1.41 | 1.13 | 1.07 |
| 69. | 2314-Type at 25.5MBy | | MMBy | | | | | | | | | | | | | .28 | 1.71 | 4.08 | 7.09 | 8.11 | 7.68 | 6.93 | 5.92 |
| 70. | 3330-Type at 100MBy | | MMBy | | | | | | | | | | | | | | | | | 1.00 | 4.00 | 7.00 | 11.00 |
| 71. | 2310/5444 Av. Capy. Per Disk | | MBy | | | | | | | | | | | | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3.2 | 3.4 |
| 72. | Off-Line Capacity | | MMBy | | | | | | | | | | | | | | | | .01 | .03 | .04 | .07 | .08 |
| 73. | Total Off-Line Capacity | 1.27.8 | MMBy | | | | | | | | | | | .02 | .15 | .74 | 2.76 | 5.75 | 9.05 | 10.95 | 13.13 | 15.13 | 18.07 |
| | **Print Ribbons** | | | | | | | | | | | | | | | | | | | | | | |
| 74. | Shipment Value | | $M | | | | | 1 | 1 | 1 | 2 | 2 | 3 | 4 | 6 | 8 | 9 | 11 | 12 | 14 | 15 | 16 | 17 |
| 75. | Per Line Printer | | $k | .32 | .31 | .30 | .29 | .28 | .27 | .26 | .25 | .24 | .23 | .23 | .23 | .23 | .23 | .23 | .23 | .23 | .23 | .23 | .23 |

my source indicates that the first year of international shipments lagged the first year of domestic shipments for the 2311's and 2314's, my assumption leads to a price differential between domestic and overseas shipments in the first years. The 2310/5444 disk pack shipped value on line 58 is an estimate based on domestic shipments on line 45.

59-67. Total packs in use, total packs shipped, and the total shipped value of disk packs are the sums of the corresponding figures for 2311-type, 2314/19-type, 3330-type, and 2310/5444-type packs from the data above on domestic business. Similarly, the international figures are corresponding sums from the "international business" section of the table; and the worldwide figures are the sums of the domestic and international numbers.

In addition to my usual warnings about the uncertainty of data presented here, let me submit a couple of other comments. First, note that the data indicates that domestic shipments of a given model disk pack stop soon after a new model moving-head-file is introduced. In fact, of course, shipments do not end so abruptly, though the number of disk packs in use drops from the end of one year to the end of the next. In such a year, when no new spindles are shipped, nevertheless a variety of disk pack shipments occur. Customers who still have the old spindle may add disk packs, thus increasing their inventory per spindle. They may also take delivery of additional spindles, along with disk packs to go with them. Simultaneously, some users are selling their owned spindles, or returning rented ones to the manufacturer, and are simultaneously selling or returning associated disk packs. The disk pack manufacturer may thus still be shipping packs in the years in which I show zero shipments. By ignoring shipments in these years, I am in effect counting the shipment of newly-manufactured packs only.

However, by keeping international and domestic shipments separate, I run the risk of overstating total shipments. Consider, for example, shipment of disk packs for the 2311. Looking at the years 1970 and 1971, we see that the total number of packs in use—domestic and international—is 360k and 371k, respectively (the sum of lines 28 and 46). Therefore, if all surplus domestic disk packs were returned and shipped abroad, the total new shipments for 1971 would be 11k packs. By keeping the two categories separate, I show a total shipment of 30k packs (the sum of lines 29 and 47 for the year 1971).

A second difficulty centers around the problem of estimating the dollar value of shipments. To begin with, disk packs are both purchased and leased—in the sample of 100 file users referred to previously, for example, 50 leased their packs, 25 purchased them, and the other 25 purchased some packs and leased others. My figures are for shipments, not revenues, and assume that all disks shipped are sold. Furthermore, the prices I used generally represent the lowest prices available in the marketplace. Since many disk packs are sold or leased by IBM, which maintains a substantially higher selling price, I am in effect understating shipment value by some difficult-to-determine amount.

68-73. Off-line disk pack capacity is computed by multiplying the number of (domestic) disk packs in use each year by the capacity shown in the table headings on lines 68-70. For the 2310/5444, I used an average capacity as shown on line 71. That capacity increases between 1969 and 1971 as the 5444 (shipped with IBM's System 3) becomes important. Total off-line capacity on line 73 is the sum of lines 68, 69, 70, and 72.

**Print Ribbons.** 74-75. The data presented here is once again based on the flimsiest of sources—a private report estimating that $11M of print ribbons were shipped for EDP use in 1969. Dividing that number by the number of line printers in use from Table II.1.22, I conclude (line 75) that $230 per printer was spent in that year for ribbons. I next assume that print ribbon costs per printer and continuous forms costs per printer must have followed similar trends—a bold and, as usual, unsupported assumption. Looking back at line 5 of the present table, we see that forms cost per printer has been relatively constant since 1964, and was about 50% higher in 1955. I therefore made the entries shown on line 75, assuming a constant $230 per printer since 1964, and a drop from $320 per printer during the years 1955-1964. Multiplying these numbers by the number of line printers in use from Table II.1.22, I find the remaining numbers on line 74.

**Summary.** 76-87. Shipments for each of the major categories of supplies, as shown on lines 76 through 80, are copied from earlier entries in this table. Line 81 is the sum of lines 76 through 80. Line 82 is the quotient of line 81 and the number of GP systems in use from Table II.1.21. Lines 83 through 87 are the ratios of lines 76 through 80 to line 81.

88-90. Line 88 is the sum of total domestic shipments on line 81 and international disk pack shipments on line 64. Note it does not include international shipments of printing paper, tabulating cards, magnetic tape, or print ribbons. Line 89 shows supplies shipments from various issues of the Annual Review and Forecast of *EDP/IR*. It appears that the *EDP/IR* figures include shipments of printing paper and tabulating cards for tabulating machines as well as for computers–it must be for that reason that shipments in the early years are so high. For comparative purposes, here are some *EDP/IR* (or IDC) break-downs for the years 1970 and 1971.

From *EDP/IR* April 9, 1971: disk pack sales, $115M; punched cards, $310M; magnetic tape reels, $90M; paper forms, $630M; other, $25M; total, $1.17B.

From Standard and Poor's *Industrial Surveys*, dated April, 1973, page O 20: (IDC is given as the source. For each category, sales were given for 1970 and for 1971, and I quote the sales in that same sequence) Paper forms, $570M, $600M; tabulating cards, $275M, $292M; disk packs, $76M, $86M; magnetic tapes reels, $85M, $78M; other, $12M, $21M; and totals, $1.018B, $1.077B. Note that the 1970 total published in Standard and Poor's is different from that published earlier in *EDP/IR*, but is the same as the later *EDP/IR* figure shown on line 88 of the table.

Line 90 is the sum of lines 22 and 73.

## TABLE II.1.27 SUPPLIES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Summary** | | | | | | | | | | | | | | | | | | | | | | |
| | Shipments | | | | | | | | | | | | | | | | | | | | | | |
| 76. | Continuous Forms | | $M | 2 | 6 | 12 | 22 | 34 | 50 | 73 | 98 | 144 | 173 | 217 | 268 | 330 | 394 | 490 | 554 | 581 | 652 | 750 | 880 |
| 77. | Tabulating Cards | | $M | 1 | 3 | 6 | 10 | 16 | 23 | 34 | 46 | 67 | 97 | 127 | 168 | 212 | 240 | 268 | 282 | 312 | 324 | 438 | 895 |
| 78. | Magnetic Tape | | $M | | | 1 | 2 | 4 | 11 | 26 | 36 | 55 | 81 | 95 | 128 | 139 | 77 | 57 | 60 | 67 | 65 | 58 | 56 |
| 79. | Disk Packs (Domestic) | | $M | | | | | | | | | | | 1 | 8 | 24 | 61 | 71 | 59 | 25 | 31 | 27 | 28 |
| 80. | Print Ribbons | | $M | | | | | 1 | 1 | 1 | 2 | 2 | 3 | 4 | 6 | 8 | 9 | 11 | 12 | 14 | 15 | 16 | 17 |
| 81. | Total | 1.27.1 | $B | .003 | .009 | .019 | .034 | .055 | .085 | .134 | .182 | .268 | .354 | .444 | .578 | .713 | .781 | .897 | .967 | .999 | 1.087 | 1.289 | 1.876 |
| 82. | Per GP System in Use | | $k | 13 | 13 | 15 | 16 | 18 | 19 | 22 | 22 | 23 | 21 | 21 | 20 | 20 | 19 | 20 | 20 | 18 | 19 | 21 | 29 |
| | Percentages Of Total | | | | | | | | | | | | | | | | | | | | | | |
| 83. | Continuous Forms | 1.27.1 | % | 67 | 67 | 63 | 65 | 62 | 59 | 54 | 54 | 54 | 49 | 49 | 46 | 46 | 50 | 55 | 57 | 58 | 60 | 58 | 47 |
| 84. | Tabulating Cards | 1.27.1 | % | 33 | 33 | 32 | 29 | 29 | 27 | 25 | 25 | 25 | 27 | 29 | 29 | 30 | 31 | 30 | 29 | 31 | 30 | 34 | 48 |
| 85. | Magnetic Tape | 1.27.1 | % | | | 5 | 6 | 7 | 13 | 19 | 20 | 21 | 23 | 21 | 22 | 19 | 10 | 6 | 6 | 7 | 6 | 4 | 3 |
| 86. | Disk Packs (Domestic) | 1.27.1 | % | | | | | | | | | | | | 1 | 3 | 8 | 8 | 6 | 3 | 3 | 2 | 1 |
| 87. | Print Ribbons | | % | | | | | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Comparisons | | | | | | | | | | | | | | | | | | | | | | |
| 88. | Shipments, incl. WW Disk Packs | | $B | .003 | .009 | .019 | .034 | .055 | .085 | .134 | .182 | .268 | .354 | .444 | .578 | .718 | .797 | .921 | 1.006 | 1.045 | 1.116 | 1.312 | 1.884 |
| 89. | Shipments, EDP/IR | | $B | .155 | .175 | .195 | .230 | .270 | .370 | .485 | .530 | .595 | .630 | .660 | .725 | .805 | .895 | .995 | 1.020 | 1.075 | 1.180 | | |
| 90. | Total Tape/Disk Off-Line Capy. | | MMBy | | .02 | .11 | .30 | .73 | 3.24 | 9.67 | 20.30 | 37.80 | 66.14 | 106 | 173 | 266 | 345 | 400 | 460 | 511 | 555 | 606 | 677 |

## TABLE II.1.28 WORLDWIDE COMPUTER INDUSTRY—NOTES

**Computers In Use.** 1-38. In these lines I present a variety of estimates on the numbers of mini and GP computers installed in various countries, together with my resulting consensuses. Citations not explicitly discussed here (for example, BruiW66,67 on line 1) are listed and described in the Bibliography.

5, 9, 13. The computer counts on these lines come from several sources. The 1961 and 1966 figures are from OECDGapCtrs69. The 1962 figures are from DataCens62, and are counts as of July 1 of 1962. The 1963-1965 figures on from *ADP/N* dated December 9, 1963, April 26, 1965, and June 6, 1966. The censuses for 1967, 1969, 1971, and 1974 are from *EDP/IR* dated July 24, 1968, July 27, 1970, December 17, 1971, and October 24, 1975, respectively. The 1968 figure is from SelCom71, volume 3. (The source given is IDC's *EDP Europa Report.*)

10. My source for data on British installations is a tabulation sent to me by Derek Pedder, consulting editor for the British *Computer Survey* magazine. The tabulation summarizes total installations by machine type and manufacturer.

15-22. Data for the years 1955-1960 is from BruiW66. The 1961, 1966, 1967, 1969, 1971, and 1974 figures have the same sources as those for lines 5, 9, and 13 as described above. BDCom7/68 is the source for the 1962-1964 figures, and CompC68 for the 1968 figures. Line 22 is the sum of lines 15 through 21.

23-27. Western Europe includes, in addition to the countries listed on lines 1 through 21 above, the following additional countries: Finland, Norway, Austria, Greece, Ireland, and Portugal. The *EDP/IR* figures on line 26 are from the July 24, 1968 issue along with the four issues mentioned in the discussion of lines 5, 9, and 13 above.

28-29. The Russian and East European figures for 1969 are from *EDP/IR* July 27, 1970; and the 1970 and 1972 figures are from the July 27, 1973, issue. (The 8,000 installations for 1972 are there described as Russia's "plan", and no actual installation figures are given.) The 1971 numbers are from the December 15, 1971 issue of *Datamation* magazine, which contains four articles on EDP in Europe.

30-34. Japanese censuses typically are taken as of a day of the year other than December 31. Thus the numbers on lines 30 and 32 are as of March 31 of each year. And those on line 33 are as of the end of September. The sources for line 33 are BDComm12/68 and 4/72 for the 1967 and 1971 figures, respectively; *EDP/IR* of October 24, 1975, for the 1974 figures; JCUsag70 and 71 for the remaining figures. The consensus on line 34 is intended to be as of December 31 of each year.

35-38. The Australian numbers are from ThorB75. A news item in the May 4, 1970 issue of *Electronic News* provided the 1970 figure for Brazil; the 1971 figure comes from *EDP/IR* of December 17, 1971; and the 1973 figure is from BarqR74. The 1970 figure for Canada is from the November 15, 1971 issue of *Electronic News*, and the 1969, 1971 and 1974 figures come from *EDP/IR* of July 27, 1970, December 17, 1971, and October 24, 1975. The 1964-1968 data is an interpolation from LeeW71. The South African figure is also from *EDP/IR* of Dec. 17, 1971.

39-43. The French, UK, West Germany, and total West Europe figures are copied from lines 6, 10, 14, and 27 above. "Other West Europe" on line 42 was found by subtracting the sum of lines 39 through 41 from line 43.

44, 47. The Japanese entry is copied from line 34 above, and that for the United States comes from Table II.1.21.

48. I computed the 1969 and 1971 world total figures by starting with the *EDP/IR* world censuses published in the July 27, 1970 and December 17, 1971 issues (104,750 and 142,400, respectively), and adjusting those figures where necessary to take into account differences between my entries for France, the United Kingdom, West Germany, Japan, and the United States, and those of *EDP/IR*. Earlier figures for the world total I computed based on the assumption that the United States has supplied 90% of all the computers installed in countries other than the five mentioned in the last sentence. Thus I computed the world total of 68,600 for 1967 as follows: 19,400 American made computers were installed outside of the United States in 1967 (line 66 below); 6,826 of them were installed in France, the United Kingdom, West Germany, and Japan (line 76 below); thus 12,574 were installed in other countries; since, by my assumption, that represented 90% of the total, I conclude that 14,000 computers were installed worldwide outside of the above five countries; 5,509 of these were installed in other countries in Western Europe (line 42) therefore the 8,500 machines shown on line 45 must have been installed in other countries (14,000 minus 5,500); the world total on line 48 is then the sum of lines 43, 44, 45, and 47. The data and assumptions are, as usual, subject to various criticisms. One obvious difficulty is apparent when we look at the 1971 figures. If my assumptions about U.S. installations in the three major European countries and Japan are correct, then 28,770 American made computers are installed in "other countries" (line 77). However, if the *EDP/IR* figure of 150,000 installations (line 48) is correct, we deduce, by subtracting American installations, that there are 61,000 non-U.S. installations (line 46), and (by subtracting West European and Japanese totals) 17,000 "other international" computers (line 45). But then the number of computers in use outside of France, the U.K., West Germany, Japan, and the United States is 27,700 (the sum of lines 42 and 45); and this number is less than the independently calculated number of American computers in those countries (line 77). Clearly, something is wrong—perhaps the world total is too low, perhaps my figures on the number of American computers installed in the major countries are wrong, perhaps my numbers for total European installations are wrong.

49-52. These figures show the ratio of lines 47, 43, 44, and 45 to line 48.

53-57. Computers per million population is the ratio of the number of computers on lines 47, 39, 40, 41, and 44 above, to the population of the various countries in millions.

58-65. Similarly, computers per billion dollars of gross national product is computed by dividing the various computer populations by GNP's for the various countries and areas. The GNP figures are from Table II.1.1.2.

**U.S. Manufacturers' Number in Use.** 66-67. Line 66 is copied from Table II.1.21; line 67 is the ratio of line 66 to line 46. Note that this percentage is strongly influenced by my assumption that 90% of all installations outside the

## TABLE II.1.28 WORLDWIDE COMPUTER INDUSTRY

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Computers in Use | | | | | | | | | | | | | | | | | | | | | | |
| 1. | France—BruiW66,67 | | | 5 | 10 | 15 | 35 | 65 | 165 | 275 | 520 | 790 | 1050 | 1250 | 1850 | 2600 | | | | | | | |
| 2. | BDComm2/70 | | | | | | | | | | 524 | 778 | 1058 | 1624 | 2323 | 3430 | 5010 | | | | | | |
| 3. | BDComm1/72 | | | | | | | | | | | | | | | 2927 | 3731 | 4365 | 5460 | | | | |
| 4. | BDComm7/68 | | | | | | | | | | 455 | 681 | 1043 | 1568 | 2008 | | | | | | | | |
| 5. | Misc. Sources | | | | | | | | | 285 | 342 | 556 | 1043 | 1578 | 2008 | 2980 | 4200 | 4500 | | 6700 | | | 16107 |
| 6. | Consensus | | | 5 | 10 | 15 | 35 | 65 | 165 | 285 | 460 | 700 | 1050 | 1500 | 2000 | 2920 | 3730 | 4500 | 5460 | 6700 | | | 16100 |
| 7. | United Kingdom—BruiW66,67 | | | 15 | 35 | 75 | 130 | 170 | 240 | 340 | 510 | 750 | 1100 | 1400 | 2150 | 2850 | | | | | | | |
| 8. | BDComm7/68 | | | | | | | | | | 480 | 670 | 1160 | 1600 | 2252 | | | | | | | | |
| 9. | Misc. Sources | | | | | | | | | 312 | 389 | 934 | | 1890 | 2252 | 3020 | 3990 | 5900 | | 7600 | | | 14424 |
| 10. | Pedder | | | 13 | 24 | 62 | 116 | 153 | 217 | 314 | 502 | 740 | 1120 | 1582 | 2134 | 2971 | 4008 | 5083 | 6269 | 6802 | | | 14400 |
| 11. | West Germany—BruiW66,67 | | | 5 | 10 | 20 | 85 | 145 | 190 | 390 | 640 | 980 | 1460 | 1800 | 2700 | 3800 | | | | | | | |
| 12. | BDComm7/68 | | | | | | | | | | 690 | 1019 | 1657 | 2291 | 2963 | 3800 | | | | | | | |
| 13. | Misc. Sources | | | | | | | | | 548 | 472 | 996 | 1657 | 2523 | 2963 | 4150 | 4640 | 6070 | | 7800 | | | 18843 |
| 14. | Consensus | | | 5 | 10 | 20 | 85 | 200 | 300 | 500 | 690 | 1020 | 1650 | 2300 | 2960 | 3800 | 4640 | 6070 | 7000 | 7800 | | | 18800 |
| | Other European—Various Sources | | | | | | | | | | | | | | | | | | | | | | |
| 15. | Belgium & Luxembourg | | | | | 5 | 10 | 20 | 37 | 71 | 115 | 170 | 220 | 295 | 385 | 560 | 590 | 650 | | 1050 | | | |
| 16. | Denmark | | | | | | | 1 | 5 | 10 | 30 | 65 | 100 | 140 | 186 | | 365 | | | 390 | | | |
| 17. | Italy | | | | 5 | 10 | 25 | 55 | 90 | 165 | 295 | 430 | 710 | 1000 | 1360 | 1710 | 873 | 2730 | | 3300 | | | 7675 |
| 18. | Netherlands | | | 1 | 2 | 5 | 20 | 30 | 40 | 69 | 141 | 185 | 228 | 338 | 553 | 620 | 504 | 1080 | | 1680 | | | |
| 19. | Spain | | | | | | | 1 | 2 | | 25 | 40 | 60 | 75 | 95 | | 211 | | | 720 | | | 2050 |
| 20. | Sweden | | | | | 5 | 10 | 15 | 35 | 46 | 100 | 160 | 225 | 300 | 404 | | 519 | | | 800 | | | |
| 21. | Switzerland | | | | | 5 | 10 | 25 | 30 | 50 | 125 | 200 | 275 | 360 | 420 | 560 | 920 | 870 | | 750 | | | 2975 |
| 22. | Subtotal | | | 1 | 7 | 30 | 75 | 147 | 239 | | 831 | 1245 | 1818 | 2508 | 3403 | | 3982 | | | 8690 | | | |
| 23. | Western Europe—BruiW66,67 | | | 27 | 63 | 143 | 336 | 548 | 866 | 1555 | 2625 | 4000 | 5605 | 6960 | 10300 | 14360 | | | | | | | |
| 24. | BDComm7/68 | | | | | | | | | | 2561 | 3815 | 5993 | 8422 | 11273 | | | | | | | | |
| 25. | CounEur71 | | | | | | | | 1000 | 1600 | 2500 | 3800 | 6000 | 7500 | 10700 | 15140 | 18500 | 22000 | | | | | |
| 26. | EDP/IR | | | | | | 370 | 610 | 1000 | 1600 | 2500 | 3800 | 6000 | 7500 | 10710 | 15140 | | 24380 | | 32000 | | | 74770 |
| 27. | Consensus | | | 27 | 63 | 140 | 340 | 610 | 1000 | 1650 | 2620 | 3900 | 6000 | 8400 | 11250 | 15200 | 18500 | 24000 | 28000 | 32000 | | | 74800 |
| 28. | USSR | | | | | | | | | | | | | | | | | 4500 | 4500 | 7000 | 8000 | | |
| 29. | East Europe | | | | | | | | | | | | | | | | | 630 | | 1510 | | | |
| 30. | Japan—LeviG67 | | | | | | 3 | 11 | 37 | 103 | 222 | 450 | 935 | 1497 | 2133 | 2978 | | | | | | | |
| 31. | CounEur71 | | | | | | | | | | | | | 1455 | | 3559 | 4132 | 5601 | 6718 | | | | |
| 32. | EDP/IR 9/15/71 | | | | | | | | | | | | | | 1937 | 2606 | 3546 | 4870 | 6718 | 9482 | | | |
| 33. | Various Sources | | | | | | | | | | | | | | | 3040 | 4132 | 5601 | 7933 | 11237 | | | 26069 |
| 34. | Consensus | | | | | | 9 | 35 | 85 | 200 | 440 | 825 | 1350 | 1870 | 2525 | 3340 | 4540 | 6240 | 8800 | 12000 | | | 26100 |
| | Other Countries | | | | | | | | | | | | | | | | | | | | | | |
| 35. | Australia | | | | | | | | 34 | 58 | 102 | 137 | 217 | 348 | 487 | 608 | 714 | 863 | 1121 | 1421 | 1772 | 2136 | 2420 |
| 36. | Brazil | | | | | | | | | | | | | | | | | | 500 | 730 | | 754 | |
| 37. | Canada | | | | | | | | | | | | 630 | 830 | 1130 | 1470 | 1800 | 3000 | 2700 | 3800 | | | 6158 |
| 38. | South Africa | | | | | | | | | | | | | | | | | | | 480 | | | |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| 39. | France | 1.28.1 | | 5 | 10 | 15 | 35 | 65 | 165 | 285 | 460 | 700 | 1050 | 1500 | 2000 | 2920 | 3730 | 4500 | 5460 | 6700 | | | 16100 |
| 40. | United Kingdom | 1.28.1 | | 13 | 24 | 62 | 116 | 153 | 217 | 314 | 502 | 740 | 1120 | 1582 | 2134 | 2971 | 4008 | 5083 | 6269 | 6802 | 6725 | | 14400 |
| 41. | West Germany | 1.28.1 | | 5 | 10 | 20 | 85 | 200 | 300 | 500 | 690 | 1020 | 1650 | 2300 | 2960 | 3800 | 4640 | 6070 | 7000 | 7800 | | | 18800 |
| 42. | Other West Europe | | | 4 | 19 | 43 | 104 | 192 | 318 | 551 | 968 | 1440 | 2180 | 3018 | 4156 | 5509 | 6122 | 8347 | 9271 | 10698 | | | 25500 |
| 43. | Total West Europe | 1.28.2 | | 27 | 63 | 140 | 340 | 610 | 1000 | 1650 | 2620 | 3900 | 6000 | 8400 | 11250 | 15200 | 18500 | 24000 | 28000 | 32000 | | | 74800 |
| 44. | Japan | 1.28.1 | | | | | 9 | 35 | 85 | 200 | 440 | 825 | 1350 | 1870 | 2525 | 3340 | 4540 | 6240 | 8800 | 12000 | | | 26100 |
| 45. | Other International | 1.28.2 | k | .03 | | .15 | | .35 | | .5 | | .66 | | 2.28 | | 8.5 | | 10.7 | | 17.0 | | | 34.1 |
| 46. | Total Non-U.S. | | k | .06 | | .29 | .58 | 1.0 | | 2.35 | | 5.39 | | 12.55 | 18.70 | 27.0 | 33.0 | 40.9 | | 61.0 | | | 135.0 |

five major countries were manufactured by American companies.

68-71. The percent of total installations by American manufacturers for France and West Germany for the years 1961 and 1966 come from OECDGapCtrs69. The French figure for 1962, and the West German figures for 1962 and 1969 are from CounEur71. Other figures on lines 68 and 70 are my own extrapolations. Incidentally, the percentages shown are the ratios of computers manufactured by American-based companies to total computers in use. I exclude computers manufactured under license to American companies. In the case of France, I exclude the computers manufactured by Bull/GE, along with those identified (in "Gaps in Technology") as being manufactured by NCR/Elliott. The Council of Europe Report (CounEur71) shows 91% of French installations by American companies in 1969, and I have rejected it because I believe it includes Bull/GE as an American company. The American international installations on line 66 do not include the Bull machines.

The UK figures on line 69 are computed from the tabulation described in connection with line 10 above. The percentages given on line 71 for Japan are from LeviG67 (for the years 1958 through 1965) and from BDComm4/72 (for 1966 through 1971). Line 71a is the ratio of total U.S. computers in use, worldwide, from Table II.1.21, to the World Total on line 48.

72-77. Lines 72 through 75 were computed by applying the percentages of lines 60 through 71 to the number of installations on line 39 through 41 and 44. Line 76 is the sum of line 72 through 75. Line 77 is the difference between line 66 and line 76, and thus identifies the American computers which are installed in countries other than France, the UK, West Germany, Japan, and the United States.

**U.S. Balance of Trade.** 78-80. U.S. exports of computers, parts, and accessories is from CenStatAb. It is in agreement with data for the years 1958 through 1966 in OECDGapCtrs69, which also is the source of the data processing import data on line 79. However, in 1973 CenStatAb revised and restated the earlier figures for exports, generally increasing them. I have used the old figures for the years through 1971, and the revised data thereafter. Line 80 is the difference between lines 78 and 79.

81-83. Annual American shipments abroad, on line 81, is from Table II.1.21, and includes both GP and minicomputers. Line 82, the assumed value of data processing equipment manufactured by American companies overseas, is the difference between lines 81 and 78; and line 83 is the ratio of line 82 to line 81, and shows the proportion of the total American shipments which are manufactured abroad.

84-85. Total U.S. exports are the exports of merchandise manufactured in the United States, and comes from CenStatAb. Line 85, giving computer exports as a percent of the total, is the ratio of line 78 to line 84.

## TABLE II.1.28 WORLDWIDE COMPUTER INDUSTRY

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47. | United States | 1.28.2 | | 240 | 750 | 1500 | 2550 | 3810 | 5400 | 7550 | 9900 | 13800 | 19200 | 24700 | 32300 | 41600 | 50500 | 62100 | 74060 | 89015 | 107080 | 133250 | 165040 |
| 48. | World Total | 1.28.2 | k | .3 | | 1.79 | 3.13 | 4.81 | | 9.90 | | 19.19 | | 37.3 | 51.0 | 68.6 | 83.5 | 103 | | 150 | | | 300 |
| 49. | Percent of World Tot.–US | 1.28.3 | % | 80 | | 84 | | 79 | | 76 | | 72 | | 66 | | 61 | | 60 | | 59 | | | 55 |
| 50. | Western Europe | 1.28.3 | % | 9 | | 8 | | 13 | | 17 | | 20 | | 23 | | 22 | | 23 | | 21 | | | 25 |
| 51. | Japan | 1.28.3 | % | 0 | | 0 | | 1 | | 2 | | 4 | | 5 | | 5 | | 6 | | 8 | | | 9 |
| 52. | Other International | 1.28.3 | % | 11 | | 8 | | 7 | | 5 | | 4 | | 6 | | 12 | | 10 | | 11 | | | 11 |
| | **Computers Per Million Pop.** | | | | | | | | | | | | | | | | | | | | | | |
| 53. | United States | 1.28.4 | no/M | 1.5 | 4.5 | 8.8 | 14.6 | 21.4 | 29.9 | 41.1 | 53.0 | 72.9 | 99.9 | 126.9 | 164.0 | 208.9 | 251.0 | 305.6 | 361.4 | 429.8 | 512.8 | 633.3 | 778.9 |
| 54. | France | 1.28.4 | no/M | .1 | .2 | .3 | .8 | 1.4 | 3.6 | 6.2 | 9.8 | 14.6 | 21.7 | 30.7 | 40.5 | 58.5 | 74.7 | 89.5 | 107.5 | 130.6 | | | 306.7 |
| 55. | United Kingdom | 1.28.4 | no/M | .3 | .5 | 1.2 | 2.2 | 2.9 | 4.1 | 5.9 | 9.4 | 13.8 | 20.7 | 29.0 | 38.9 | 53.9 | 72.5 | 91.6 | 113.8 | 122.1 | | | 257.1 |
| 56. | West Germany | 1.28.4 | no/M | .1 | .2 | .4 | 1.6 | 3.6 | 5.4 | 8.9 | 12.1 | 17.7 | 28.3 | 39.0 | 49.6 | 63.4 | 77.1 | 99.8 | 113.6 | 127.2 | | | 303.2 |
| 57. | Japan | 1.28.4 | no/M | | | | .1 | .4 | .9 | 2.1 | 4.6 | 8.6 | 13.9 | 19.0 | 25.5 | 33.3 | 44.9 | 61.0 | 85.1 | 114.6 | | | 237.9 |
| | **Computers Per Bil. $ GNP** | | | | | | | | | | | | | | | | | | | | | | |
| 58. | United States | 1.28.5 | no/$B | .6 | 1.8 | 3.4 | 5.7 | 7.9 | 10.7 | 14.5 | 17.7 | 23.4 | 30.4 | 36.3 | 43.1 | 52.4 | 58.3 | 66.8 | 76.0 | 84.7 | 92.5 | 102.9 | 118.1 |
| 59. | France | | no/$B | | | | .7 | | | | | 8.4 | | 15.2 | 18.5 | 25.2 | 29.4 | 32.1 | 37.7 | 41.1 | | | 54.0 |
| 60. | United Kingdom | | no/$B | | | | 1.8 | | | | | 11.4 | | 15.8 | 19.9 | 27.0 | 38.9 | 46.2 | 52.7 | 50.4 | | | |
| 61. | West Germany | | no/$B | | | | 1.5 | | | | | 10.6 | | 20.4 | 24.1 | 30.0 | 34.4 | 39.7 | 37.2 | 35.6 | | | 45.6 |
| 62. | Europe | 1.28.5 | no/$B | | | | 1.2 | | | | | 9.1 | | 16.4 | 20.3 | 25.9 | 30.2 | 35.4 | 36.8 | 37.1 | | | |
| 63. | Japan | 1.28.5 | no/$B | | | | .3 | | | | | 12.1 | | 21.3 | 24.8 | 27.8 | 32.0 | 37.4 | 44.4 | 52.4 | | | 59.6 |
| 64. | World | | no/$B | | | | 3.2 | | | | | 13.8 | | 22.6 | 28.4 | | 40.5 | 45.4 | | | | | |
| 65. | Non-U.S. | 1.28.5 | no/$B | | | | 1.1 | | | | | 6.8 | | 13.2 | 18.1 | | 28.0 | 30.5 | | | | | |
| | **US Manufact'ers No In Use** | | | | | | | | | | | | | | | | | | | | | | |
| 66. | International Inst'lns by U.S. | | | 6 | 55 | 200 | 400 | 690 | 1100 | 1600 | 2450 | 3650 | 5600 | 8700 | 13200 | 19400 | 24900 | 30200 | 36940 | 45410 | 55790 | 71550 | 90800 |
| 67. | Percent of all Int'l | | % | | | 69 | | 69 | | 68 | | 68 | | 69 | | 72 | | 74 | | 74 | | | 67 |
| 68. | % by U.S. Mfgrs.–France | 1.28.6 | % | 50 | 50 | 50 | 50 | 50 | 50 | 48.7 | 49.1 | 50 | 50 | 50 | 50.5 | 50 | 50 | 50 | 50 | 50 | | | |
| 69. | United Kingdom | 1.28.6 | % | | | | 7.7 | 9.8 | 11.1 | 16.9 | 30.3 | 34.2 | 39.1 | 46.5 | 50.6 | 52.2 | 52.3 | 51.2 | 49.3 | 49.5 | 50.2 | | |
| 70. | West Germany | 1.28.6 | % | 70 | 70 | 70 | 70 | 70 | 70 | 70.1 | 73.9 | 73 | 72 | 72 | 72.1 | 74 | 76 | 78 | 78 | 78 | | | |
| 71. | Japan | 1.28.6 | % | | | | 33 | 55 | 62 | 56 | 59 | 49 | 45 | 44 | 35 | 30 | 28 | 27 | 29 | 32 | | | |
| 71a. | Worldwide | | % | 82.0 | | 95.0 | 93.6 | 93.6 | | 92.4 | | 90.9 | | 87.5 | 89.2 | 88.9 | 90.3 | 89.6 | | 89.6 | | | |
| 72. | Number by US Mfgrs–France | | | 2 | 5 | 7 | 17 | 32 | 82 | 139 | 226 | 350 | 525 | 750 | 1010 | 1460 | 1865 | 2250 | 2730 | 3350 | | | |
| 73. | United Kingdom | | | 1 | 1 | 4 | 9 | 15 | 24 | 53 | 152 | 253 | 438 | 736 | 1090 | 1552 | 2096 | 2600 | 3092 | 3366 | 3377 | | |
| 74. | West Germany | | | 3 | 7 | 14 | 60 | 140 | 210 | 350 | 510 | 745 | 1188 | 1656 | 2134 | 2812 | 3526 | 4735 | 5460 | 6084 | | | |
| 75. | Japan | | | | | | 3 | 19 | 53 | 112 | 260 | 404 | 608 | 823 | 884 | 1002 | 1271 | 1685 | 2552 | 3840 | | | |
| 76. | Subtotal | | | 6 | 13 | 25 | 89 | 206 | 369 | 654 | 1148 | 1752 | 2759 | 3965 | 5118 | 6826 | 8758 | 11270 | 13834 | 16640 | | | |
| 77. | Other Countries | | | - | 42 | 175 | 311 | 484 | 731 | 946 | 1302 | 1898 | 2841 | 4735 | 8082 | 12574 | 16142 | 18930 | 23106 | 28770 | | | |
| | **U.S. Balance of Trade** | | | | | | | | | | | | | | | | | | | | | | |
| 78. | US Comp. Equip. Exports | 1.28.7 | $B | | | | .018 | .023 | .048 | .110 | .136 | .187 | .218 | .223 | .295 | .432 | .485 | .728 | 1.104 | 1.261 | 1.341 | 1.717 | 2.198 |
| 79. | Imports | 1.28.7 | $B | | | | | | .004 | .005 | .008 | .010 | .019 | .025 | .043 | | | | | | | | |
| 80. | Net Exports | | $B | | | | .018 | .023 | .044 | .105 | .128 | .177 | .199 | .198 | .252 | | | | | | | | |
| 81. | US Intrn'l. DP Shipm'ts | 1.28.8 | $B | .002 | .014 | .040 | .065 | .105 | .130 | .200 | .318 | .502 | .777 | 1.190 | 1.785 | 2.345 | 2.255 | 2.470 | 2.790 | 2.930 | 3.295 | 3.675 | 4.245 |
| 82. | Manufactured Overseas | | $B | | | | .047 | .082 | .082 | .090 | .182 | .315 | .559 | .967 | 1.490 | 1.913 | 1.770 | 1.742 | 1.686 | 1.669 | 1.954 | 1.958 | 2.047 |
| 83. | Proportion of Total | 1.28.8 | % | | | | 72.3 | 78.1 | 63.1 | 45.0 | 57.2 | 62.7 | 71.9 | 81.3 | 83.5 | 81.6 | 78.5 | 70.5 | 60.4 | 57.0 | 59.3 | 53.3 | 48.2 |
| 84. | Total U.S. Exports | | $B | 15.42 | 18.95 | 20.68 | 17.75 | 17.45 | 20.40 | 20.75 | 21.43 | 23.10 | 26.30 | 27.18 | 29.99 | 31.24 | 34.20 | 37.46 | 42.59 | 43.49 | 48.98 | 70.25 | 97.14 |
| 85. | Comp. Export–% of Tot. | 1.28.7 | % | | | | 0.10 | 0.13 | 0.24 | 0.53 | 0.63 | 0.81 | 0.83 | 0.82 | 0.98 | 1.38 | 1.42 | 1.94 | 2.59 | 2.90 | 2.74 | 2.44 | 2.26 |

## II.1.3 Companies

In Table II.1.20, we reviewed estimates of hardware shipments, and of revenues from various segments of the data processing industry. The tables in this section contain information on some of the companies which participated in and contributed to industry growth. In Table II.1.30 we briefly touch on important and interesting companies which supply systems, peripherals, and supplies. In subsequent tables we examine the operations of specific companies in more detail.

### TABLE II.1.30 DATA PROCESSING INDUSTRY REVENUES—NOTES

**System Manufacturer's Revenues.** 1-137. In this section of the table, we examine the revenues of the system manufacturers (that is, the companies which manufacture and market CPU's and related products) from three points of view: In lines 1 through 10 we record summaries, basically compiled by IDC; in lines 11 to 109 we record the total revenue of major companies, and the percentages they have variously reported as representing the data processing part of their business; and on lines 110 to 137 we compute revenue from previously-recorded data on annual shipments and value in use, making various assumptions about the ratio of system sales and leases.

1-3. Line 1 describes worldwide revenues from the sale and lease of GP systems by U.S. manufacturers. Data for 1960 to 1972 comes from various issues of *EDP/IR's* Annual Review and Forecast. The figures for 1955 through 1959 are my own estimates, computed as 50% of the annual shipment rate. Estimates for 1973 and 1974 are based on line 135 below—*EDP/IR* stopped publishing revenue figures in 1973. Minisystem revenues, on line 2, are the same as minisystem shipments on line 23 of Table II.1.20—consistent with the assumption that most minisystems have been sold, not leased, so that shipment value and annual revenues are the same thing. Line 3 is the sum of lines 1 and 2, and line 2a is the ratio of line 2 to line 3.

4-10. Lines 4 through 10 come from the December 31, 1971 issue of *EDP/IR*. The source is given as "annual reports, quarterly statements, proxy statements, internal modeling techniques, and Wall Street estimates." *EDP/IR* describes the data on line 6 as "total worldwide EDP revenue of U.S.-based mainframe manufacturers", but gives no further definition. Since the figures given here are larger than *EDP/IR's* figures for worldwide revenue from general purpose and minisystems (for example, the March 30, 1972 *EDP/IR* shows a GP and mini revenue total of \$8.02B for 1970, compared with the \$8.475B in line 6), the "EDP revenue" presumably includes income from data processing services and supplies, as well as from the sale and lease of equipment. Lines 8a and 9a are the ratios of line 8 to line 4, and line 9 to line 5, respectively.

11-48. The revenue figures in this portion of the table come from annual reports, 10K reports, MoodI, and S&PCR. Comments on other sources are as follows:

11-13. See Table II.1.310, lines 1-28.

14-16. See Table II.1.312. The total of lines 15 and 16 was reported by CDC as "data processing products" up until 1965. I have assumed that total has dropped in recent years as CDC's service revenue became more important (1973 and later figures of course reflect a substantial increase in service revenues, due to the purchase from IBM of the Service Bureau Corporation). The distribution between mini and GP revenues is discussed in connection with line 85 below.

18-20. See Table II.1.313. The breakdown between GP and mini revenue is my own, and is discussed further in connection with line 87 below.

22-24. General Electric's computer revenue is given on line 44 of Table II.1.310, in connection with the analysis of Honeywell, Inc. However, only data for the four years 1966-1969 was provided. Earlier figures are my own estimate, based on an assumed uniform increase in percentages, starting in 1960. The estimate of the percent of GE's revenue from computer services, on line 24, is my own.

26. See discussion in connection with line 89 below.

27-29. See Table II.1.310, lines 29-48. The sum of lines 28 and 29 comes from line 35 of that table. Line 29 is derived from and discussed in connection with line 90 below; and line 28 is the difference between line 29 and the total.

31-35. See Table II.1.311. The sum of lines 32 and 33 are IBM's "data processing systems revenue" as shown on line 3 of that table.

36-38. See Table II.1.310, lines 49 to 66.

39-40. In RCAAR71, RCA reported its computer sales for all of 1970 and for the first nine months of 1971 as \$.266B and \$.182B, respectively. (It also reported corresponding losses of \$.016B and \$.034B.) I used these figures in computing the numbers for 1970 and 1971 on line 40. For earlier years, I computed RCA's assumed revenue from the "value shipped" and "value in use" figures of Table II.1.31, assuming that RCA's annual lease revenue was 24% of the lease value in use, and that 90% of RCA's equipment was under lease, with 10% being sold each year.

42-43. See Table II.1.310, lines 67 to 84.

44-45. The derivation of line 45 is discussed in connection with line 94 below.

46-48. Line 46a is the ratio of line 46b, XDS total revenue, to line 46, Xerox Corp. total revenue. Lines 47 and 48 are the percentages of total XDS revenue attributable to GP and minisystems. The minisystem percentage, on line 48, is discussed further in connection with line 95 below.

**Total DP System Revenue.** 49-64. These figures represent, as best as one is able to deduce from information supplied by the companies, the total dollar value of revenue from the sale or lease of data processing hardware by the major companies in the industry. In general, data processing system revenue includes a variety of things other than revenue from GP and minisystems. Accounting and tabulating machines in particular are not uniformly treated in this table. IBM, for example, has never distinguished tabulating machine revenue from computer revenue, so both categories are included in line 58 (see Table II.1.311). NCR, on the other hand, has in recent years distinguished "data processing system" revenues from "accounting machine" revenues (see Table II.1.310, lines 56 and 57). Generally speaking, of course, the effect of including non-computer revenues is much more important in the early years than it is today. If we compare lines 3 and 66 of this Table, the effect is obvious: total revenue from data processing activities was

## TABLE II.1.30 DATA PROCESSING INDUSTRY REVENUES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **System Manuf. Revenues** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | From GP Systems | 1.31.24 | $B | .030 | .080 | .190 | .220 | .290 | .420 | .845 | 1.210 | 1.760 | 2.250 | 2.700 | 3.735 | 4.895 | 6.910 | 7.145 | 7.645 | 8.355 | 9.740 | 10.3 | 11.7 |
| 2. | From Minisystems | 1.31.24 | $B | | .003 | .010 | .014 | .020 | .030 | .030 | .038 | .092 | .127 | .180 | .165 | .175 | .240 | .355 | .375 | .400 | .600 | .815 | 1.210 |
| 2a. | % of Total | 1.31.24 | % | | 3.6 | 5.0 | 6.0 | 6.5 | 6.7 | 3.4 | 3.0 | 5.0 | 5.3 | 6.3 | 4.2 | 3.5 | 3.4 | 4.7 | 4.7 | 4.6 | 5.8 | 7.3 | 9.4 |
| 3. | Total Revenue | 1.31.24 | $B | .030 | .083 | .200 | .234 | .310 | .450 | .875 | 1.248 | 1.852 | 2.377 | 2.880 | 3.900 | 5.070 | 7.150 | 7.500 | 8.020 | 8.755 | 10.340 | 11.1 | 12.9 |
| 4. | WW EDP Revenue–IBM | 1.31.26 | $B | | | | | | | | | | | | 2.603 | 3.562 | 4.873 | 4.935 | 5.195 | 5.400 | | | |
| 5. | Non-IBM | 1.31.27 | $B | | | | | | | | | | | | 1.479 | 1.874 | 2.329 | 3.032 | 3.280 | 3.547 | | | |
| 6. | Total | | $B | | | | | | | | | | | | 4.082 | 5.436 | 7.202 | 7.967 | 8.475 | 8.947 | | | |
| 7. | Non-IBM GP Systems | | $B | | | | | | | | | | | | 1.314 | 1.699 | 2.089 | 2.677 | 2.905 | 3.147 | | | |
| 8. | WW Pre-Tax-Income–IBM | 1.31.26 | $B | | | | | | | | | | | | .627 | .843 | 1.343 | 1.389 | 1.412 | 1.403 | | | |
| 8a. | % of IBM Rev. | 1.31.26 | % | | | | | | | | | | | | 24.1 | 23.7 | 27.6 | 28.1 | 27.2 | 26.0 | | | |
| 9. | Non-IBM (Net) | 1.31.27 | $B | | | | | | | | | | | | d.088 | .012 | .123 | .168 | .034 | .073 | | | |
| 9a. | % of Non-IBM Rev. | 1.31.27 | % | | | | | | | | | | | | d5.9 | 0.6 | 5.3 | 5.5 | 1.0 | 2.1 | | | |
| 10. | Total | | $B | | | | | | | | | | | | .539 | .855 | 1.466 | 1.557 | 1.446 | 1.476 | | | |
| | **Revenue Breakdowns** | | | | | | | | | | | | | | | | | | | | | | |
| 11. | Burroughs–Tot. Rev. | | $B | .220 | .273 | .283 | .294 | .359 | .389 | .399 | .423 | .387 | .390 | .457 | .490 | .551 | .651 | .752 | .884 | .933 | 1.040 | 1.284 | 1.533 |
| 12. | % GP Systems | 1.31.35 | % | 10 | 12 | 14 | 16 | 18 | 20 | 23 | 26 | 29 | 31 | 34 | 37 | 40 | 42 | 49 | 54 | 53 | 60 | 58 | 60 |
| 13. | % Supplies | | % | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 11 | 10.9 | 10.2 | 9.4 | 9.5 | 9.5 | 9.5 | 10.5 |
| 14. | Control Data Corp.–Tot. Rev. | | $B | | | | .001 | .005 | .010 | .020 | .041 | .063 | .121 | .161 | .168 | .245 | .388 | .571 | .540 | .571 | .664 | .948 | 1.101 |
| 15. | % GP Systems | 1.31.35 | % | | | | | | 20 | 40 | 63 | 64 | 84 | 88 | 86 | 85 | 86 | 86 | 86 | 85 | 85 | 80 | 75 |
| 16. | % Mini Systems | 1.31.35 | % | | | | | | 50 | 40 | 24 | 32 | 10 | 5 | 6 | 6 | 4 | 3 | 2 | 2 | 1 | 1 | 1 |
| 17. | Data General–Tot. Rev. | | $B | | | | | | | | | | | | | | | .001 | .007 | .015 | .030 | .053 | .083 |
| 18. | Digital Equip. Corp.–Tot. Rev. | | $B | | | | | | | | .007 | .010 | .011 | .015 | .023 | .039 | .057 | .088 | .135 | .147 | .188 | .265 | .422 |
| 19. | % GP Systems | | % | | | | | | | | | | 4 | 21 | 13 | 10 | 11 | 17 | 15 | 18 | 20 | 20 | 20 |
| 20. | % Mini Systems | | % | | | | | | | | | | 45 | 42 | 53 | 62 | 84 | 77 | 74 | 77 | 75 | 75 | 75 |
| 21. | General Automation–Tot. Rev. | | $B | | | | | | | | | | | | | | | | .005 | .011 | .016 | .030 | .061 |
| 22. | General Electric–Tot. Rev. | | $B | 3.464 | 4.090 | 4.336 | 4.121 | 4.350 | 4.198 | 4.457 | 4.793 | 4.919 | 4.941 | 6.214 | 7.176 | 7.737 | 8.380 | 8.447 | 8.727 | 9.425 | 10.239 | 11.575 | 13.413 |
| 23. | % GP Systems | 1.31.34 | % | | | | | | 0.5 | 1. | 1.5 | 2. | 2.5 | 3.00 | 3.47 | 4.07 | 4.26 | 4.87 | 0 | 0 | 0 | 0 | 0 |
| 24. | % Services | | % | | | | | | | | | | | | | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 | | |
| 25. | Hewlett Packard–Tot. Rev. | | $B | | | | | | .060 | .086 | .109 | .115 | .124 | .164 | .205 | .243 | .269 | .324 | .347 | .375 | .479 | .661 | .884 |
| 26. | % Mini Systems | | % | | | | | | | | | | | | 0 | 0.4 | 3.0 | 10.8 | 12.4 | 6.1 | 5.2 | 9.8 | 11.9 |
| 27. | Honeywell–Tot. Rev. | | $B | .244 | .288 | .325 | .328 | .381 | .426 | .470 | .596 | .648 | .667 | .735 | .914 | 1.045 | 1.281 | 1.426 | 1.921 | 1.951 | 2.125 | 2.391 | 2.626 |
| 28. | % GP Systems | 1.31.33 | % | | | | | | 0.9 | 3.7 | 1.7 | 3.8 | 8.7 | 14.1 | 18.0 | 19.4 | 18.5 | 23.8 | 43.2 | 45.8 | 48.6 | 47.1 | 44.8 |
| 29. | % Mini Systems | 1.31.33 | % | | | | | | | | | | | 0 | 2.0 | 1.7 | 2.2 | 0.8 | 2.5 | 2.9 | 1.4 | 2.1 | 2.2 |
| 30. | Interdata–Tot. Rev. | | $B | | | | | | | | | | | | | | .002 | .006 | .006 | .009 | .013 | .030 | .050 |
| 31. | IBM–Tot. Rev. | | $B | .697 | .892 | 1.203 | 1.418 | 1.613 | 1.817 | 2.202 | 2.591 | 2.863 | 3.239 | 3.573 | 4.248 | 5.345 | 6.889 | 7.197 | 7.504 | 8.274 | 9.533 | 10.993 | 12.675 |
| 32. | % GP Systems | 1.31.33 | % | | 58 | 61 | 64 | 66 | 68 | 70 | 74 | 78 | 72.5 | 77 | 75.4 | 77.9 | 80.1 | 77.7 | 78.5 | 78.9 | 78.5 | 78.2 | 77.8 |
| 33. | % Mini Systems | 1.31.33 | % | | | | | | | | | | | | .6 | 1.1 | 0.9 | 1.3 | .5 | .1 | .5 | .08 | 1.2 |
| 34. | % Supplies | | % | 8.6 | 7.3 | 5.4 | 4.9 | 4.3 | 4.1 | 3.6 | 3.3 | 3.1 | 2.9 | 2.8 | 2.6 | 2.2 | 1.7 | 1.7 | 1.5 | 1.5 | 1.4 | 1.4 | 1.4 |
| 35. | % Services | | % | 5.0 | 3.9 | 2.9 | 2.8 | 2.5 | 2.5 | 2.0 | 2.2 | 2.3 | 3.4 | 3.5 | 3.5 | 2.5 | 1.7 | 1.4 | 1.0 | 0.7 | 0.7 | | |
| 36. | Nat. Cash Register–Tot. Rev. | | $B | .301 | .341 | .383 | .393 | .419 | .458 | .519 | .564 | .593 | .666 | .737 | .871 | 1.005 | 1.102 | 1.265 | 1.421 | 1.466 | 1.558 | 1.816 | 1.979 |
| 37. | % GP Systems | 1.31.35 | % | 4.9 | 5.3 | 5.8 | 6.3 | 6.7 | 7.2 | 7.7 | 8.1 | 8.6 | 9.1 | 9.5 | 10.0 | 10.1 | 11.3 | 10.6 | 13.5 | 14.6 | 16.1 | 16.3 | 15.8 |
| 38. | % Supplies | | % | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 9 | 9.2 | 9.1 | 9.3 | 9.2 | 9.3 | 9.7 |
| 39. | RCA–Total Revenue | | $B | 1.051 | 1.121 | 1.171 | 1.171 | 1.388 | 1.486 | 1.538 | 1.743 | 1.779 | 1.797 | 2.042 | 2.549 | 3.014 | 3.106 | 3.188 | 3.292 | 3.530 | | | |
| 40. | % GP Systems | 1.31.34 | % | | | | 0.3 | 0.4 | 0.7 | 1.2 | 1.5 | 2.1 | 3.1 | 3.6 | 4.3 | 4.8 | 6.7 | 8.4 | 8.08 | 6.87 | | | |
| 41. | Syst. Engineer Labs–Tot. Rev. | | $B | | | | | | | | | .002 | .003 | .005 | .006 | .008 | .012 | .017 | .021 | .013 | .016 | .017 | .015 |
| 42. | Univac (Sperry Rand)–Tot. Rev. | | $B | .711 | .868 | .864 | .990 | 1.173 | 1.177 | 1.183 | 1.227 | 1.279 | 1.248 | 1.280 | 1.487 | 1.563 | 1.607 | 1.755 | 1.739 | 1.824 | 2.229 | 2.614 | 3.041 |
| 43. | % GP Systems | 1.31.33 | % | 27 | 26 | 27 | 23 | 23 | 25 | 25 | 24 | 26 | 29 | 29 | 29 | 30.4 | 33.7 | 36.4 | 40.7 | 42.2 | 41.1 | 41 | 39 |
| 44. | Varian Associates–Tot. Rev | | $B | | | | | | .046 | .058 | .071 | .064 | .053 | .100 | .145 | .161 | .171 | .190 | .196 | .187 | .204 | .241 | .293 |
| 45. | % Mini Systems | | % | | | | | | | | | | | | 0 | 1 | 5 | 5 | 8 | 8 | 4 | 12 | 11 |

$.611B in 1955, compared with an estimated $.030B from GP and minisystems; by 1970 the figures were $9.264B and $8.02B. In other words, in this fifteen year span, computer revenues went from 5% to over 85% of reported data processing revenues.

65-67. Line 65 estimates the revenue of minisystem manufacturers not shown in this Table. It was computed by subtracting the total minisystem revenue of these companies (line 96 below) from total minisystem shipments on line 97. Line 66 is the sum of lines 49 through 65; and line 67 is the difference between lines 66 and 58.

68-84. These percentages are computed by dividing the entries on lines 49 through 65 by total revenue from line 66.

85-97. Two classes of companies appear in this table. The companies which ship no GP systems (Data General, General Automation, Hewlett Packard, Interdata, SEL, and Varian Associates) I assume derive all their data processing revenue from minicomputers, and therefore I simply copy lines 51, 53, 55, 57, and 63 into this portion of the Table. For the other companies, which ship both GP and minisystems, I estimated minisystem shipments by reviewing the censuses carried in *C & A* and *EDP/IR*, listing the number of minisystems in use for each manufacturer at the end of each year. Wherever the number of systems in use increased, I assumed the increase was from shipments in that year, computed the difference, multiplied by the average system price given in the census, and added together the resulting individual shipments. I then made some arbitrary adjustments to the resulting figures, as seemed appropriate. The major adjustments involved Digital Equipment Corp., where I smoothed out some large fluctuations arising in the raw data; and Xerox Data Systems, where I arbitrarily increased minisystem revenues to allow for the fact that XDS derived substantial revenues from designing special input-output equipment to deliver with their standard minisystem products. Line 96 is the sum of lines 85 through 95; and line 97, total minisystem revenues (i.e. sales) is the same as line 2 above.

98-109. These percentages were computed by taking the ratio of lines 85 through 96 to line 97.

**Computed Revenue.** The various manufacturers provide little or no data regarding the proportion of their systems which are sold and the proportion leased. They generally give the gross and net (after depreciation) value of rental equipment (see, for example, entries in Tables II.1.310 to II.1.314), but these values are shown at manufacturing cost, not at sales price, and are very difficult to interpret. It is, however, possible to compute revenue knowing the annual value of equipment in use and equipment shipped, and making appropriate assumptions regarding the proportion of equipment which is sold and leased. In lines 110 to 121 we compute worldwide revenues to American firms from the sale and lease of GP systems, assuming that 25% of the systems were sold and 75% leased. In lines 122 through 129, we make the same calculation under the same assumptions for IBM's worldwide GP and mini shipments. In lines 130 to 133 we deduce some other observations about industry revenues under this same assumption. And in lines 134 through 137 we show the results of calculations on worldwide revenue from GP systems, with certain other assumptions about the relative proportion of systems sold and leased.

110-121. Here I have computed total worldwide industry revenue from GP systems, assuming 25% of the systems are sold and 75% are leased. I begin with the total value of GP systems in use and the annual value shipped, on lines 110 and 111 (from Table II.1.21). I assume there are three components to total revenue: sales revenue, lease revenue, and maintenance revenue for the maintenance of systems which have been sold. Sales revenue, on line 112, is simply 25% of line 111, since we are assuming that 25% of the systems shipped are sold. To compute lease revenue, we begin by computing an assumed value for the lease base at the end of each year (line 114). I assume that each year, when equipment is retired, 75% of the retirements are from the lease base and 25% from the sales base. If that is the case, then 75% of the value in use will be the lease base, and line 114 is computed by multiplying line 110 by 0.75. I compute lease revenue, on line 115, assuming that the average dollar value of equipment on lease during the year is the average of the two year-end figures; and that monthly lease revenue (including the maintenance of leased equipment) is found by dividing the lease base by 44. For example, the $1.021B figure in line 115 for 1963 is found by adding $3.191B to $4.298B, dividing the result by 2 to obtain the average lease base, dividing that result by 44 to get the monthly payments on that average lease base, and finally multiplying by 12 to convert monthly to annual payments.

To compute the cost of maintaining the equipment which has been sold, I first compute the sales base (line 117) by subtracting line 114 from line 110. I then take an assumed maintenance cost, shown on line 118 in dollars per month per $100k of installed equipment. (These figures are based on a review of the history of maintenance cost, from various sources including WeikM, GillA61, and GSA catalogues for the various manufacturers. See Section 4.4.) I then compute the annual maintenance charge by multiplying lines 117 and 118, and multiplying the result by 12, adjusting the position of the decimal point appropriately. In performing the calculation, I used average sales base, just as I used average lease base in computing lease revenue.

Total revenue, on line 121, is then the sum of lines 112, 115, and 119; and the percentages represented by sales, lease, and maintenance revenue, on lines 113, 116, and 120, are the ratios of lines 112, 115, and 119 to 121.

122-129. Total IBM revenue was computed using exactly the same rules as were followed in connection with lines 110 through 121, except that I used the ratio 46:1 in computing monthly rental from sales price instead of the 44:1 used in calculating line 115 above. The starting point this time was IBM GP and mini shipments and value in use, on lines 122 and 123, which were copied from Table II.1.31, lines 85 and 126.

130-133. IBM revenue excluding minisystem sales, on line 130, is found by subtracting line 92 from line 129. Total GP revenue from companies other than IBM, shown on line 131, is then found by subtracting line 130 from line 121; and total non-IBM revenue from minis and GP systems, on line 132, is found by adding line 97 to line 131 and then subtracting line 92, IBM's mini shipments. Finally, total GP and mini revenue on line 133 is the sum of lines 132 and 129 (or alternatively, lines 97 and 121).

134-137. These revenues were computed using the same

## TABLE II.1.30 DATA PROCESSING INDUSTRY REVENUES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46. | Xerox Corp.–Tot. Rev. | | $B | | | | | | .040 | .066 | .116 | .184 | .338 | .549 | .753 | .983 | 1.224 | 1.483 | 1.719 | 1.961 | 2.419 | 2.990 | 3.576 |
| 46a. | % SDS/XDS | 1.31.34 | % | | | | | | | | 0.9 | 4.3 | 5.9 | 8.0 | 7.3 | 7.3 | 8.3 | 8.4 | 4.8 | 3.3 | 3.2 | 2.7 | 2.5 |
| 46b. | XDS (SDS) Tot. Rev | | $B | | | | | | | | .001 | .008 | .020 | .044 | .055 | .072 | .101 | .125 | .083 | .065 | .077 | .080 | .090 |
| 47. | % GP Systems | | % | | | | | | | | 0 | 0 | 0 | 10 | 15 | 25 | 80 | 87 | 70 | 70 | 80 | 85 | 85 |
| 48. | % Mini Systems | | % | | | | | | | | 100 | 90 | 90 | 70 | 65 | 65 | 15 | 8 | 25 | 25 | 15 | 10 | 10 |
| | **Total DP System Revenue** | | | | | | | | | | | | | | | | | | | | | | |
| | Including GP & Mini Systems | | | | | | | | | | | | | | | | | | | | | | |
| 49. | Burroughs | | $B | .022 | .033 | .040 | .047 | .065 | .078 | .092 | .110 | .112 | .121 | .155 | .181 | .220 | .273 | .368 | .477 | .494 | .624 | .745 | .920 |
| 50. | Control Data Corp. | | $B | | | | | | .007 | .016 | .036 | .060 | .114 | .150 | .155 | .223 | .349 | .508 | .475 | .497 | .571 | .768 | .837 |
| 51. | Data General | | $B | | | | | | | | | | | | | | | .001 | .007 | .015 | .030 | .053 | .083 |
| 52. | Digital Equipment Corp. | | $B | | | | | | | | | | .005 | .009 | .015 | .028 | .054 | .083 | .120 | .140 | .179 | .252 | .401 |
| 53. | General Automation | | $B | | | | | | | | | | | | | | | | .005 | .011 | .016 | .030 | .061 |
| 54. | General Electric | | $B | | | | | | .021 | .045 | .072 | .098 | .124 | .186 | .249 | .315 | .357 | .412 | - | - | - | - | - |
| 55. | Hewlett Packard | | $B | | | | | | | | | | | | | .001 | .008 | .035 | .043 | .023 | .025 | .065 | .105 |
| 56. | Honeywell | | $B | | | | | | .004 | .015 | .010 | .025 | .058 | .104 | .183 | .221 | .265 | .351 | .859 | .950 | 1.061 | 1.177 | 1.234 |
| 57. | Interdata | | $B | | | | | | | | | | | | | | .002 | .006 | .006 | .009 | .013 | .030 | .050 |
| 58. | IBM | 1.31.25 | $B | .383 | .517 | .734 | .907 | 1.065 | 1.236 | 1.541 | 1.917 | 2.233 | 2.510 | 2.751 | 3.228 | 4.223 | 5.580 | 5.686 | 5.928 | 6.536 | 7.531 | 8.684 | 10.013 |
| 59. | National Cash Register | | $B | .015 | .018 | .022 | .025 | .028 | .033 | .040 | .046 | .051 | .061 | .070 | .087 | .102 | .125 | .134 | .192 | .214 | .251 | .296 | .313 |
| 60. | RCA | | $B | | | | .004 | .006 | .010 | .018 | .026 | .037 | .056 | .074 | .110 | .145 | .208 | .268 | .266 | .240 | - | - | - |
| 61. | SEL | | $B | | | | | | | | | .002 | .003 | .005 | .006 | .008 | .012 | .017 | .021 | .013 | .016 | .017 | .015 |
| 62. | Univac | | $B | .191 | .226 | .233 | .228 | .270 | .294 | .296 | .294 | .332 | .362 | .371 | .425 | .475 | .542 | .639 | .708 | .770 | .916 | 1.072 | 1.186 |
| 63. | Varian Associates | | $B | | | | | | | | | | | | | .002 | .008 | .010 | .016 | .015 | .009 | .029 | .033 |
| 64. | Xerox Data System (SDS) | | $B | | | | | | | | .001 | .007 | .018 | .035 | .044 | .065 | .096 | .119 | .079 | .062 | .073 | .076 | .086 |
| 65. | Other Mini Manufacturers | | $B | | .003 | .010 | .014 | .020 | .025 | .022 | .027 | .063 | .089 | .130 | .059 | - | .033 | .083 | .062 | .102 | .260 | .234 | .306 |
| 66. | Total Revenue | 1.31.25 | $B | .611 | .797 | 1.039 | 1.225 | 1.454 | 1.708 | 2.085 | 2.539 | 3.020 | 3.522 | 4.040 | 4.742 | 6.028 | 7.912 | 8.720 | 9.264 | 10.091 | 11.575 | 13.528 | 15.643 |
| 67. | Non-IBM Revenue | 1.31.25 | $B | .228 | .280 | .305 | .318 | .324 | .472 | .544 | .622 | .787 | 1.012 | 1.289 | 1.514 | 1.805 | 2.332 | 3.034 | 3.336 | 3.555 | 4.044 | 4.844 | 5.630 |
| | Percent of Total Revenue | | | | | | | | | | | | | | | | | | | | | | |
| 68. | Burroughs | 1.31.32 | % | 3.6 | 4.1 | 3.8 | 3.8 | 4.5 | 4.6 | 4.4 | 4.3 | 3.7 | 3.4 | 3.8 | 3.8 | 3.6 | 3.5 | 4.2 | 5.1 | 4.9 | 5.4 | 5.5 | 5.9 |
| 69. | Control Data Corp. | 1.31.32 | % | | | | | | 0.4 | 0.8 | 1.4 | 2.0 | 3.2 | 3.7 | 3.3 | 3.7 | 4.4 | 5.8 | 5.1 | 4.9 | 4.9 | 5.7 | 5.4 |
| 70. | Data General | | % | | | | | | | | | | | | | | | 0 | 0.1 | 0.1 | 0.3 | 0.4 | 0.5 |
| 71. | Digital Equipment Corp. | | % | | | | | | | | | | 0.1 | 0.2 | 0.3 | 0.5 | 0.7 | 1.0 | 1.3 | 1.4 | 1.5 | 1.9 | 2.6 |
| 72. | General Automation | | % | | | | | | | | | | | | | | | | 0.1 | 0.1 | 0.1 | 0.2 | 0.4 |
| 73. | General Electric | 1.31.31 | % | | | | | | 1.2 | 2.2 | 2.8 | 3.2 | 3.5 | 4.6 | 5.3 | 5.2 | 4.5 | 4.7 | | | | | |
| 74. | Hewlett Packard | | % | | | | | | | | | | | | | 0 | 0.1 | 0.4 | 0.5 | 0.2 | 0.2 | 0.5 | 0.7 |
| 75. | Honeywell | 1.31.30 | % | | | | | | 0.2 | 0.7 | 0.4 | 0.8 | 1.6 | 2.6 | 3.9 | 3.7 | 3.3 | 4.0 | 9.3 | 9.4 | 9.2 | 8.7 | 7.9 |
| 76. | Interdata | | % | | | | | | | | | | | | | | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 |
| 77. | IBM | 1.31.30 | % | 62.7 | 64.9 | 70.6 | 74.0 | 73.2 | 72.4 | 73.9 | 75.5 | 73.9 | 71.3 | 68.1 | 68.1 | 70.1 | 70.5 | 65.2 | 64.0 | 64.8 | 65.1 | 64.2 | 64.0 |
| 78. | National Cash Register | 1.31.32 | % | 2.5 | 2.3 | 2.1 | 2.0 | 1.9 | 1.9 | 1.9 | 1.8 | 1.7 | 1.7 | 1.7 | 1.8 | 1.7 | 1.6 | 1.5 | 2.1 | 2.1 | 2.2 | 2.2 | 2.0 |
| 79. | RCA | 1.31.31 | % | | | | 0.3 | 0.4 | 0.6 | 0.9 | 1.0 | 1.2 | 1.6 | 1.8 | 2.3 | 2.4 | 2.6 | 3.1 | 2.9 | 2.4 | | | |
| 80. | SEL | | % | | | | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| 81. | Univac | 1.31.30 | % | 31.3 | 28.4 | 22.4 | 18.6 | 18.6 | 17.2 | 14.2 | 11.6 | 11.0 | 10.3 | 9.2 | 9.0 | 7.9 | 6.9 | 7.3 | 7.6 | 7.6 | 7.9 | 7.9 | 7.6 |
| 82. | Varian Associates | | % | | | | | | | | | | | | | 0 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 |
| 83. | Xerox Data Systems (SDS) | 1.31.31 | % | | | | | | | | 0 | 0.2 | 0.5 | 0.9 | 0.9 | 1.1 | 1.2 | 1.4 | 0.9 | 0.6 | 0.6 | 0.6 | 0.5 |
| 84. | Other Mini Manufacturers | | % | | .4 | 1.0 | 1.1 | 1.4 | 1.5 | 1.1 | 1.1 | 2.1 | 2.5 | 3.2 | 1.2 | - | 0.4 | 1.0 | 0.7 | 1.0 | 2.2 | 1.7 | 2.0 |
| | **Mini System Revenue** | | | | | | | | | | | | | | | | | | | | | | |
| 85. | Control Data Corp. | | $B | | | | | | .005 | .008 | .010 | .020 | .012 | .008 | .010 | .015 | .016 | .018 | .010 | .014 | .007 | .009 | .024 |
| 86. | Data General | | $B | | | | | | | | | | | | | | | .001 | .007 | .015 | .030 | .053 | .083 |
| 87. | Digital Equipment Corp. | | $B | | | | | | | | | | .005 | .006 | .012 | .024 | .048 | .068 | .100 | .114 | .140 | .200 | .317 |
| 88. | General Automation | | $B | | | | | | | | | | | | | | | | .005 | .011 | .016 | .030 | .061 |
| 89. | Hewlett Packard | | $B | | | | | | | | | | | | | .001 | .008 | .035 | .043 | .023 | .025 | .065 | .105 |
| 90. | Honeywell | | $B | | | | | | | | | | | | .018 | .023 | .036 | .015 | .049 | .057 | .029 | .050 | .057 |

## TABLE II.1.30 DATA PROCESSING INDUSTRY REVENUES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91. | Interdata | | $B | | | | | | | | | | | | | | .002 | .006 | .006 | .009 | .013 | .030 | .050 |
| 92. | IBM | | $B | | | | | | | | | | | | .024 | .057 | .062 | .092 | .035 | .009 | .043 | .090 | .150 |
| 93. | SEL | | $B | | | | | | | | | .002 | .003 | .005 | .006 | .008 | .012 | .017 | .021 | .013 | .016 | .017 | .015 |
| 94. | Varian Associates | | $B | | | | | | | | | | | | | .002 | .008 | .010 | .016 | .015 | .009 | .029 | .033 |
| 95. | Xerox (SDS, XDS) | | $B | | | | | | | | .001 | .007 | .018 | .031 | .036 | .047 | .015 | .010 | .021 | .018 | .012 | .008 | .009 |
| 96. | Subtotal | | $B | | | | | | .005 | .008 | .011 | .029 | .038 | .050 | .106 | .177 | .207 | .272 | .313 | .298 | .340 | .581 | .904 |
| 97. | Total Minisystem Rev. | | $B | | .003 | .010 | .014 | .020 | .030 | .030 | .038 | .092 | .127 | .180 | .165 | .175 | .240 | .355 | .375 | .400 | .600 | .815 | 1.210 |
| | % of Tot. Minisystem Rev. | | | | | | | | | | | | | | | | | | | | | | |
| 98. | Control Data Corp. | 1.31.36 | % | | | | | | 16.7 | 26.7 | 26.3 | 21.7 | 9.4 | 4.4 | 6.1 | 8.6 | 6.7 | 5.1 | 2.7 | 3.5 | 1.2 | 1.1 | 2.0 |
| 99. | Data General | 1.31.37 | % | | | | | | | | | | | | | | | 0.3 | 1.9 | 3.8 | 5.0 | 6.5 | 6.9 |
| 100. | Digital Equipment Corp. | 1.31.36 | % | | | | | | | | | | 3.9 | 3.3 | 7.2 | 13.7 | 20.0 | 19.2 | 26.7 | 28.5 | 23.3 | 24.5 | 26.2 |
| 101. | General Automation | | % | | | | | | | | | | | | | | | | 1.3 | 2.8 | 2.7 | 3.7 | 5.0 |
| 102. | Hewlett Packard | 1.31.37 | % | | | | | | | | | | | | | 0.6 | 3.3 | 9.9 | 11.5 | 5.8 | 4.2 | 8.0 | 8.7 |
| 103. | Honeywell | 1.31.37 | % | | | | | | | | | | | | 10.9 | 13.1 | 15.0 | 4.2 | 13.1 | 14.3 | 4.8 | 6.1 | 4.7 |
| 104. | Interdata | | % | | | | | | | | | | | | | | 0.8 | 1.7 | 1.6 | 2.3 | 2.2 | 3.7 | 4.1 |
| 105. | IBM | 1.31.36 | % | | | | | | | | | | | | 14.5 | 32.5 | 25.8 | 25.9 | 9.3 | 2.3 | 7.2 | 11.0 | 12.4 |
| 106. | SEL | 1.31.37 | % | | | | | | | | | 2.2 | 2.4 | 2.8 | 3.6 | 4.6 | 5.0 | 4.8 | 5.6 | 3.3 | 2.7 | 2.1 | 1.2 |
| 107. | Varian Associates | | % | | | | | | | | | | | | | 1.1 | 3.3 | 2.8 | 4.3 | 3.8 | 1.5 | 3.6 | 2.7 |
| 108. | Xerox Data Systems (SDS) | 1.31.36 | % | | | | | | | | 2.6 | 7.6 | 14.2 | 17.2 | 21.8 | 26.9 | 6.2 | 2.8 | 5.6 | 4.5 | 2.0 | 1.0 | 0.7 |
| 109. | Subtotal | | | | | | | | 16.7 | 26.7 | 28.9 | 31.5 | 29.9 | 27.7 | 64.2 | 101.1 | 86.3 | 76.6 | 83.5 | 74.5 | 56.7 | 71.3 | 74.7 |
| | **Computed Revenue, WW** | | | | | | | | | | | | | | | | | | | | | | |
| | Assumes 25% Sales, 75% Lease | | | | | | | | | | | | | | | | | | | | | | |
| 110. | GP–Tot. Val. in Use, WW | | $B | .180 | .340 | .590 | 1.010 | 1.550 | 2.195 | 3.105 | 4.255 | 5.730 | 7.800 | 10.650 | 15.200 | 19.600 | 25.200 | 31.200 | 35.300 | 38.700 | 42.100 | 44.500 | 49.500 |
| 111. | Val. Shipped, WW | | $B | .065 | .166 | .275 | .446 | .580 | .690 | 1.050 | 1.370 | 1.710 | 2.320 | 3.070 | 4.950 | 6.200 | 6.850 | 7.032 | 6.768 | 6.805 | 8.315 | 8.805 | 10.065 |
| 112. | GP Val. Sold, WW | | $B | .016 | .042 | .069 | .112 | .145 | .173 | .263 | .343 | .428 | .580 | .768 | 1.238 | 1.550 | 1.713 | 1.758 | 1.692 | 1.701 | 2.079 | 2.201 | 2.516 |
| 113. | % of Tot. Rev. | 1.31.28 | % | | 42.8 | 40.8 | 39.3 | 34.5 | 30.1 | 31.6 | 30.4 | 28.7 | 28.7 | 28.1 | 31.1 | 29.6 | 26.6 | 22.8 | 19.5 | 17.9 | 19.7 | 19.4 | 20.2 |
| 114. | End-year Lease Base | | $B | .135 | .255 | .443 | .758 | 1.163 | 1.646 | 2.329 | 3.191 | 4.298 | 5.850 | 7.988 | 11.400 | 14.700 | 18.900 | 23.400 | 26.475 | 29.025 | 31.575 | 33.375 | 37.125 |
| 115. | Lease Rev. | | $B | | .053 | .095 | .164 | .262 | .383 | .542 | .753 | 1.021 | 1.384 | 1.887 | 2.644 | 3.559 | 4.582 | 5.768 | 6.801 | 7.568 | 8.264 | 8.857 | 9.614 |
| 116. | % of Tot. Rev. | 1.31.28 | % | | 54.1 | 56.2 | 57.5 | 62.4 | 66.6 | 65.2 | 66.6 | 68.4 | 68.5 | 69.1 | 66.4 | 68.0 | 71.0 | 74.8 | 78.2 | 79.7 | 78.1 | 78.2 | 77.2 |
| 117. | Sales Base | | $B | .045 | .085 | .148 | .252 | .388 | .549 | .776 | 1.064 | 1.433 | 1.950 | 2.663 | 3.800 | 4.900 | 6.300 | 7.800 | 8.825 | 9.675 | 10.525 | 11.125 | 12.375 |
| 118. | Maintenance Cost/$100k | | $/mo | | 380 | 370 | 360 | 350 | 340 | 325 | 310 | 295 | 280 | 265 | 253 | 241 | 229 | 217 | 205 | 200 | 195 | 205 | 225 |
| 119. | Maint. Charge/yr. | | $B | | .003 | .005 | .009 | .013 | .019 | .026 | .034 | .044 | .057 | .074 | .098 | .126 | .154 | .183 | .204 | .222 | .237 | .266 | .317 |
| 120. | % of Tot. Rev. | 1.31.28 | % | | 3.1 | 3.0 | 3.2 | 3.1 | 3.3 | 3.1 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.2 | 2.3 | 2.5 |
| 121. | Tot. GP Rev., WW | 1.31.28 | $B | | .098 | .169 | .285 | .420 | .575 | .831 | 1.130 | 1.493 | 2.021 | 2.729 | 3.980 | 5.235 | 6.449 | 7.709 | 8.697 | 9.491 | 10.580 | 11.324 | 12.447 |
| 122. | IBM GP & Mini Val. In Use, WW | | $B | .122 | .244 | .439 | .759 | 1.222 | 1.780 | 2.555 | 3.520 | 4.680 | 6.180 | 8.020 | 11.055 | 14.200 | 17.930 | 22.510 | 25.210 | 26.890 | 28.440 | 29.017 | 32.000 |
| 123. | Val. Shipped, WW | | $B | .050 | .131 | .217 | .347 | .481 | .588 | .887 | 1.129 | 1.295 | 1.605 | 2.040 | 3.410 | 4.540 | 4.900 | 4.800 | 4.300 | 4.300 | 5.660 | 5.974 | 6.960 |
| 124. | Value Sold, WW | | $B | .013 | .033 | .054 | .087 | .120 | .147 | .222 | .282 | .324 | .401 | .510 | .853 | 1.135 | 1.225 | 1.200 | 1.075 | 1.075 | 1.415 | 1.494 | 1.740 |
| 125. | End-Year Lease Base | | $B | .092 | .183 | .329 | .569 | .917 | 1.335 | 1.916 | 2.640 | 3.510 | 4.635 | 6.015 | 8.291 | 10.650 | 13.448 | 16.888 | 18.903 | 20.168 | 21.330 | 21.763 | 24.000 |
| 126. | Lease Revenue | | $B | | .035 | .067 | .117 | .194 | .294 | .424 | .594 | .802 | 1.062 | 1.389 | 1.866 | 2.470 | 3.143 | 3.956 | 4.688 | 5.097 | 5.413 | 5.621 | 5.969 |
| 127. | Sales Base | | | | .061 | .110 | .190 | .306 | .445 | .639 | .880 | 1.170 | 1.545 | 2.005 | 2.764 | 3.550 | 4.483 | 5.628 | 6.303 | 6.723 | 7.110 | 7.254 | 8.000 |
| 128. | Maint. Charge/yr. | | $B | | .002 | .004 | .006 | .010 | .015 | .021 | .028 | .036 | .046 | .057 | .072 | .092 | .108 | .131 | .149 | .156 | .162 | .177 | .206 |
| 129. | Total IBM Revenue, WW | 1.31.26 | $B | | .070 | .125 | .210 | .324 | .456 | .667 | .894 | 1.162 | 1.509 | 1.956 | 2.791 | 3.697 | 4.776 | 5.297 | 5.912 | 6.327 | 6.990 | 7.292 | 7.915 |
| 130. | Excluding Mini Sales | | $B | | .070 | .125 | .210 | .324 | .456 | .667 | .894 | 1.162 | 1.509 | 1.956 | 2.767 | 3.640 | 4.714 | 5.195 | 5.877 | 6.318 | 6.947 | 7.202 | 7.765 |
| 131. | Non-IBM Tot. GP Revenue | | $B | | .027 | .045 | .073 | .096 | .118 | .163 | .236 | .332 | .515 | .773 | 1.213 | 1.595 | 1.735 | 2.514 | 2.820 | 3.173 | 3.633 | 4.122 | 4.682 |
| 132. | Non-IBM Total Revenue | 1.31.27 | $B | | .030 | .055 | .087 | .116 | .148 | .193 | .274 | .424 | .642 | .953 | 1.354 | 1.713 | 1.913 | 2.777 | 3.160 | 3.564 | 4.190 | 4.847 | 5.742 |
| 133. | Total GP & Mini Rev., WW | | $B | | .101 | .181 | .299 | .443 | .607 | .864 | 1.173 | 1.591 | 2.157 | 2.909 | 4.145 | 5.410 | 6.689 | 8.064 | 9.072 | 9.891 | 11.180 | 12.139 | 13.657 |
| | Computed WW GP Rev., Assuming: | | | | | | | | | | | | | | | | | | | | | | |
| 134. | 100% Sales | 1.31.29 | | | .178 | .296 | .480 | .634 | .767 | 1.153 | 1.507 | 1.887 | 2.547 | 3.364 | 5.341 | 6.703 | 7.467 | 7.763 | 7.584 | 7.693 | 9.263 | 9.868 | 11.334 |
| 135. | 75% Sales, 25% Lease | 1.31.29 | | | .152 | .253 | .416 | .562 | .703 | 1.047 | 1.381 | 1.756 | 2.371 | 3.153 | 4.887 | 6.213 | 7.128 | 7.745 | 7.955 | 8.293 | 9.702 | 10.353 | 11.706 |
| 136. | 50% Sales, 50% Lease | 1.31.29 | | | .124 | .211 | .349 | .492 | .638 | .938 | 1.221 | 1.595 | 2.197 | 2.940 | 4.434 | 5.725 | 6.789 | 7.726 | 8.326 | 8.892 | 10.141 | 10.839 | 12.076 |

## TABLE II.1.30 DATA PROCESSING INDUSTRY REVENUES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 137. | 100% Lease | 1.31.29 | | | .071 | .127 | .218 | .349 | .511 | .723 | 1.004 | 1.362 | 1.845 | 2.516 | 3.525 | 4.745 | 6.109 | 7.691 | 9.068 | 10.091 | 11.018 | 11.809 | 12.818 |
| | **Peripheral Manufacturers** | | | | | | | | | | | | | | | | | | | | | | |
| 138. | Calcomp | | $B | | | | | | | .001 | .002 | .003 | .005 | .004 | .006 | .011 | .017 | .020 | .028 | .040 | .041 | .080 | .129 |
| 139. | Computer Machinery Corp. | | $B | | | | | | | | | | | | | | | | | .009 | .030 | .053 | .055 |
| 140. | Data Products | | $B | | | | | | | | | .003 | .007 | .008 | .010 | .015 | .033 | .036 | .045 | .045 | .051 | .060 | .076 |
| 141. | Mohawk Data Sciences | | $B | | | | | | | | | | | | .002 | .028 | .054 | .083 | .099 | .068 | .120 | .143 | .169 |
| 142. | Pertec Corp. | | $B | | | | | | | | | | | | | | | .002 | .009 | .021 | .023 | .027 | .033 |
| 143. | Photon | | $B | | | | | | | .001 | .002 | .003 | .004 | .005 | .009 | .016 | .020 | .018 | .019 | .022 | | | |
| 144. | Potter Instrument Corp. | | $B | | | | | | | .005 | .008 | .013 | .011 | .013 | .015 | .017 | .020 | .031 | .035 | .031 | .033 | .045 | .047 |
| 145. | Recognition Equipment Inc. | | $B | | | | | | | | | | | .001 | .001 | .004 | .013 | .036 | .035 | .039 | .043 | .042 | .043 |
| 146. | Subtotal | | $B | | | | | | | .007 | .012 | .022 | .027 | .031 | .043 | .091 | .157 | .226 | .270 | .275 | .341 | .450 | .552 |
| 147. | Ampex | | $B | .008 | .011 | .021 | .034 | .049 | .073 | .070 | .084 | .119 | .140 | .153 | .170 | .216 | .233 | .296 | .314 | .291 | .284 | .257 | .272 |
| 148. | Electronic Memories & Mag. | | $B | | | | | | | | | | .034 | .041 | .056 | .057 | .066 | .089 | .093 | .071 | .076 | .106 | .111 |
| 149. | Memorex | | $B | | | | | | | | | .003 | .008 | .013 | .024 | .034 | .058 | .078 | .079 | .107 | .145 | .177 | .218 |
| 150. | Telex | | $B | | | | | | .012 | .021 | .030 | .034 | .026 | .026 | .026 | .033 | .034 | .034 | .057 | .081 | .073 | .068 | .090 |
| 151. | Subtotal—All Sales | | $B | .008 | .011 | .021 | .034 | .049 | .085 | .098 | .126 | .178 | .235 | .264 | .319 | .431 | .548 | .723 | .813 | .825 | .919 | 1.058 | 1.243 |
| | Periph. Equip. Only | | | | | | | | | | | | | | | | | | | | | | |
| 152. | Ampex | | $B | | | | | | | | | | | | | .006 | .012 | .027 | .041 | .052 | .060 | .062 | .076 |
| 153. | Electronic Memories & Mag. | | $B | | | | | | | | | | .003 | .005 | .009 | .021 | .032 | .044 | .050 | .045 | .052 | .074 | .079 |
| 154. | Memorex | | $B | | | | | | | | | | | | | | .008 | .015 | .016 | .033 | .060 | .093 | .116 |
| 155. | Telex | | $B | | | | | | | | | | | | | | .005 | .011 | .030 | .058 | .050 | .043 | .062 |
| 156. | Total Periph. Equip. | | $B | | | | | | | .007 | .012 | .022 | .030 | .036 | .052 | .118 | .214 | .323 | .407 | .463 | .563 | .722 | .885 |
| | **Supplies Manufacturers** | | | | | | | | | | | | | | | | | | | | | | |
| 157. | Burroughs Corp. | | $B | .011 | .014 | .014 | .015 | .018 | .019 | .025 | .030 | .031 | .035 | .046 | .054 | .061 | .071 | .077 | .083 | .089 | .099 | .122 | .161 |
| 158. | Ennis Business Forms | | $B | .007 | .008 | .008 | .009 | .011 | .012 | .013 | .014 | .015 | .016 | .018 | .022 | .026 | .033 | .042 | .044 | .041 | .042 | .050 | .059 |
| 159. | IBM | | $B | .060 | .065 | .065 | .070 | .070 | .075 | .080 | .085 | .090 | .095 | .100 | .110 | .115 | .120 | .120 | .115 | .120 | .130 | .150 | .175 |
| 160. | Memorex (Magnetic Media) | | $B | | | | | | | | | .003 | .008 | .013 | .024 | .034 | .053 | .059 | .063 | .074 | .086 | .084 | .102 |
| 161. | Moore Corp. | | $B | .099 | .114 | .127 | .128 | .144 | .155 | .162 | .178 | .190 | .215 | .241 | .279 | .307 | .341 | .[illegible]99 | .432 | .449 | .499 | .587 | 1.032 |
| 162. | Nashua Corp. | | $B | .028 | .031 | .033 | .034 | .037 | .035 | .039 | .039 | .044 | .051 | .059 | .065 | .071 | .085 | .[illegible]01 | .125 | .138 | .171 | .223 | .316 |
| 163. | National Cash Register | | $B | .015 | .017 | .019 | .020 | .021 | .023 | .026 | .028 | .036 | .047 | .059 | .070 | .090 | .099 | .116 | .129 | .136 | .143 | .169 | .192 |
| 164. | Standard Register Corp. | | $B | .034 | .043 | .047 | .046 | .052 | .055 | .058 | .065 | .065 | .069 | .077 | .084 | .090 | .091 | .103 | .102 | .107 | .108 | .128 | .167 |
| 165. | UARCO, Inc. | | $B | .025 | .030 | .034 | .036 | .038 | .042 | .045 | .049 | .051 | .055 | .059 | .067 | .073 | .079 | .089 | .099 | .105 | .114 | .129 | .170 |
| 166. | Wallace Business Forms | | $B | .009 | .011 | .012 | .011 | .011 | .012 | .012 | .014 | .018 | .019 | .022 | .023 | .024 | .026 | .029 | .034 | .034 | .036 | .041 | .056 |
| 167. | Total | | $B | .288 | .333 | .359 | .369 | .402 | .428 | .460 | .502 | .543 | .610 | .694 | .798 | .891 | .998 | 1.135 | 1.226 | 1.293 | 1.428 | 1.683 | 2.430 |

techniques described above, but with different assumptions about the relative proportion of sales and leases.

**Peripheral Equipment Manufacturers.** 138-156. Lines 138 to 145 recount the revenues of eight prominent manufacturers whose sole product, generally, is computer peripheral equipment. Line 146 is the sum of lines 138 to 145. Lines 147 to 150 show the total revenues of four other companies which are important peripheral manufacturers, but which also manufacture other products. Line 151 is the sum of lines 146 to 150. Lines 152 to 155 itemize the *peripheral equipment* revenue subtotals of the four companies whose total revenues are given on lines 147-150, and line 156 is the sum of lines 146 and 152 to 155. Presumably line 156 is comparable to line 4 of Table II.1.20, which estimates total U.S. peripheral equipment shipments.

**Supplies Manufacturers.** 157-167. Lines 157 to 166 show the revenues, from data processing-related supplies, of the companies generally recognized as being principal manufacturers of such supplies. Line 167 is the sum of lines 157 to 166.

The data on the supplies revenues for IBM, Burroughs, and NCR were derived from the data earlier in this table on lines 13, 34, and 38. All the other data on lines 138 to 166 is from S&PCR, which in turn is from public corporation records like annual reports.

## TABLE II.1.31.1 SYSTEM MANUFACTURERS—NOTES

**Number of Systems in Use.** 1-84. These entries were derived from the computer censuses published in *C & A* and *EDP/IR*. The method used in calculating the numbers shown in the table is the same method as that described in connection with lines 1-7 of Table II.1.22. Basically, I applied the proportions given in the censuses to my assumed total number of units installed shown in Table II.1.21, lines 107, 119, and 135 (which are repeated in this table as lines 43, 66, and 84). For example, the number of IBM 650's in use at the end of 1962 (line 3 on the table) was computed as follows: the census in *Computers and Automation* for January, 1963, shows 997 IBM 650's in use. Of the 12,882 machines shown in that census, 9,910 were of the type we classify as GP systems (see Table II.1.21, lines 9 through 12). The IBM 650 thus represented 997/9910, or 10.06% of the total. Applying that percentage to the assumed total of 8,100 machines installed in the U.S. at the end of 1962 (line 43 of this table), I estimate that 815 IBM 650's were installed at that time. Other entries on lines 1 through 84 were computed in the same fashion. Figures for the numbers of machines installed by various manufacturers were computed by applying the percentages given in Table II.1.21, lines 172-187, 204-218, and 219-232 to the appropriate totals. For example, the number of RCA systems in use worldwide at the end of 1970 was computed by applying the percentage shown on line 222 of Table II.1.21 (2.3%) to the total number of GP systems in use worldwide at the end of 1970 (79,000) from line 103 of Table II.1.21. Once again, let me draw attention to a flaw in the data: the censuses I have used did not distinquish domestic and worldwide installations until 1967, so that the U.S. section of the table (lines 1 through 66) is based on the same percentages as is the worldwide portion (lines 67 to 84) for all years prior to 1967. Since the *C & A* censuses for 1956 to 1959 were based on U.S. installations, and those for 1964 to 1966 included worldwide installations (the coverage for the years 1961 to 1963 was not stated), the figures shown are distorted accordingly.

29, 35, 44, 70, 73, 80, 88, 91. Mergers or combinations have taken place over the life of the industry, and the effects on data in this table are indicated by the use of light-face type. For example, in 1971 RCA sold its computer operations to Univac (Sperry Rand). The number of computers shown on lines 29 and 70 are totals as if RCA and Univac had been combined for the entire history of the industry. The light-face figures are used to show installations "as if" the two companies had been combined; the bold-face figures distinguish the years when the merger was actually in force. Similarly, Honeywell bought General Electric's computer business in 1970; Control Data bought Bendix's in 1963 and the Librascope business in 1966; and Honeywell bought the Computer Control Company in 1966. In each case, light-face figures indicate periods of time when the computer populations shown "belonged", in whole or in part, to some manufacturer other than that shown.

67-84. This portion of the table, as mentioned above, was derived from the percentages in Table II.1.21, lines 219-232. Note that the percentages of GP systems were applied to the total GP population; the percentages of minisystems were applied to the minipopulation; and the resulting computer populations were summed. For example, lines 219 and 229 of Table I.1.21 shows that 64.4% of GP systems and 5.9% of minisystems in use at the end of 1969 were manufactured by IBM. 64.4% of the 72,000 GP systems in use is the 46,368 systems shown on line 68 of the table. 5.9% of the 20,300 minisystems in use is the 1,198 systems shown on line 69. And line 67 is the sum of lines 68 and 69.

**GP and Minisystem Value in Use.** 85-111. Generally speaking, the data shown in lines 85 to 97 is derived by applying the percentages of lines 99 to 111 to the "total worldwide value of all systems in use" from Table II.1.21, line 137—which is repeated here as line 98. The percentages shown on lines 99 to 111 came from two sources. Data for years 1955 through 1968 came from a private report. For 1969 and later, *EDP/IR* has annually published an estimate of worldwide system value in use, by manufacturers, in its annual review issue, and I used those figures for the years 1969 and later. (I had to make some special adjustments to the 1971 figures to correct inconsistencies in the *EDP/IR* data. For example, comparing the March, 1971, and March, 1972 "Review and Forecast" issues, we find that Honeywell had \$2.9B worth of equipment in use at the end of 1970, \$3.9B at the end of 1971, but that only \$.6B had been shipped during 1971. Although the March 1973 issue of *EDP/IR* made an implied correction to the 1971 year-end figures, by showing a net change from the previous year, their correction did not affect Honeywell figures. I therefore made an adjustment by reducing the 1971 Honeywell percentage on line 105 and correspondingly increasing the Univac figure on line 102. I made the compensating adjustment in the Univac figure because it resulted in a more reasonable-looking decline for the years 1969 to 1972.)

The IBM figures on lines 85 through 87 were derived as follows. The installed value of IBM plug-compatible equipment, on line 86, was derived from line 4a of Table II.1.20 (which shows plug-compatible shipments) by assuming that no plug-compatible equipment was removed from use until 1972, so that the value in use at the end of each year before 1972 is the sum of all shipments up to and including that year. For 1972, I used the "percentage of total

## TABLE II.1.31.1 SYSTEM MANUFACTURERS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GP Systems in Use, US** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | IBM Total | 1.311.2 | k | .190 | .560 | 1.000 | 1.680 | 2.545 | 3.520 | 4.860 | 6.545 | 8.890 | 11.690 | 14.170 | 19.100 | 24.530 | 26.900 | 31.060 | 32.685 | 36.337 | 38.480 | 40.930 | 42.820 |
| 2. | First Generation | 1.311.2 | k | .190 | .560 | 1.000 | 1.680 | 2.542 | 2.640 | 2.350 | 1.820 | 1.170 | .750 | .455 | .310 | .250 | .200 | .060 | .035 | .017 | .007 | .004 | .004 |
| 3. | IBM 650 | | k | | .470 | .803 | 1.350 | 1.554 | 1.300 | .988 | .815 | .490 | .300 | .207 | .133 | .108 | .082 | .025 | .008 | .004 | | | |
| 4. | IBM 704 | | k | | .025 | .077 | .130 | .127 | .110 | .091 | .073 | .051 | .033 | .033 | .025 | .022 | .018 | .009 | .006 | .002 | .001 | .001 | .001 |
| 5. | IBM 705 & 705III | | k | | .028 | .078 | .140 | .175 | .170 | .167 | .131 | .094 | .065 | .050 | .040 | .035 | .029 | .022 | .019 | .010 | .005 | .003 | .003 |
| 6. | IBM 305 | | k | | - | .021 | .250 | .610 | .950 | 1.064 | .756 | .514 | .350 | .138 | .109 | .082 | .060 | .008 | ,002 | .001 | .001 | | |
| 7. | Second Generation | 1.311.2 | k | | | | | .003 | .880 | 2.510 | 4.725 | 7.720 | 10.940 | 13.090 | 14.150 | 12.280 | 8.100 | 5.700 | 4.025 | 3.720 | 2.840 | 2.220 | 1.772 |
| 8. | IBM 7090 | | k | | | | | .002 | .065 | .127 | .174 | .210 | .038 | .037 | .035 | .020 | .030 | .034 | .028 | .023 | .021 | .018 | .014 |
| 9. | IBM 1401 | | k | | | | | | .260 | 1.773 | 3.148 | 5.227 | 6.295 | 5.487 | 6.000 | 4.700 | 2.970 | 2.123 | 1.808 | 1.618 | 1.350 | 1.100 | .965 |
| 10. | IBM 7094I & II | | k | | | | | | | | .001 | .073 | .248 | .185 | .191 | .229 | .200 | .092 | .092 | .082 | .066 | .054 | .044 |
| 11. | IBM 1460 | | k | | | | | | | | | .093 | .706 | 1.748 | 1.391 | 1.061 | .616 | .173 | .130 | .087 | .065 | .055 | .050 |
| 12. | IBM 1620 | | k | | | | | | .050 | .415 | 1.103 | 1.138 | 1.263 | 1.382 | 1.305 | 1.017 | .866 | .746 | .440 | .430 | .390 | .325 | .280 |
| 13. | IBM 707x | | k | | | | | | | .192 | .200 | .379 | .428 | .276 | .252 | .200 | .155 | .191 | .176 | .138 | .113 | .101 | .097 |
| 14. | Third Gen.–360 | 1.311.2 | k | | | | | | | | | | | .625 | 4.105 | 10.000 | 15.400 | 21.700 | 23.700 | 22.370 | 17.760 | 11.187 | 8.522 |
| 15. | IBM 360/2x | | k | | | | | | | | | | | .002 | .940 | 3.470 | 5.680 | 8.640 | 10.490 | 11.140 | 9.370 | 5.271 | 3.410 |
| 16. | IBM 360/30 | | k | | | | | | | | | | | .325 | 1.950 | 3.520 | 5.360 | 7.960 | 7.270 | 6.000 | 4.300 | 3.104 | 2.685 |
| 17. | IBM 360/4x | | k | | | | | | | | | | | .285 | 1.070 | 2.070 | 2.770 | 3.190 | 3.720 | 3.250 | 2.640 | 1.578 | 1.328 |
| 18. | IBM 360/50 | | k | | | | | | | | | | | .010 | .110 | .630 | 1.020 | 1.240 | 1.420 | 1.225 | .870 | .662 | .585 |
| 19. | IBM 360/6x | | k | | | | | | | | | | | .001 | .020 | .280 | .530 | .600 | .720 | .675 | .510 | .521 | .463 |
| 20. | IBM 360/75, 85, 195 | | k | | | | | | | | | | | | .010 | .030 | .040 | .070 | .080 | .080 | .070 | .051 | .051 |
| 21. | IBM 360/20 | | k | | | | | | | | | | | .002 | .940 | 3.470 | 5.622 | 7.348 | 8.440 | 8.390 | 6.500 | 3.402 | 2.400 |
| 22. | IBM 360/40 | | k | | | | | | | | | | | .285 | 1.055 | 1.907 | 2.524 | 3.022 | 3.576 | 3.146 | 2.550 | 1.510 | 1.275 |
| 23. | IBM 360/65 | | k | | | | | | | | | | | .001 | .022 | .269 | .490 | .563 | .660 | .610 | .460 | .482 | .430 |
| 24. | IBM 370 Family | 1.311.2 | k | | | | | | | | | | | | | | | | | 1.028 | 3.480 | 6.286 | 8.926 |
| 25a. | IBM 370/115 | | k | | | | | | | | | | | | | | | | | | | | .850 |
| 25b. | IBM 370/125 | | k | | | | | | | | | | | | | | | | | | | .770 | 1.750 |
| 25c. | IBM 370/135 | | k | | | | | | | | | | | | | | | | | | .970 | 2.200 | 2.750 |
| 25d. | IBM 370/145 | | k | | | | | | | | | | | | | | | | | .450 | 1.270 | 1.700 | 1.925 |
| 25e. | IBM 370/155 | | k | | | | | | | | | | | | | | | | | .490 | 1.045 | 1.190 | .695 |
| 25f. | IBM 370/158 | | k | | | | | | | | | | | | | | | | | | | .147 | .635 |
| 25g. | IBM 370/165 | | k | | | | | | | | | | | | | | | | | .088 | .195 | .210 | .150 |
| 25h. | IBM 370/168 | | k | | | | | | | | | | | | | | | | | | | .050 | .151 |
| 25i. | IBM 370/195 | | k | | | | | | | | | | | | | | | | | | | .019 | .020 |
| 26. | System 3 & 1130 | 1.311.2 | k | | | | | | | | | | | | .535 | 2.000 | 3.200 | 3.600 | 4.925 | 9.200 | 14.400 | 21.233 | 23.594 |
| 27. | System 3/10 | | k | | | | | | | | | | | | | | | | 1.568 | 3.496 | 8.700 | 15.500 | 16.825 |
| 28. | All Other GP Manufacturers | | k | .050 | .140 | .260 | .420 | .565 | .880 | 1.290 | 1.555 | 2.810 | 5.010 | 7.430 | 9.200 | 11.070 | 14.100 | 14.940 | 15.815 | 18.063 | 19.250 | 21.320 | 22.220 |
| 29. | Univac–Total with RCA | | k | .022 | .060 | .093 | .189 | .317 | .484 | .764 | .783 | 1.460 | 2.900 | 3.938 | 4.345 | 4.504 | 5.026 | 5.550 | 5.700 | 6.168 | 6.155 | 5.921 | 5.361 |
| 30. | Univac | | k | .022 | .060 | .093 | .189 | .301 | .440 | .643 | .581 | 1.066 | 2.364 | 3.300 | 3.589 | 3.597 | 3.872 | 4.439 | 4.680 | 5.118 | 5.033 | 4.960 | 4.508 |
| 31. | Univac I | | k | | .036 | .038 | .065 | .085 | .080 | .060 | .051 | .034 | .025 | .023 | .019 | .018 | .017 | .017 | .013 | .003 | .004 | .003 | .003 |
| 32. | Univac 1004 | | k | | | | | | | | | .548 | 1.787 | 2.600 | 2.500 | 1.932 | 1.712 | 1.383 | 1.174 | 1.100 | .975 | .900 | .815 |
| 33. | Univac 1108 | | k | | | | | | | | | | | .003 | .023 | .067 | .120 | .116 | .137 | .148 | .140 | .135 | .130 |
| 34. | RCA | | k | | | | | .016 | .044 | .122 | .202 | .394 | .536 | .638 | .756 | .908 | 1.154 | 1.111 | 1.070 | 1.050 | 1.122 | .961 | .853 |
| 35. | Honeywell (HIS with GE) | | k | | | | | | .044 | .133 | .183 | .336 | .542 | 1.170 | 2.044 | 2.992 | 3.640 | 3.790 | 3.582 | 4.575 | 5.419 | 5.899 | 5.851 |
| 36. | Honeywell | | k | | | | | | .035 | .049 | .082 | .125 | .312 | .750 | 1.248 | 1.853 | 2.216 | 2.394 | | 3.382 | 4.036 | 4.246 | 4.198 |
| 37. | GE | | k | | | | | | .009 | .084 | .101 | .211 | .230 | .420 | .796 | 1.140 | 1.423 | 1.396 | | 1.194 | 1.383 | 1.653 | 1.653 |
| 38. | National Cash Register | | k | .012 | .029 | .033 | .042 | .035 | .066 | .128 | .323 | .578 | .878 | 1.283 | 1.540 | 1.900 | 3.413 | 3.048 | 3.692 | 3.832 | 3.985 | 4.441 | 5.045 |
| 39. | Burroughs | | k | .017 | .046 | .087 | .126 | .160 | .176 | .163 | .176 | .307 | .521 | .713 | .814 | 1.135 | 1.327 | 1.618 | 1.701 | 2.250 | 2.260 | 2.801 | 3.257 |
| 40. | Burroughs 205 | | k | .017 | .046 | .087 | .120 | .127 | .120 | .103 | .071 | .056 | .050 | .042 | .033 | .030 | .022 | .006 | .001 | .001 | - | | |
| 41. | Control Data Corp. | | k | | | | | | | .027 | .033 | .073 | .109 | .240 | .352 | .389 | .480 | .507 | .527 | .486 | .522 | .515 | .529 |
| 42. | CDC 6600 | | k | | | | | | | | | | .001 | .006 | .016 | .026 | .045 | .062 | .066 | .061 | .059 | .058 | .059 |

## TABLE II.1.31.1 SYSTEM MANUFACTURERS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43. | Total, All Manufacturers | | k | .240 | .700 | 1.260 | 2.100 | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 28.300 | 35.600 | 41.000 | 46.000 | 48.500 | 54.400 | 57.730 | 62.250 | 65.040 |
| | **Mini Systems in Use, US** | | | | | | | | | | | | | | | | | | | | | | |
| 44. | CDC—Total | | k | | .025 | .202 | .420 | .640 | .860 | 1.153 | 1.279 | 1.455 | 1.563 | 1.420 | 1.235 | 1.466 | 1.907 | 1.528 | 1.559 | 1.786 | 1.728 | 1.600 | 1.609 |
| 45. | Bendix | | k | | .025 | .102 | .200 | .284 | .370 | .419 | .432 | .323 | .358 | .383 | .340 | | | | | | | | |
| 46. | G-15 | | k | | .025 | .102 | .200 | .284 | .370 | .419 | .432 | .323 | .358 | .383 | .340 | .357 | .432 | .270 | .265 | | | | |
| 47. | Librascope | | k | | | .100 | .220 | .356 | .460 | .579 | .580 | .727 | .745 | .485 | .323 | | | | | | | | |
| 48. | LGP-30 | | k | | | .100 | .220 | .356 | .450 | .530 | .497 | .531 | .480 | .300 | .134 | .145 | .160 | .295 | .290 | | | | |
| 49. | CDC | | k | | | | | | .030 | .143 | .267 | .405 | .460 | .552 | .571 | | | | | | | | |
| 50. | CDC 160, 160A | | k | | | | | | .030 | .143 | .267 | .381 | .430 | .518 | .504 | .569 | .740 | .249 | | | | | |
| 51. | Digital Equipment Corp. | | k | | | | | | | | .048 | .078 | .208 | .422 | .972 | 1.888 | 2.676 | 6.558 | 9.868 | 12.550 | 15.800 | 20.320 | 27.511 |
| 52. | PDP-8 | | k | | | | | | | | | | | .112 | .603 | 1.350 | 1.814 | 1.189 | 1.185 | .950 | .900 | .777 | .758 |
| 53. | PDP-8L | | k | | | | | | | | | | | | | | | 1.955 | 3.320 | 3.190 | 2.600 | 2.250 | 2.194 |
| 54. | PDP-8/E,F,M | | k | | | | | | | | | | | | | | | | | 2.365 | 4.654 | 7.233 | 10.336 |
| 55. | PDP-11 | | k | | | | | | | | | | | | | | | | .430 | 1.482 | 1.556 | 6.382 | 10.610 |
| 55a. | PDP.11/05,10 | | k | | | | | | | | | | | | | | | | | | 1.392 | 2.902 | 4.691 |
| 56. | Xerox (SDS, XDS) | | k | | | | | | | | .012 | .074 | .203 | .443 | .615 | 1.061 | 1.494 | .716 | .772 | .917 | .953 | .888 | .898 |
| 57. | Honeywell (Computer control) | | k | | | | | | | | .011 | .019 | .058 | .144 | .321 | .536 | .965 | 1.178 | 1.820 | 2.325 | 3.130 | 3.655 | 4.263 |
| 58. | IBM | | k | | | | | | | | | | | | .110 | .315 | .715 | .840 | .942 | .932 | 1.453 | 2.400 | 3.970 |
| 59. | General Electric | | k | | | | | | | | | | | | | | .265 | .395 | .393 | .524 | .561 | .506 | .571 |
| 60. | Hewlett Packard | | k | | | | | | | | | | | | | | | 1.123 | 2.065 | 2.592 | 3.516 | 5.003 | 7.961 |
| 60a. | HP 2100-A | | k | | | | | | | | | | | | | | | | | | .450 | 3.073 | 4.871 |
| 61. | Varian Data Machines | | k | | | | | | | | | | | | | | | .910 | 1.653 | 2.368 | 2.740 | 3.137 | 3.688 |
| 62. | Data General | | k | | | | | | | | | | | | | | | .225 | .755 | 1.790 | 3.905 | 6.655 | 10.597 |
| 63. | Interdata | | k | | | | | | | | | | | | | | | .312 | .614 | .764 | 1.183 | 1.472 | 2.058 |
| 64. | General Automation | | k | | | | | | | | | | | | | | | .200 | .605 | 1.203 | 2.060 | 3.452 | 6.409 |
| 65. | Others | | k | | .025 | .038 | .030 | .060 | .140 | .247 | .449 | .475 | .468 | .671 | .747 | .733 | 1.488 | 2.122 | 4.510 | 6.583 | 12.316 | 21.912 | 30.465 |
| 66. | Total, All Manufacturers | | k | | .050 | .240 | .450 | .700 | 1.000 | 1.400 | 1.800 | 2.100 | 2.500 | 3.100 | 4.000 | 6.000 | 9.500 | 16.100 | 25.560 | 34.615 | 49.345 | 71.000 | 100.00 |
| | **GP & Mini No. in Use, WW** | | | | | | | | | | | | | | | | | | | | | | |
| 67. | IBM—Total | | k | .197 | .602 | 1.159 | 2.0 | 3.108 | 4.400 | 6.123 | 8.484 | 11.552 | 15.330 | 19.418 | 27.341 | 38.252 | 43.780 | 47.566 | 50.845 | 58.118 | 64.842 | 70.745 | 76.348 |
| 68. | GP | | k | .197 | .602 | 1.159 | 2.0 | 3.108 | 4.400 | 6.123 | 8.484 | 11.552 | 15.330 | 19.418 | 27.198 | 37.754 | 42.714 | 46.368 | 49.533 | 56.716 | 62.784 | 67.380 | 70.597 |
| 69. | Mini | | k | | | | | | | | | | | | .143 | .498 | 1.066 | 1.198 | 1.312 | 1.402 | 2.058 | 3.365 | 5.751 |
| 70. | Univac—Total with RCA | | k | .022 | .067 | .108 | .23 | .388 | .605 | .969 | 1.019 | 1.900 | 3.810 | 5.417 | 6.187 | 6.531 | 7.434 | 9.576 | 10.42 | 10.057 | 9.936 | 9.814 | 9.099 |
| 71. | Univac | | k | .022 | .065 | .108 | .23 | .369 | .550 | .814 | .756 | 1.383 | 3.110 | 4.530 | 5.111 | 5.310 | 5.796 | 7.776 | 8.611 | 8.969 | 8.772 | 8.815 | 8.211 |
| 72. | RCA | | k | | .002 | | | .019 | .055 | 1.55 | .263 | .517 | .700 | .887 | 1.076 | 1.221 | 1.638 | 1.800 | 1.817 | 1.088 | 1.164 | .998 | .888 |
| 73. | Honeywell (HIS, with GE) | | k | | | | | | .055 | .171 | .253 | .461 | .790 | 1.769 | 3.328 | 4.726 | 6.519 | 8.815 | 10.806 | 14.877 | 17.071 | 19.046 | 20.174 |
| 74. | Honeywell—Total | | k | | | | | | .044 | .062 | .116 | .187 | .483 | 1.207 | 2.195 | 3.133 | 4.251 | 4.927 | | 8.626 | 10.134 | 11.211 | 12.208 |
| 75. | GP | | k | | | | | | .044 | .062 | .105 | .167 | .416 | 1.036 | 1.777 | 2.390 | 2.961 | 3.384 | | 5.164 | 5.866 | 6.141 | 6.083 |
| 76. | Mini | | k | | | | | | | | .011 | .020 | .067 | .171 | .418 | .743 | 1.290 | 1.543 | 2.432 | 3.462 | 4.268 | 5.070 | 6.125 |
| 77. | GE | | k | | | | | | .011 | .109 | .137 | .274 | .307 | .562 | 1.133 | 1.593 | 2.268 | 3.888 | | 6.251 | 6.937 | 7.835 | 7.966 |
| 78. | National Cash Register | | k | .012 | .031 | .038 | .05 | .042 | .083 | .163 | .420 | .745 | 1.160 | 1.746 | 2.194 | 2.814 | 5.040 | 5.184 | 6.636 | 7.067 | 7.417 | 7.734 | 8.770 |
| 79. | Burroughs | | k | .017 | .050 | .101 | .15 | .198 | .220 | .209 | .231 | .395 | .680 | .977 | 1.160 | 1.328 | 1.575 | 2.232 | 2.528 | 3.443 | 3.450 | 4.378 | 5.129 |
| 80. | Control Data Corp.—Total | | k | | .025 | .202 | .38 | .441 | .820 | 1.184 | 1.356 | 1.650 | 1.966 | 2.001 | 2.105 | 2.318 | 2.936 | 2.762 | 2.821 | 3.532 | 3.535 | 3.616 | 3.819 |
| 81. | GP | | k | | | | | | | .031 | .042 | .091 | .153 | .325 | .500 | .478 | .630 | .792 | .869 | .815 | .898 | .931 | .961 |
| 82. | Mini | | k | | .025 | .202 | .38 | .441 | .820 | 1.153 | 1.314 | 1.559 | 1.813 | 1.676 | 1.605 | 1.840 | 2.306 | 1.970 | 1.952 | 2.717 | 2.637 | 2.683 | 2.858 |
| 83. | All Others | | k | .002 | .030 | .092 | .14 | .323 | .387 | .331 | .587 | .747 | 1.064 | 2.072 | 3.185 | 5.031 | 8.116 | 16.165 | 26.936 | 37.331 | 56.619 | 89.467 | 132.50 |
| 83a. | DEC—Total | | k | | | | | | | | | | | | | | | 8.547 | 13.076 | 16.876 | 22.678 | 32.048 | 45.793 |
| 83b. | GP | | k | | | | | | | | | | | | | | | .134 | .192 | .228 | .280 | .311 | .337 |
| 83c. | Mini | | k | | | | | | | | | | | | | | | 8.413 | 12.884 | 16.648 | 22.398 | 31.737 | 45.456 |
| 84. | Total—GP & Mini, WW | | k | .246 | .805 | 1.700 | 2.930 | 4.500 | 6.500 | 9.150 | 12.350 | 17.450 | 24.800 | 33.400 | 45.500 | 61.000 | 75.400 | 92.300 | 111.00 | 134.43 | 162.87 | 204.80 | 255.84 |

## TABLE II.1.31.1 SYSTEM MANUFACTURERS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GP & Mini Val. in Use, WW** | | | | | | | | | | | | | | | | | | | | | | |
| 85. | IBM (without PCM) | 1.31.9 | $B | .122 | .244 | .439 | .759 | 1.222 | 1.780 | 2.555 | 3.520 | 4.680 | 6.180 | 8.020 | 11.055 | 14.200 | 17.930 | 22.510 | 25.210 | 26.890 | 28.440 | 29.017 | 32.000 |
| 86. | IBM Plug-compat. Manu. | 1.31.9 | $B | | | | | | | | | | | | .015 | .040 | .090 | .200 | .480 | .850 | 1.170 | 1.620 | 2.200 |
| 87. | IBM with PCM | 1.31.9 | $B | .122 | .244 | .439 | .759 | 1.222 | 1.780 | 2.555 | 3.520 | 4.680 | 6.180 | 8.020 | 11.070 | 14.240 | 18.020 | 22.710 | 25.690 | 27.740 | 29.610 | 30.637 | 34.200 |
| 88. | Univac–Total with RCA | 1.31.9 | $B | .035 | .048 | .089 | .157 | .227 | .302 | .369 | .422 | .540 | .770 | 1.110 | 1.570 | 2.020 | 2.680 | 3.030 | 3.370 | 3.380 | 3.400 | 3.618 | 3.900 |
| 89. | Univac | 1.31.11 | $B | .035 | .048 | .089 | .141 | .203 | .263 | .302 | .321 | .390 | .550 | .810 | 1.130 | 1.430 | 1.840 | 1.920 | 2.220 | | | | |
| 90. | RCA | 1.31.11 | $B | | | | .015 | .024 | .039 | .067 | .101 | .150 | .220 | .300 | .440 | .590 | .840 | 1.110 | 1.150 | | | | |
| 91. | Honeywell (HIS, with GE) | 1.31.9 | $B | | | .004 | .007 | .016 | .027 | .058 | .106 | .180 | .310 | .630 | 1.270 | 1.780 | 2.280 | 2.700 | 2.920 | 3.600 | 4.480 | 5.010 | 5.300 |
| 92. | Honeywell | 1.31.11 | $B | | | .003 | .006 | .011 | .014 | .039 | .062 | .110 | .200 | .420 | .790 | 1.080 | 1.340 | 1.400 | | | | | |
| 93. | GE | 1.31.11 | $B | | | | .001 | .005 | .013 | .019 | .044 | .070 | .110 | .210 | .480 | .690 | .940 | 1.300 | | | | | |
| 94. | National Cash Register | 1.31.13 | $B | | | | | .002 | .011 | .019 | .053 | .100 | .160 | .270 | .380 | .510 | .710 | .720 | .810 | .950 | 1.070 | 1.205 | 1.400 |
| 95. | Burroughs | 1.31.13 | $B | .006 | .009 | .014 | .033 | .045 | .045 | .055 | .070 | .120 | .180 | .270 | .360 | .450 | .660 | 1.040 | 1.220 | 1.750 | 2.020 | 2.244 | 2.800 |
| 96. | Control Data Corp. | 1.31.13 | $B | | | | | .004 | .014 | .039 | .080 | .160 | .320 | .540 | .810 | .980 | 1.340 | 1.400 | 1.550 | 1.630 | 1.880 | 1.996 | 2.200 |
| 97. | All Others | 1.31.13 | $B | .017 | .039 | .052 | .075 | .086 | .091 | .116 | .150 | .180 | .230 | .310 | .400 | .450 | .580 | .980 | 1.440 | 1.750 | 2.330 | 3.218 | 4.300 |
| 97a.* | DEC | | $B | | | | | | | | | | | | | | | .285 | .410 | .514 | .689 | .964 | 1.300 |
| 98. | Total–GP & Mini, WW | | $B | .180 | .340 | .600 | 1.030 | 1.600 | 2.270 | 3.210 | 4.400 | 5.960 | 8.150 | 11.154 | 15.860 | 20.425 | 26.250 | 32.580 | 37.020 | 40.805 | 44.790 | 47.928 | 54.100 |
| | GP & Mini, % of Val in Use, WW | | | | | | | | | | | | | | | | | | | | | | |
| 99. | IBM (Without PCM) | 1.31.10 | % | 67.7 | 71.7 | 73.1 | 73.7 | 76.4 | 78.4 | 79.6 | 80.0 | 78.6 | 75.9 | 71.9 | 69.7 | 69.5 | 68.3 | 69.1 | 68.1 | 65.9 | 63.5 | 60.5 | 59.1 |
| 100. | IBM Plug-Compat. Manu. | 1.31.10 | % | | | | | | | | | | | | .1 | .2 | .3 | .6 | 1.3 | 2.1 | 2.6 | 3.4 | 4.1 |
| 101. | IBM (with PCM) | 1.31.10 | % | 67.7 | 71.7 | 73.1 | 73.7 | 76.4 | 78.4 | 79.6 | 80.0 | 78.6 | 75.9 | 71.9 | 69.8 | 69.7 | 68.6 | 69.7 | 69.4 | 68.0 | 66.1 | 63.9 | 63.2 |
| 102. | Univac–Total with RCA | 1.31.10 | % | 19.4 | 14.0 | 14.8 | 15.2 | 14.2 | 13.3 | 11.5 | 9.6 | 9.0 | 9.4 | 10.0 | 9.9 | 9.9 | 10.2 | 9.3 | 9.1 | 8.3 | 7.6 | 7.5 | 7.2 |
| 103. | Univac | 1.31.12 | % | 19.4 | 14.0 | 14.8 | 13.7 | 12.7 | 11.6 | 9.4 | 7.3 | 6.5 | 6.7 | 7.3 | 7.1 | 7.0 | 7.0 | 5.9 | 6.0 | | | | |
| 104. | RCA | 1.31.12 | % | | | | 1.5 | 1.5 | 1.7 | 2.1 | 2.3 | 2.5 | 2.7 | 2.7 | 2.8 | 2.9 | 3.2 | 3.4 | 3.1 | | | | |
| 105. | Honeywell (HIS with GE) | 1.31.10 | % | | | .6 | .6 | 1.0 | 1.2 | 1.8 | 2.4 | 3.0 | 3.8 | 5.7 | 8.0 | 8.7 | 8.7 | 8.3 | 7.9 | 8.8 | 10.0 | 10.5 | 9.8 |
| 106. | Honeywell | 1.31.12 | % | | | .5 | .6 | .7 | .6 | 1.2 | 1.4 | 1.8 | 2.5 | 3.8 | 5.0 | 5.3 | 5.1 | 4.3 | | | | | |
| 107. | GE | 1.31.12 | % | | | | | .3 | .6 | .6 | 1.0 | 1.2 | 1.3 | 1.9 | 3.0 | 3.4 | 3.6 | 4.0 | | | | | |
| 108. | National Cash Register | 1.31.14 | % | | | | | .1 | .5 | .6 | 1.2 | 1.6 | 2.0 | 2.4 | 2.4 | 2.5 | 2.7 | 2.2 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 |
| 109. | Burroughs | 1.31.14 | % | 3.2 | 2.7 | 2.3 | 3.2 | 2.8 | 2.0 | 1.7 | 1.6 | 2.0 | 2.2 | 2.4 | 2.3 | 2.2 | 2.5 | 3.2 | 3.3 | 4.3 | 4.5 | 4.7 | 5.2 |
| 110. | Control Data Corp. | 1.31.14 | % | | | | | .3 | .6 | 1.2 | 1.8 | 2.7 | 3.9 | 4.8 | 5.1 | 4.8 | 5.1 | 4.3 | 4.2 | 4.0 | 4.2 | 4.2 | 4.1 |
| 111. | All Others | 1.31.14 | % | 9.7 | 11.6 | 8.6 | 7.3 | 5.3 | 4.0 | 3.6 | 3.4 | 3.1 | 2.8 | 2.8 | 2.5 | 2.2 | 2.2 | 3.0 | 3.9 | 4.3 | 5.2 | 6.7 | 7.9 |
| | **GP & Mini Av Val in Use WW** | | | | | | | | | | | | | | | | | | | | | | |
| 112. | IBM (without PCM) | 1.31.15 | $M | .619 | .405 | .379 | .380 | .393 | .405 | .417 | .415 | .405 | .403 | .413 | .404 | .371 | .410 | .473 | .496 | .463 | .439 | .410 | .419 |
| 113. | Plug-Compat. Manu | 1.31.15 | $M | | | | | | | | | | | | .001 | .001 | .002 | .004 | .009 | .015 | .018 | .023 | .029 |
| 114. | IBM with PCM | | $M | .619 | .405 | .379 | .380 | .393 | .405 | .417 | .415 | .405 | .403 | .413 | .405 | .372 | .412 | .477 | .505 | .477 | .457 | .433 | .448 |
| 115. | Univac–Total with RCA | 1.31.15 | $M | 1.591 | .716 | .824 | .683 | .585 | .499 | .381 | .414 | .284 | .202 | .205 | .254 | .309 | .361 | .316 | .323 | .336 | .342 | .369 | .429 |
| 116. | Univac | 1.31.16 | $M | 1.591 | .738 | .824 | .613 | .550 | .478 | .371 | .425 | .282 | .177 | .179 | .221 | .269 | .317 | .247 | .258 | | | | |
| 117. | RCA | 1.31.16 | $M | | | | | 1.263 | .709 | .432 | .384 | .290 | .314 | .338 | .409 | .484 | .513 | .617 | .633 | | | | |
| 118. | Honeywell (HIS with GE) | 1.31.15 | $M | | | | | | .491 | .339 | .419 | .390 | .393 | .356 | .382 | .377 | .350 | .306 | .270 | .242 | .262 | .263 | .263 |
| 119. | Honeywell | 1.31.16 | $M | | | | | | .318 | .629 | .534 | .588 | .414 | .348 | .360 | .345 | .315 | .284 | | | | | |
| 120. | GE | 1.31.16 | $M | | | | | | 1.272 | .174 | .321 | .255 | .358 | .374 | .424 | .433 | .414 | .334 | | | | | |
| 121. | National Cash Register | 1.31.17 | $M | | | | | | .132 | .117 | .126 | .134 | .138 | .155 | .173 | .181 | .141 | .139 | .122 | .134 | .145 | .156 | .160 |
| 122. | Burroughs | 1.31.17 | $M | .353 | .180 | .139 | .220 | .227 | .205 | .263 | .303 | .304 | .265 | .276 | .310 | .339 | .419 | .466 | .483 | .508 | .586 | .513 | .546 |
| 123. | Control Data Corp. | 1.31.17 | $M | | | | | .009 | .017 | .033 | .059 | .097 | .163 | .270 | .385 | .423 | .456 | .507 | .549 | .461 | .532 | .552 | .576 |
| 124. | All Others | 1.31.17 | $M | | 1.3 | .565 | .536 | .279 | .270 | .350 | .256 | .241 | .216 | .150 | .126 | .089 | .071 | .061 | .053 | .047 | .041 | .036 | .032 |
| 124a. | DEC | | $M | | | | | | | | | | | | | | | .034 | .031 | .030 | .030 | .030 | .028 |
| 125. | Total–GP & Mini, WW | 1.31.15 | $M | .732 | .422 | .353 | .352 | .356 | .349 | .351 | .356 | .342 | .329 | .334 | .349 | .335 | .348 | .353 | .334 | .304 | .275 | .234 | .211 |

* Line 97a is included in line 97. Line 98 is the sum of lines 87, 88, 91, and 94 through 97.

## TABLE II.1.31.1 SYSTEM MANUFACTURERS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GP & Mini Val Shipped WW** | | | | | | | | | | | | | | | | | | | | | | |
| 126. | IBM (without PCM) | 1.31.18 | $B | .050 | .131 | .217 | .347 | .481 | .588 | .887 | 1.129 | 1.295 | 1.605 | 2.040 | 3.410 | 4.540 | 4.900 | 4.800 | 4.300 | 4.300 | 5.660 | 5.974 | 6.960 |
| 127. | Plug-Compat. Manu. Ship | 1.31.18 | $B | | | | | | | | | | | | .015 | .025 | .050 | .110 | .280 | .370 | .410 | .574 | .735 |
| 128. | Univac—Total (with RCA) | 1.31.18 | $B | .007 | .014 | .044 | .068 | .079 | .085 | .083 | .092 | .175 | .280 | .340 | .460 | .560 | .670 | .650 | .710 | .560 | .490 | .554 | .590 |
| 129. | Univac | 1.31.20 | $B | .007 | .014 | .044 | .063 | .071 | .072 | .051 | .048 | .125 | .205 | .260 | .320 | .380 | .420 | .380 | .450 | | | | |
| 130. | RCA | 1.31.20 | $B | | | | .005 | .008 | .013 | .032 | .044 | .050 | .075 | .080 | .140 | .180 | .250 | .270 | .260 | | | | |
| 131. | Honeywell (HIS with GE) | 1.31.18 | $B | | | .003 | .003 | .009 | .012 | .038 | .052 | .080 | .170 | .370 | .640 | .610 | .540 | .580 | .550 | .680 | .880 | .831 | .685 |
| 132. | Honeywell | 1.31.20 | $B | | | .003 | .003 | .005 | .004 | .029 | .027 | .050 | .130 | .250 | .370 | .360 | .290 | | | | | | |
| 133. | GE | 1.31.20 | $B | | | | | .004 | .008 | .009 | .025 | .030 | .040 | .120 | .270 | .250 | .250 | | | | | | |
| 134. | National Cash Register | 1.31.22 | $B | | | | | .002 | .008 | .009 | .039 | .055 | .090 | .110 | .130 | .160 | .200 | .200 | .250 | .270 | .210 | .270 | .320 |
| 135. | Burroughs | 1.31.22 | $B | .002 | .003 | .004 | .019 | .013 | .004 | .009 | .017 | .055 | .065 | .090 | .090 | .130 | .210 | .380 | .390 | .530 | .430 | .456 | .565 |
| 136. | Control Data Corp. | 1.31.22 | $B | | | | | | .010 | .025 | .041 | .095 | .175 | .220 | .280 | .240 | .360 | .270 | .210 | .180 | .260 | .243 | .230 |
| 137. | All Others | 1.31.22 | $B | .006 | .021 | .016 | .023 | .017 | .013 | .028 | .038 | .047 | .062 | .080 | .090 | .110 | .160 | .400 | .460 | .310 | .580 | .673 | 1.150 |
| 137a. | DEC | | $B | | | | | | | | | | | | | | | .080 | .130 | .140 | .180 | .275 | .432 |
| 138. | Total Shipments | | $B | .065 | .169 | .285 | .460 | .600 | .720 | 1.080 | 1.408 | 1.802 | 2.447 | 3.250 | 5.115 | 6.375 | 7.090 | 7.389 | 7.145 | 7.205 | 8.915 | 9.575 | 11.235 |
| | GP & Mini, % of Val. Shipped | | | | | | | | | | | | | | | | | | | | | | |
| 139. | IBM (without PCM) | 1.31.19 | % | 77.2 | 77.5 | 76.4 | 75.3 | 80.1 | 81.7 | 82.1 | 80.1 | 71.9 | 65.5 | 62.7 | 66.7 | 71.2 | 69.1 | 65.0 | 60.2 | 59.7 | 63.5 | 62.4 | 61.9 |
| 140. | Plug-Compat. Manu. | 1.31.19 | % | | | | | | | | | | | | 0.3 | 0.4 | 0.7 | 1.5 | 3.9 | 5.1 | 4.6 | 6.0 | 6.5 |
| 141. | Univac—Total with RCA | 1.31.19 | % | 10.5 | 8.3 | 15.3 | 14.8 | 13.2 | 11.8 | 7.7 | 6.5 | 9.7 | 11.5 | 10.5 | 9.0 | 8.8 | 9.4 | 8.8 | 9.9 | 7.8 | 5.5 | 5.8 | 5.3 |
| 142. | Univac | 1.31.21 | % | 10.5 | 8.3 | 15.3 | 13.6 | 11.8 | 10.0 | 4.7 | 3.4 | 6.9 | 8.4 | 8.0 | 6.2 | 5.9 | 5.9 | 5.1 | 6.3 | | | | |
| 143. | RCA | 1.31.21 | % | | | | 1.2 | 1.4 | 1.8 | 3.0 | 3.1 | 2.8 | 3.1 | 2.5 | 2.7 | 2.9 | 3.5 | 3.7 | 3.6 | | | | |
| 144. | Honeywell (HIS with GE) | 1.31.19 | % | | | 1.1 | 0.7 | 1.5 | 1.6 | 3.5 | 3.7 | 4.4 | 7.0 | 11.4 | 12.5 | 9.6 | 7.6 | 7.8 | 7.7 | 9.4 | 9.9 | 8.7 | 6.1 |
| 145. | Honeywell | 1.31.21 | % | | | 1.1 | 0.7 | 0.8 | 0.6 | 2.7 | 1.9 | 2.8 | 5.3 | 7.7 | 7.2 | 5.6 | 4.1 | | | | | | |
| 146. | GE | 1.31.21 | % | | | | | 0.7 | 1.0 | 0.8 | 1.8 | 1.7 | 1.7 | 3.7 | 5.3 | 4.0 | 3.5 | | | | | | |
| 147. | National Cash Register | 1.31.23 | % | | | | | 0.3 | 1.1 | 0.8 | 2.8 | 3.1 | 3.6 | 3.4 | 2.5 | 2.5 | 2.8 | 2.7 | 3.5 | 3.7 | 2.4 | 2.8 | 2.8 |
| 148. | Burroughs | 1.31.23 | % | 3.5 | 1.8 | 1.5 | 4.2 | 2.1 | 0.6 | 0.8 | 1.2 | 3.1 | 2.7 | 2.8 | 1.8 | 2.0 | 3.0 | 5.1 | 5.5 | 7.4 | 4.8 | 4.8 | 5.0 |
| 149. | Control Data Corp. | 1.31.23 | % | | | | | | 1.4 | 2.4 | 2.9 | 5.3 | 7.2 | 6.8 | 5.5 | 3.8 | 5.1 | 3.7 | 2.9 | 2.5 | 2.9 | 2.5 | 2.0 |
| 150. | All Others | 1.31.23 | % | 8.8 | 12.4 | 5.7 | 5.0 | 2.8 | 1.8 | 2.7 | 2.7 | 2.6 | 2.5 | 2.5 | 1.8 | 1.7 | 2.3 | 5.4 | 6.4 | 4.3 | 6.5 | 7.0 | 10.2 |
| 150a. | DEC | | % | | | | | | | | | | | | | | | 1.1 | 1.8 | 1.9 | 2.0 | 2.9 | 3.8 |

value in use" figure from the March 30, 1973, *EDP/IR*. Since 1971, *EDP/IR* has explicitly shown the value of plug-compatible shipments and installations. In earlier years, such equipment was included in the IBM total. The percentage figures shown on lines 99 and 101 were derived with those facts in mind. In other words, for the years 1966 through 1970, I computed the IBM plug-compatible percentage on line 100 by dividing line 86 by line 98. I then computed the percentages on line 99 by subtracting line 100 from line 101 for those five years. For the years since 1971, on the other hand, I computed the percentages on line 101 by adding lines 99 and 100—where line 99 came from *EDP/IR*, and line 100 was again computed by dividing line 86 by line 98.

**GP and MiniSystem Average Value.** 112-125. These average values were computed by dividing the total value in use figures from lines 85 through 98 by the total number of systems in use from lines 67 through 84. In every case the divisor was the *total* number of systems in use, including both GP and mini systems. Note that, since the 1955 through 1968 data on value of systems in use and number of systems in use come from two different sources, the averages are perhaps to be viewed with an extra helping of suspicion.

**GP and Minisystem Worldwide Shipments.** 126-150. These figures were derived in three steps. I started with percentages of total value shipped (lines 139 to 150)—the 1955 to 1967 from a private source, and the remaining figures from the annual survey issues of *EDP/IR*. I applied these percentages to the figure for total worldwide GP and mini shipments from Table II.1.21, line 136. I compared the resulting annual shipments with the "total value in use" figures from lines 85 through 98, above. For various manufacturers in various years, I found inconsistencies of the type "value in use last year plus value shipped this year is less than value in use this year". I corrected all such inconsistencies by adjusting shipment values (except for the year 1971 where I also adjusted "in use" values, as described above), and when I had a reasonable-looking set of adjusted shipment figures, I recomputed the percentages on lines 139 to 150.

It would, of course, be desirable to derive shipment values and in-use values directly from financial data provided by the various manufacturers in their reports to stockholders and to the S.E.C. However, several factors make it impossible for one to achieve this end. In the first place, most manufacturers derive their income from a variety of sources, some completely unrelated to the computer business (typewriters, heater controls, scientific instruments, cash registers, etc.), and some part of the data processing industry but unrelated to system shipments (computer services, supplies shipments, revenue from accounting machines and data entry equipment, etc.). It is therefore often impossible to determine, for such companies, the amount of revenue associated with system shipments. In the second place, companies report revenue, not shipments, and revenue in a given year includes payments for systems purchased that year plus rental or lease income from systems installed both in that year and in any previous years. The lease revenue is a function of the value of equipment shipped in previous years, the proportion of such shipments which were leased rather than purchased, the number of leased systems which were subsequently returned to the manufacturer, and the number leased systems which were subsequently purchased by the user. Since none of these factors is known for any given manufacturer, it is impossible to deduce shipment data from revenue data.

## Table II.1.31.2 DISTRIBUTION OF GP SYSTEMS—NOTES

This table is derived from the end-year census published by *EDP/IR* for the years 1964, 1969 and 1974, and by *C & A* (July, 1960 issue) for 1959. Worldwide installations of GP computers manufactured by American firms are included in all censuses except for that of 1959, which excludes foreign business. The seven cost categories were arbitrarily chosen to cover the ranges of system *selling price* of 0-$125k, $125k-$250k, $250k-$500k, $500k-$1M, $1M-$2M, $2M-$4M, and over $4M—the same ranges employed in lines 147-153 of Table II.1.21 (q.v.). However, note that the data in that table represents a non-uniform mixture of domestic and foreign systems, and of GP and mini systems. Note also that, especially in the early years, the reclassification of a system (a change in its estimated average rental from one census to the next) can make a large difference in some percentage figures. I have eliminated such reclassifications in this table, though there may be some in some entries of Table II.1.21.

The entries for "number of systems" are copied from the various censuses. The "system value" entries were computed by multiplying the "number of systems" figure for each system model number by the average rental for that model number, as given in the census. (The 1959 census did not give average rental data, and consequently I used rental figures from the 1964 census in computing 1959 values.) Percentages are computed in the obvious way.

In classifying systems, I have lumped GE systems in with HIS, and RCA in with Univac. "Others" include DEC, Philco, Singer, Standard Computer Corp., and XDS (formerly SDS.)

### TABLE II.1.31.2 DISTRIBUTION OF GP SYSTEMS, WW, BY SIZE AND MANUFACTURER ●

| Manufacturer Year | Range of System Sizes, in $k per Month 0-3.2 | 3.2-6.3 | 6.3-12.5 | 12.5-25 | 25-50 | 50-100 | Over 100 | Total |
|---|---|---|---|---|---|---|---|---|
| NUMBER OF SYSTEMS | | | | | | | | |
| Burroughs—1959 | 0 | 26 | 94 | 31 | 0 | 0 | 0 | 151 |
| 1964 | 114 | 246 | 189 | 65 | 13 | 0 | 0 | 627 |
| 1969 | 0 | 549 | 1158 | 298 | 164 | 0 | 2 | 2171 |
| 1974 | 1196 | 758 | 1553 | 1033 | 429 | 153 | 7 | 5129 |
| CDC—1959 | - | - | - | - | - | - | - | - |
| 1964 | 0 | 0 | 15 | 28 | 60 | 27 | 1 | 131 |
| 1969 | 0 | 0 | 139 | 131 | 381 | 33 | 80 | 764 |
| 1974 | 0 | 0 | 130 | 139 | 340 | 222 | 130 | 961 |
| HIS—1959 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 7 |
| 1964 | 5 | 349 | 160 | 129 | 9 | 0 | 0 | 652 |
| 1969 | 2866 | 1067 | 2261 | 691 | 115 | 105 | 0 | 7105 |
| 1974 | 6165 | 3444 | 1511 | 2140 | 463 | 320 | 6 | 14049 |
| NCR—1959 | 0 | 30 | 0 | 3 | 0 | 0 | 0 | 33 |
| 1964 | 781 | 0 | 250 | 26 | 0 | 0 | 0 | 1057 |
| 1969 | 3970 | 0 | 925 | 172 | 0 | 0 | 0 | 5067 |
| 1974 | 6745 | 671 | 1290 | 64 | 0 | 0 | 0 | 8770 |
| Univac—1959 | 0 | 0 | 51 | 118 | 125 | 0 | 5 | 299 |
| 1964 | 2150 | 530 | 500 | 199 | 106 | 0 | 5 | 3490 |
| 1969 | 5216 | 1290 | 1571 | 768 | 324 | 218 | 1 | 9388 |
| 1974 | 4410 | 1821 | 1020 | 967 | 553 | 328 | 0 | 9099 |
| Others—1959 | 42 | 0 | 0 | 0 | 0 | 3 | 0 | 45 |
| 1964 | 24 | 0 | 17 | 0 | 19 | 5 | 0 | 65 |
| 1969 | 0 | 0 | 374 | 113 | 92 | 13 | 0 | 592 |
| 1974 | 1950 | 243 | 88 | 872 | 79 | 7 | 0 | 3239 |
| Subtotal—1959 | 42 | 56 | 145 | 152 | 132 | 3 | 5 | 535 |
| 1964 | 3074 | 1125 | 1131 | 447 | 207 | 32 | 6 | 6022 |
| 1969 | 12052 | 2906 | 6428 | 2173 | 1076 | 369 | 83 | 25087 |
| 1974 | 20466 | 6937 | 5592 | 5215 | 1864 | 1030 | 143 | 41247 |
| IBM—1959 | 0 | 1784 | 276 | 0 | 335 | 2 | 0 | 2397 |
| 1964 | 1920 | 9546 | 1383 | 632 | 174 | 415 | 6 | 14076 |
| 1969 | 16462 | 7470 | 13245 | 4850 | 2239 | 1065 | 86 | 45417 |
| 1974 | 34688 | 10766 | 10332 | 7331 | 4182 | 2789 | 509 | 70597 |
| Total—1959 | 42 | 1840 | 421 | 152 | 467 | 5 | 5 | 2932 |
| 1964 | 4994 | 10671 | 2514 | 1079 | 381 | 447 | 12 | 20098 |
| 1969 | 28514 | 10376 | 19673 | 7023 | 3315 | 1434 | 169 | 70504 |
| 1974 | 55154 | 17703 | 15924 | 12546 | 6046 | 3819 | 652 | 111,844 |

## TABLE II.1.31.2 DISTRIBUTION OF GP SYSTEMS, WW, BY SIZE AND MANUFACTURER (continued) ●

| Manufacturer Year | Range of System Sizes, in $k per Month 0-3.2 | 3.2-6.3 | 6.3-12.5 | 12.5-25 | 25-50 | 50-100 | Over 100 | Total |
|---|---|---|---|---|---|---|---|---|
| **SYSTEM VALUE, IN $M PER MONTH** | | | | | | | | |
| Burroughs—1959 | 0 | 0.09 | 0.66 | 0.43 | 0 | 0 | 0 | 1.18 |
| 1964 | 0.09 | 1.02 | 0.71 | 0.96 | 0.46 | 0 | 0 | 3.23 |
| 1969 | 0 | 2.51 | 8.54 | 4.17 | 6.19 | 0 | 0.40 | 21.81 |
| 1974 | 2.32 | 4.16 | 11.45 | 17.34 | 12.64 | 8.80 | 0.84 | 57.55 |
| CDC—1959 | - | - | - | - | - | - | - | - |
| 1964 | 0 | 0 | 0.18 | 0.45 | 2.28 | 1.57 | 0.11 | 4.59 |
| 1969 | 0 | 0 | 1.46 | 2.13 | 11.21 | 1.80 | 10.39 | 26.99 |
| 1974 | 0 | 0 | 1.18 | 2.32 | 11.25 | 12.57 | 16.92 | 44.24 |
| HIS—1959 | 0 | 0 | 0 | 0 | 0.28 | 0 | 0 | 0.28 |
| 1964 | 0.01 | 1.62 | 1.24 | 2.43 | 0.31 | 0 | 0 | 5.61 |
| 1969 | 6.20 | 5.19 | 18.95 | 12.26 | 3.52 | 7.87 | 0 | 53.99 |
| 1974 | 12.30 | 16.09 | 12.44 | 33.93 | 15.02 | 20.10 | 0.68 | 110.56 |
| NCR—1959 | 0 | 0.11 | 0 | 0.04 | 0 | 0 | 0 | 0.15 |
| 1964 | 1.45 | 0 | 2.13 | 0.36 | 0 | 0 | 0 | 3.94 |
| 1969 | 5.47 | 0 | 8.13 | 2.18 | 0 | 0 | 0 | 15.78 |
| 1974 | 14.01 | 3.35 | 11.02 | 1.45 | 0 | 0 | 0 | 29.83 |
| Univac—1959 | 0 | 0 | 0.41 | 1.77 | 3.58 | 0 | 0.50 | 6.26 |
| 1964 | 4.09 | 3.18 | 4.08 | 3.28 | 3.29 | 0 | 0.57 | 18.48 |
| 1969 | 10.23 | 5.24 | 13.67 | 14.21 | 10.20 | 14.45 | 0.13 | 68.14 |
| 1974 | 8.29 | 7.80 | 10.86 | 18.44 | 21.54 | 24.67 | 0 | 91.60 |
| Other—1959 | 0.11 | 0 | 0 | 0 | 0 | 0.20 | 0 | 0.31 |
| 1964 | 0.04 | 0 | 0.12 | 0 | 0.76 | 0.26 | 0 | 1.18 |
| 1969 | 0 | 0 | 3.43 | 1.87 | 2.50 | 0.68 | 0 | 8.47 |
| 1974 | 4.97 | 0.85 | 0.75 | 14.21 | 3.14 | 0.36 | 0 | 24.28 |
| Subtotal—1959 | 0.10 | 0.20 | 1.07 | 2.25 | 3.86 | 0.20 | 0.50 | 8.17 |
| 1964 | 5.69 | 5.82 | 8.46 | 7.48 | 7.09 | 1.83 | 0.68 | 37.04 |
| 1969 | 21.90 | 12.93 | 54.19 | 36.83 | 33.62 | 24.80 | 10.92 | 195.20 |
| 1974; | 41.89 | 32.25 | 47.70 | 87.69 | 63.59 | 66.50 | 18.44 | 358.06 |
| IBM-1959 | 0 | 6.92 | 2.46 | 0 | 10.79 | 0.13 | 0 | 20.29 |
| 1964 | 4.56 | 41.18 | 14.53 | 14.28 | 5.23 | 28.06 | 0.96 | 108.80 |
| 1969 | 41.24 | 39.22 | 134.48 | 92.78 | 72.75 | 67.59 | 12.36 | 460.42 |
| 1974 | 83.58 | 43.45 | 106.92 | 135.96 | 132.98 | 183.40 | 60.93 | 747.22 |
| Total—1959 | 0.10 | 7.11 | 3.53 | 2.24 | 14.65 | 0.33 | 0.50 | 28.47 |
| 1964 | 10.25 | 47.00 | 22.99 | 21.77 | 12.32 | 29.88 | 1.64 | 145.84 |
| 1969 | 63.14 | 52.15 | 188.67 | 129.62 | 106.35 | 92.39 | 23.28 | 655.62 |
| 1974 | 125.47 | 75.70 | 154.62 | 223.65 | 196.57 | 249.90 | 79.37 | 1105.28 |

**TABLE II.1.31.2 DISTRIBUTION OF GP SYSTEMS, WW, BY SIZE AND MANUFACTURER (continued) ●**

| Manufacturer Year | Range of System Sizes, in $k per Month 0-3.2 | 3.2-6.3 | 6.3-12.5 | 12.5-25 | 25-50 | 50-100 | Over 100 | Total |
|---|---|---|---|---|---|---|---|---|
| **PERCENT DISTRIBUTION, BY NUMBER** | | | | | | | | |
| Burroughs—1959 | 0 | 0.9 | 3.2 | 1.1 | 0 | 0 | 0 | 5.2 |
| 1964 | 0.6 | 1.2 | 0.9 | 0.3 | 0.1 | 0 | 0 | 3.1 |
| 1969 | 0 | 0.8 | 1.6 | 0.4 | 0.2 | 0 | 0 | 3.1 |
| 1974 | 1.1 | 0.7 | 1.4 | 0.9 | 0.4 | 0.1 | 0 | 4.6 |
| CDC—1959 | - | - | - | - | - | - | - | - |
| 1964 | 0 | 0 | 0.1 | 0.1 | 0.3 | 0.1 | 0 | 0.6 |
| 1969 | 0 | 0 | 0.2 | 0.2 | 0.5 | 0 | 0.1 | 1.1 |
| 1974 | 0 | 0 | 0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.9 |
| HIS—1959 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0.2 |
| 1964 | 0 | 1.7 | 0.8 | 0.6 | 0 | 0 | 0 | 3.2 |
| 1969 | 4.1 | 1.5 | 3.2 | 1.0 | 0.2 | 0.1 | 0 | 10.1 |
| 1974 | 5.5 | 3.1 | 1.4 | 1.9 | 0.4 | 0.3 | 0 | 12.6 |
| NCR-1959 | 0 | 1.0 | 0 | 0.1 | 0 | 0 | 0 | 1.1 |
| 1964 | 3.9 | 0 | 1.2 | 0.1 | 0 | 0 | 0 | 5.2 |
| 1969 | 5.6 | 0 | 1.3 | 0.2 | 0 | 0 | 0 | 7.2 |
| 1974 | 6.0 | 0.6 | 1.2 | 0.1 | 0 | 0 | 0 | 7.8 |
| Univac—1959 | 0 | 0 | 1.7 | 4.0 | 4.3 | 0 | 0.2 | 10.2 |
| 1964 | 10.7 | 2.6 | 2.5 | 1.0 | 0.5 | 0 | 0 | 17.4 |
| 1969 | 7.4 | 1.8 | 2.2 | 1.1 | 0.5 | 0.3 | 0 | 13.3 |
| 1974 | 3.9 | 1.6 | 0.9 | 0.9 | 0.5 | 0.3 | 0 | 8.1 |
| Others—1959 | 1.4 | 0 | 0 | 0 | 0 | 0.1 | 0 | 1.5 |
| 1964 | 0.1 | 0 | 0.1 | 0 | 0.1 | 0 | 0 | 0.3 |
| 1969 | 0 | 0 | 0.5 | 0.2 | 0.1 | 0 | 0 | 0.8 |
| 1974 | 1.7 | 0.2 | 0.1 | 0.8 | 0.1 | 0 | 0 | 2.9 |
| Subtotal—1959 | 1.4 | 1.9 | 4.9 | 5.2 | 4.5 | 0.1 | 0.2 | 18.2 |
| 1964 | 15.3 | 5.6 | 5.6 | 2.2 | 1.0 | 0.2 | 0 | 30.0 |
| 1969 | 17.1 | 4.1 | 9.1 | 3.1 | 1.5 | 0.5 | 0.1 | 35.6 |
| 1974 | 18.3 | 6.2 | 5.0 | 4.7 | 1.7 | 0.9 | 0.1 | 36.9 |
| IBM—1959 | 0 | 60.8 | 9.4 | 0 | 11.4 | 0.1 | 0 | 81.8 |
| 1964 | 9.6 | 47.5 | 6.9 | 3.1 | 0.9 | 2.1 | 0 | 70.0 |
| 1969 | 23.3 | 10.6 | 18.8 | 6.9 | 3.2 | 1.5 | 0.1 | 64.4 |
| 1974 | 31.0 | 9.6 | 9.2 | 6.6 | 3.7 | 2.5 | 0.5 | 63.1 |
| Total—1959 | 1.4 | 62.8 | 14.4 | 5.2 | 15.9 | 0.2 | 0.2 | 100.0 |
| 1964 | 24.8 | 53.1 | 12.5 | 5.4 | 1.9 | 2.2 | 0.1 | 100.0 |
| 1969 | 40.4 | 14.7 | 27.9 | 10.0 | 4.7 | 2.0 | 0.2 | 100.0 |
| 1974 | 49.3 | 15.8 | 14.2 | 11.2 | 5.4 | 3.4 | 0.6 | 100.0 |

**TABLE II.1.31.2 DISTRIBUTION OF GP SYSTEMS, WW, BY SIZE AND MANUFACTURER (continued) ●**

| Manufacturer Year | 0-3.2 | 3.2-6.3 | 6.3-12.5 | 12.5-25 | 25-50 | 50-100 | Over 100 | Total |
|---|---|---|---|---|---|---|---|---|
| | Range of System Sizes, in $k per Month | | | | | | | |
| **PERCENT DISTRIBUTION, BY VALUE** | | | | | | | | |
| Burroughs—1959 | 0 | 0.3 | 2.3 | 1.5 | 0 | 0 | 0 | 4.1 |
| 1964 | 0.1 | 0.7 | 0.5 | 0.7 | 0.3 | 0 | 0 | 2.2 |
| 1969 | 0 | 0.4 | 1.3 | 0.6 | 0.9 | 0 | 0.1 | 3.3 |
| 1974 | 0.2 | 0.4 | 1.0 | 1.6 | 1.1 | 0.8 | 0.1 | 5.2 |
| CDC—1959 | - | - | - | - | - | - | - | - |
| 1964 | 0 | 0 | 0.1 | 0.3 | 1.6 | 1.1 | 0.1 | 3.1 |
| 1969 | 0 | 0 | 0.2 | 0.3 | 1.7 | 0.3 | 1.6 | 4.1 |
| 1974 | 0 | 0 | 0.1 | 0.2 | 1.0 | 1.1 | 1.5 | 4.0 |
| HIS—1959 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 | 1.0 |
| 1964 | 0 | 1.1 | 0.9 | 1.7 | 0.2 | 0 | 0 | 3.8 |
| 1969 | 0.9 | 0.8 | 2.9 | 1.9 | 0.5 | 1.2 | 0 | 8.2 |
| 1974 | 1.1 | 1.5 | 1.1 | 3.1 | 1.4 | 1.8 | 0.1 | 10.0 |
| NCR—1959 | 0 | 0.4 | 0 | 0.1 | 0 | 0 | 0 | 0.5 |
| 1964 | 1.0 | 0 | 1.5 | 0.2 | 0 | 0 | 0 | 2.7 |
| 1969 | 2.1 | 0.5 | 1.7 | 0.2 | 0 | 0 | 0 | 4.5 |
| 1974 | 1.3 | 0.3 | 1.0 | 0.1 | 0 | 0 | 0 | 2.7 |
| Univac—1959 | 0 | 0 | 1.4 | 6.2 | 12.6 | 0 | 1.8 | 22.0 |
| 1964 | 2.8 | 2.2 | 2.8 | 2.2 | 2.3 | 0 | 0.4 | 12.7 |
| 1969 | 1.6 | 0.8 | 2.1 | 2.2 | 1.6 | 2.2 | 0 | 10.4 |
| 1974 | 0.8 | 0.7 | 1.0 | 1.7 | 1.9 | 2.2 | 0 | 8.3 |
| Others—1959 | 0.4 | 0 | 0 | 0 | 0 | 0.7 | 0 | 1.1 |
| 1964 | 0 | 0 | 0.1 | 0 | 0.5 | 0.2 | 0 | 0.8 |
| 1969 | 0 | 0 | 0.5 | 0.3 | 0.4 | 0.1 | 0 | 1.3 |
| 1974 | 0.4 | 0.1 | 0.1 | 1.3 | 0.3 | 0 | 0 | 2.2 |
| Subtotal—1959 | 0.4 | 0.7 | 3.8 | 7.9 | 13.6 | 0.7 | 1.8 | 28.7 |
| 1964 | 3.9 | 4.0 | 5.8 | 5.1 | 4.9 | 1.3 | 0.5 | 25.4 |
| 1969 | 3.3 | 2.0 | 8.3 | 5.6 | 5.1 | 3.8 | 1.7 | 29.8 |
| 1974 | 3.8 | 2.9 | 4.3 | 7.9 | 5.8 | 6.0 | 1.7 | 32.4 |
| IBM—1959 | 0 | 24.3 | 8.6 | 0 | 37.9 | 0.5 | 0 | 71.3 |
| 1964 | 3.1 | 28.2 | 10.0 | 9.8 | 3.6 | 19.2 | 0.7 | 74.6 |
| 1969 | 6.3 | 6.0 | 20.5 | 14.2 | 11.1 | 10.3 | 1.9 | 70.2 |
| 1974 | 7.6 | 3.9 | 9.7 | 12.3 | 12.0 | 16.6 | 5.5 | 67.6 |
| Total—1959 | 0.4 | 25.0 | 12.4 | 7.9 | 51.4 | 1.2 | 1.8 | 100 |
| 1964 | 7.0 | 32.2 | 15.8 | 14.9 | 8.4 | 20.5 | 1.1 | 100 |
| 1969 | 9.6 | 8.0 | 28.8 | 19.8 | 16.2 | 14.1 | 3.6 | 100 |
| 1974 | 11.4 | 6.8 | 14.0 | 20.2 | 17.8 | 22.6 | 7.2 | 100 |

## TABLE II.1.310 SYSTEM COMPANIES—NOTES

The data in this table, for the four major system companies not covered in later tables, comes from annual reports, 10K reports, S&PCR, and MoodI.

**Burroughs Corporation.** 1-3. Total revenue, on line 1, is identified as "gross operating income". Line 2 shows net income after taxes and line 3 is the quotient of lines 2 and 1.

4-23. Burroughs has provided a variety of analyses of total revenue in recent annual reports and 10K reports, and four of them are reproduced here, identified as A,B,C, and D. The relationship between the various revenue breakdowns is not very easy to understand, although it appears that analysis C, on lines 16 through 19, is based on organizational entities, while the others are based on products and services. Here are some explanatory comments, keyed to various specific lines:

9-12. Standard equipment is broken down into large and medium computer systems, small computer systems and business minis, and "small application machines".

20. Both standard and custom computer systems are included here, along with peripherals, terminals, and data encoding equipment.

21. This line includes commercial minicomputers, accounting machines and systems, and "small application machines."

22. The 1968 to 1971 entries on this line were supplied by Burroughs, and are consistent with the number given in a different breakdown on line 15. The entries for years 1955 through 1967 are my own estimates of Burroughs business forms and supplies business, and are based on nothing more then a guess, plus the fact that Burroughs described itself as being in the "forms, equipment, and supplies" business starting in the early sixties, and mentioned "hand posting and accounting machine forms, etc." in the late 1950's.

23. This line is described as "custom products and services, and electronic components."

24. The entries for the years 1955 through 1967 are from HarmA71. The data is intended to show that proportion of total corporate revenue which comes from computer operations, and Harman says it is "a very crude index, based on linear interpolation of quite fragmentary information." His 1967 figure for Burroughs comes from an analysis of the 1967 annual report, and other figures are derived by interpolation between that number and estimates of 5%, 10%, and 20% for 1950, 1955, and 1960.

25-26. Burroughs has reported its net investment in rental equipment (line 26) in annual reports since 1955. The gross value of rental equipment has only been reported, as nearly as I can ascertain, since 1962.

27-28. Research and development expenses as reported by Burroughs are shown on line 27, and line 28 is the quotient of lines 27 and 1.

**Honeywell (and GE).** 29-31. Line 29 is total sales, services, and rentals, not including "other income". Line 30 is net income after taxes, but before extraordinary items. Line 31 is the quotient of line 30 and 29.

32-37. The revenue breakdowns shown in lines 32 to 36 have been consistently supplied by Honeywell since 1964. "Automation systems" on line 33 were originally called "industry controls". Computer and communication equipment on line 35 is also called "information systems". Note that line 32 through 36 add to 100%. International revenue, on line 37, is overseas revenue from all Honeywell products, not just computers. I could not find figures for the years 1967 through 1969. The "computer and communications" figures on line 35 for the years 1960 through 1963 are my own extrapolations of the later data.

38-39. These figures include the Honeywell (and, starting in 1970, the General Electric) computer equipment on lease. They may also include other leased Honeywell products, but certainly most of the equipment is computer equipment.

40-41. I could find no record of Honeywell research and development expenses before 1970. Line 41 is the quotient of lines 40 and line 29.

42-48. Shortly after General Electric went out of the computer business, and Honeywell acquired GE's computer products and customer base, Honeywell presented a revised statement of revenue and income. Line 42 shows what Honeywell's revenue would have been for the years 1966 through 1969 if GE's revenue were included; and line 43 shows the corresponding figures for net income. The difference between line 42 and line 29, then, represents GE computer revenue for those four years, and is shown on line 44. The difference between lines 43 and 30 was GE's net income from its computer business, and is shown on line 45. Honeywell's "computer and communications" revenue, from which the percentages on line 35 were calculated, is given on line 46. Line 47, which represents total computer revenue for both Honeywell and GE, is shown as reported by Honeywell for the years 1970 to 1972, and is the sum of lines 44 and 46 for the years 1966 through 1969. I was unable to estimate GE's computer revenue or income for the years before 1966. Line 48 is the ratio of line 47 to line 29.

Incidentally, the data presented here on lines 44 and 46 seems to be inconsistent with the data presented in Table II.1.31 on General Electric's and Honeywell's worldwide shipments. For the years 1966 to 1969, lines 44 and 46 show that GE's revenue from the computer business was substantially higher than Honeywell's. Looking at line 92, 93, 132, and 133 of Table II.1.31, we find I had estimated both Honeywell's shipments and Honeywell's value in use as greater than General Electric's. In view of the data on line 44 of this table, it would appear that Table II.1.31 understates GE's computer shipments and installed base. Probably I greatly underestimate GE's international computer business.

**National Cash Register Corp.** 49-51. Line 49 shows NCR's "income from sales, service, and equipment rentals." Net income after taxes is shown on line 50, and line 51 is the quotient of lines 50 and 49.

52-60. Lines 52, 58, 59, and 60 provide a breakdown of NCR revenues, to the extent that such a breakdown has been made available. The lightface figures are my own estimates for the years when NCR did not provide a breakdown. Equipment revenue, on line 52, is discussed below. Services, on line 58, are primarily maintenace services for all NCR products; and supplies, on line 59, are data processing supplies excluding NCR's "carbonless" paper. The "other" category, on line 60, includes defense contract receipts and NCR paper. (The "carbonless" paper is a major source of NCR revenue,

## TABLE II.1.310 SYSTEM COMPANIES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Burroughs Corp.** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Total Revenue | 1.310.1 | $B | .220 | .273 | .283 | .294 | .359 | .389 | .399 | .423 | .387 | .390 | .457 | .490 | .551 | .651 | .752 | .884 | .933 | 1.040 | 1.284 | 1.533 |
| 2. | Net Income | | $B | .012 | .014 | .010 | .006 | .007 | .009 | .010 | .009 | .009 | .010 | .018 | .033 | .035 | .043 | .055 | .067 | .074 | .088 | .116 | .143 |
| 3. | % of Revenue | 1.310.2 | % | 5.5 | 5.1 | 3.5 | 2.0 | 1.9 | 2.3 | 2.5 | 2.1 | 2.3 | 2.6 | 3.9 | 6.7 | 6.4 | 6.6 | 7.3 | 7.6 | 7.9 | 8.5 | 9.0 | 9.3 |
| | Revenue Analyses–% Tot. Rev. | | | | | | | | | | | | | | | | | | | | | | |
| 4. | A–Business Mach. Sales | | % | | | | | | | | | | | | | | | 48 | 50 | 47 | 45 | | |
| 5. | Rentals | | % | | | | | | | | | | | | | | | 18 | 19 | 22 | 18 | | |
| 6. | Field Engineering Services | | | | | | | | | | | | | | | | | 13 | 13 | 14 | 19 | | |
| 7. | Business Forms & Supplies | | % | | | | | | | | | | | | | | | 10 | 9 | 10 | 8 | | |
| 8. | Other | | % | | | | | | | | | | | | | | | 11 | 9 | 7 | 10 | | |
| 9. | B–Standard Equipment | 1.310.1 | % | | | | | | | | | | | | | 57.7 | 55.9 | 61.7 | 65.1 | 64.6 | 66.7 | 64.9 | 66.6 |
| 10. | Large & Medium Systems | | % | | | | | | | | | | | | | | | 29.6 | 35.0 | 34.0 | 37.0 | 37.5 | 39.1 |
| 11. | Small & Business Minis | | % | | | | | | | | | | | | | | | 4.8 | 7.6 | 13.8 | 17.6 | 18.2 | 20.1 |
| 12. | Small Applications Mach. | | % | | | | | | | | | | | | | | | 27.1 | 22.0 | 16.9 | 12.0 | 9.1 | 7.3 |
| 13. | Cust. Prod. & Comp. | 1.310.1 | % | | | | | | | | | | | | | | | 10.4 | 8.3 | 7.0 | 4.5 | 5.8 | 3.7 |
| 14. | Field Eng'g. Serv. | 1.310.1 | % | | | | | | | | | | | | | | | 17.1 | 17.0 | 18.9 | 19.2 | 18.3 | 17.8 |
| 15. | Bus. Forms & Suppl. | 1.310.1 | % | | | | | | | | | | | | | | | 10.1 | 9.4 | 9.5 | 9.6 | 9.5 | 10.5 |
| 16. | C–Business Machine Group | | % | | | | | | | | | | | | | | | 46.4 | 44.9 | 45.2 | 46.4 | 45.4 | 46.6 |
| 17. | Intern. Group | 1.310.2 | % | | | | | | | | | | | | | | | 30.4 | 35.3 | 36.7 | 36.5 | 35.4 | 37.2 |
| 18. | Defense, Space, etc. Group | | % | | | | | | | | | | | | | | | 14.5 | 11.9 | 10.2 | 9.1 | 10.2 | 6.9 |
| 19. | Business Forms Group | | % | | | | | | | | | | | | | | | 8.8 | 7.9 | 7.9 | 8.0 | 7.4 | 7.8 |
| 20. | D–Standard Comp. Systems | | % | | | | | | | | | | | | | | 32.9 | 39.9 | 45.7 | 44.4 | | | |
| 21. | Minis, etc. | | % | | | | | | | | | | | | | | 47.6 | 44.5 | 41.4 | 42.7 | | | |
| 22. | Bus. Forms & Suppl. | 1.310.1 | % | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 11 | 10.9 | 10.2 | 9.4 | 9.5 | 9.5 | 9.5 | 10.5 |
| 23. | Custom Products, etc. | | % | | | | | | | | | | | | | | 8.4 | 5.5 | 3.6 | 3.4 | | | |
| 24. | E–Harman 'Comp. Opns.' | 1.310.1 | % | 10.0 | 12.0 | 14.0 | 16.0 | 18.0 | 20.0 | 22.8 | 25.7 | 28.5 | 31.3 | 34.2 | 37.0 | 39.9 | 42. | 49. | 54. | 53. | 60. | 58. | 60. |
| 25. | Rental Equipment Value–Gross | | $B | | | | | | | | .036 | .056 | .069 | .091 | .131 | .181 | .263 | .377 | .558 | .635 | .710 | .789 | .938 |
| 26. | Net | | $B | .001 | .005 | .011 | .015 | .016 | .015 | .013 | .018 | .032 | .046 | .057 | .081 | .105 | .162 | .244 | .386 | .418 | .442 | .469 | .536 |
| 27. | R & D Expenses | | $B | | | | | | | | | .016 | .015 | .016 | .019 | .022 | .026 | .037 | .045 | .047 | .051 | .066 | .085 |
| 28. | % of Total Revenue | 1.310.2 | % | | | | | | | | | 4.1 | 3.8 | 3.5 | 3.9 | 4.0 | 4.0 | 4.9 | 5.1 | 5.0 | 4.9 | 5.1 | 5.5 |
| | **Honeywell (and GE)** | | | | | | | | | | | | | | | | | | | | | | |
| 29. | Total Revenue (Sales) | 1.310.3 | $B | .244 | .288 | .325 | .328 | .381 | .426 | .470 | .596 | .648 | .667 | .735 | .914 | 1.045 | 1.281 | 1.426 | 1.921 | 1.951 | 2.125 | 2.391 | 2.626 |
| 30. | Net Income | | $B | .019 | .022 | .021 | .023 | .029 | .026 | .025 | .027 | .035 | .041 | .038 | .045 | .042 | .051 | .062 | .057 | .066 | .077 | .097 | .076 |
| 31. | % of Revenue | 1.310.4 | % | 7.8 | 7.6 | 6.5 | 7.0 | 7.6 | 6.8 | 5.3 | 4.5 | 5.4 | 6.1 | 5.2 | 4.9 | 4.0 | 4.0 | 4.3 | 3.0 | 3.3 | 3.6 | 4.1 | 2.9 |
| | Revenue Analysis–% Tot. Rev. | | | | | | | | | | | | | | | | | | | | | | |
| 32. | A–Home & Bldg. Controls | 1.310.3 | % | | | | | | | | | | 32.5 | 31.3 | 27.9 | 25.1 | 22.8 | 23.1 | 17.8 | 19.0 | 18.7 | 19.0 | 19.3 |
| 33. | Automation Systems | 1.310.3 | % | | | | | | | | | | 24.4 | 26.3 | 24.1 | 20.7 | 17.7 | 16.8 | 13.3 | 13.5 | 13.3 | 14.3 | 15.9 |
| 34. | Aerospace & Defense | 1.310.3 | % | | | | | | | | | | 32.5 | 26.1 | 25.3 | 31.6 | 37.3 | 33.8 | 22.9 | 17.2 | 16.5 | 15.6 | 15.9 |
| 35. | Comp. & Commun. | 1.310.3 | % | | | | | | 0.9 | 3.7 | 1.7 | 3.8 | 8.7 | 14.1 | 20.0 | 21.1 | 20.7 | 24.6 | 44.7 | 48.7 | 50.0 | 49.2 | 47.0 |
| 36. | Photo Prod. | 1.310.3 | % | | | | | | | | | | 1.8 | 2.2 | 2.7 | 1.5 | 1.5 | 1.8 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 |
| 37. | B–Intern. Revenue | 1.310.4 | % | | | | | | | | | | 17.5 | 22.3 | 20. | | | | 33.1 | 37.5 | 38.5 | 40.4 | |
| 38. | Equip. Leased to Others–Gross | | $B | | | | | | | | | | | | | .242 | .324 | .419 | 1.161 | 1.262 | 1.380 | 1.520 | 1.439 |
| 39. | Net | | $B | | | | | | | | | | | | | .187 | .241 | | .694 | .721 | .750 | .815 | .733 |
| 40. | R & D Expenses | | $B | | | | | | | | | | | | | | | | .139 | .136 | .148 | .160 | .170 |
| 41. | % of Tot. Revenue | 1.310.4 | % | | | | | | | | | | | | | | | | 7.2 | 7.0 | 6.9 | 6.7 | 6.5 |
| 42. | Revenue Including GE | | $B | | | | | | | | | | | | 1.163 | 1.360 | 1.638 | 1.838 | | | | | |
| 43. | Net Income Including GE | | $B | | | | | | | | | | | | .009 | .016 | .041 | .062 | | | | | |
| 44. | GE Computer Revenue | | $B | | | | | | | | | | | | .249 | .315 | .357 | .412 | | | | | |
| 45. | GE Computer Income | | $B | | | | | | | | | | | | d.036 | d.026 | d.010 | 0 | | | | | |
| 46. | Honeywell Computer Revenue | | $B | | | | | | .004 | .015 | .010 | .025 | .058 | .104 | .183 | .221 | .265 | .351 | | | | | |
| 47. | Honeywell Plus GE Comp. Rev. | | $B | | | | | | | | | | | | .432 | .536 | .622 | .763 | .859 | .950 | 1.061 | 1.177 | 1.234 |

amounting to between 8% and 9% of total revenue during each of the years 1969 to 1972.)

Equipment revenues on line 52 are broken down in two different ways: On line 53 and 54 the relative proportions of sales and rental revenues are shown; on lines 55 through 57, equipment revenue is broken down into that from retail systems (primarily cash registers), accounting machines, and data processing systems–the latter being revenue from computer sales and rentals.

61. These figures show NCR's reported international revenue. I was unable to find data for the years 1963 through 1965.

62. These figures are from HarmA71 (see discussion in connection line 24 above). Harman says "the NCR figure for 1966 was obtained from a Merrill Lynch report (*Investing in the Computer Industry*, Boston, Securities Research Division, 1967). Annual figures were obtained by interpolation between this and an estimate for 1951 of 3%."

63-64. The gross and net values of rental equipment are from NCR annual reports, though no information is given as to what proportion of this equipment is in the computer category.

65-66. Research and development expenditures are as reported by NCR, and line 66 is the quotient of line 65 and line 49.

**Univac (Sperry Rand).** 67-69. Univac's total revenue is described as "net sales of products and services." Sperry Rand's fiscal year ends on March 31, and I have not attempted to adjust the figures so that they correspond to calendar years. Thus, the revenue shown for the year 1972, for example, is really revenue for the twelve months ending March 31, 1973. Net income after taxes is shown on line 68 and line 69 is the quotient of lines 68 and 67.

70-79. Sperry Rand has uniformly reported distribution of their revenue in two different ways, since before 1955. These two analyses are indicated in the Table as A and B. In addition, in recent years other categories have been identified, and are shown as C in the Table.

70-72. The first breakdown distinguishes U.S. commercial products from international business and from U.S. government contracts. (Much of Sperry Rand's research and development activity is government funded. See the comment in connection with lines 83 and 84 below.)

73-76. This second breakdown distinguishes portions of Sperry Rand revenues by product type. Business machines, on line 73, include: computer processors, memory devices, and peripherals; electronic data processing equipment and services; electromechanical filing systems; typewriters; copiers; microfilm systems; calculators; and office furniture. Hydraulic and farm equipment includes material handling apparatus, among other things. Other products and services, on line 76, includes: electric shavers and other personal care products; housewares, printing and statistical services; and (for the years 1958 through 1965 only, as identified by an asterisk) hydraulic and farm equipment.

77-79. For the years since 1965, Sperry Rand has distinguished "information handling and retrieval systems", shown on line 77, from the total business machine category in line 73. Information handling and retrieval systems include electronic data processing equipment and services, computers along with their memories and peripherals, microfilm systems, and electromechanical filing systems; and the reported percentage of total revenue of these items is shown on line 77 for the year 1965 and later. Line 78, representing other business machine products, is the difference between lines 73 and 77. For the years 1965 through 1969, Sperry Rand also identified "office machines and consumer products", and that revenue percentage is shown on line 79. The entries on line 77 for the years 1955 to 1964 are discussed in the next paragraph.

80. These figures come from HarmA71 (see discussion of line 24 above). Regarding this data, Harman says, "Sperry Rand reported the proportions of its sales in computers for 1962 (30%), 1965 (34.5%), and 1966 (34.6%). Based on an estimate of 22.5% for 1955, the combined company's index for intermediate years was calculated by interpolation." Comparing lines 80 and 77 for the years 1965 and 1966, we see that Harman apparently overestimated Sperry Rand's "computer" business, and was apparently including some of the other "business machine" revenue shown in line 73. To estimate Sperry Rand's "computer" business, I have therefore discounted Harman's figures; and the discounted number appear on line 77 for the years 1955 through 1964.

81-82. Sperry Rand's rental equipment gross value and net value are shown on these two lines. In January 1972, Sperry Rand acquired RCA's computer business and paid $70M for the RCA computer equipment on lease. This addition accounts, in part, for the large increase in rental equipment value in the year 1971 (which of course ended on March 31, 1972).

83-84. Sperry Rand's internally funded research and development expenses are shown on line 83, and line 84 is the quotient of line 83 and line 67. However, these expenditures do not include the R & D work done for the government. In Sperry10K73, Sperry Rand reports $211M in research and development expenditures for the corporation, compared with the $67M internally funded expenditures shown on line 83. In 1973 and again in 1975 Sperry Rand changed the accounting basis for its R & D expenses, adding some expenses which in earlier years would have been capitalized or charged to cost of sales. The effect in 1973 was to increase R & D expenses from the $67M shown to $106M. Thus the 1974 and 1975 expenses are not comparable to previous ones.

## TABLE II.1.310 SYSTEM COMPANIES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48. | % of Total Revenue | 1.310.3 | % | | | | | | | | | | | | 47.2 | 51.3 | 48.6 | 53.5 | 44.7 | 48.7 | 50.0 | 49.2 | 47.0 |
| | **National Cash Register** | | | | | | | | | | | | | | | | | | | | | | |
| 49. | Total Revenue | 1.310.5 | $B | .301 | .341 | .383 | .393 | .419 | .458 | .519 | .564 | .593 | .666 | .737 | .871 | 1.005 | 1.102 | 1.265 | 1.421 | 1.466 | 1.558 | 1.816 | 1.979 |
| 50. | Net Income | | $B | .015 | .018 | .018 | .016 | .019 | .020 | .022 | .021 | .020 | .023 | | | .037 | .036 | .046 | .030 | .001 | d.06 | .07 | .09 |
| 51. | % of Revenue | 1.310.6 | % | 5.0 | 5.3 | 4.7 | 4.1 | 4.5 | 4.4 | 4.2 | 3.7 | 3.4 | 3.5 | | | 3.7 | 3.3 | 3.6 | 2.1 | - | - | 4.0 | 4.4 |
| | Revenue Anal.–% of Tot. Rev. | | | | | | | | | | | | | | | | | | | | | | |
| 52. | A–Equipment Revenue | | % | | | | | | | | | 69.5 | 67.7 | 67.2 | 65.9 | 61.2 | 61.1 | 58.7 | 60.9 | 59.4 | 58.1 | 58.2 | 56.8 |
| 53. | Sales Revenue | | % | | | | | | | | | | 62.2 | 60.7 | 58.6 | 52.4 | 50.9 | 47.9 | 48.8 | 46.0 | 44.0 | 44.7 | 44.3 |
| 54. | Rental Revenue | | % | | | | | | | | | | 5.6 | 6.5 | 7.3 | 8.8 | 10.2 | 10.8 | 12.0 | 13.4 | 14.1 | 13.5 | 12.5 |
| 55. | Retail Systems | 1.310.5 | % | | | | | | | | | | | | | 23.2 | 22.3 | 21.1 | 21.2 | 19.7 | 20.3 | 20.0 | 17.7 |
| 56. | Accounting Machines | 1.310.5 | % | | | | | | | | | | | | | 24.2 | 23.3 | 23.3 | 22.9 | 21.1 | 17.5 | 18.0 | 19.1 |
| 57. | D.P. Systems | 1.310.5 | % | 4.9 | 5.3 | 5.8 | 6.3 | 6.7 | 7.2 | 7.7 | 8.1 | 8.6 | 9.1 | 9.5 | 10.0 | 10.1 | 11.3 | 10.6 | 13.5 | 14.6 | 16.1 | 16.3 | 15.8 |
| 58. | Services | 1.310.5 | % | | | | | | | | | 16.5 | 16.9 | 17.4 | 19.2 | 19.2 | 19.3 | 19.9 | 20.0 | 21.6 | 22.7 | 22.3 | 22.2 |
| 59. | Supplies | 1.310.5 | % | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 9 | 9.2 | 9.1 | 9.3 | 9.2 | 9.3 | 9.7 |
| 60. | Other | | % | | | | | | | | | | | 8 | 7 | 11 | 11 | 12.2 | 10.0 | 9.6 | 10.0 | 10.2 | 11.3 |
| 60a. | Supplies & Other | | | | | | | | | | 13.5 | 14.0 | 15.8 | 16.6 | 14.9 | 19.6 | 19.6 | 21.4 | 19.1 | 18.9 | 19.2 | 19.5 | 21.0 |
| 61. | B–International Revenue | 1.310.6 | % | | | | | | 41 | 45 | 43 | | | | 45 | 40 | 40 | 41 | 45 | 47 | 47 | 49 | 51 |
| 62. | C–Harman "Comp. Operations" | | % | 4.9 | 5.3 | 5.8 | 6.3 | 6.7 | 7.2 | 7.7 | 8.1 | 8.6 | 9.1 | 9.5 | 10.0 | | | | | | | | |
| 63. | Rental Equipment Value–Gross | | $B | | | | .003 | .006 | .011 | .023 | .044 | .071 | .098 | .130 | .186 | .250 | .313 | .416 | .527 | .567 | .573 | .607 | .678 |
| 64. | Net | | $B | | | | .003 | .006 | .009 | .017 | .032 | .048 | .059 | .074 | .106 | .133 | .162 | .222 | .280 | .285 | .254 | .258 | .289 |
| 65. | R & D Expenses | | $B | .007 | .008 | .014 | .015 | .015 | .016 | .017 | .019 | .020 | .022 | .025 | .030 | .034 | .036 | .041 | .047 | .052 | .059 | .052 | .074 |
| 66. | % of Tot. Revenue | 1.310.6 | % | 2.3 | 2.3 | 3.7 | 3.8 | 3.6 | 3.5 | 3.3 | 3.4 | 3.4 | 3.3 | 3.4 | 3.4 | 3.4 | 3.3 | 3.2 | 3.3 | 3.5 | 3.8 | 2.9 | 3.7 |
| | **Univac (Sperry Rand)** | | | | | | | | | | | | | | | | | | | | | | |
| 67. | Total Revenue | 1.310.7 | $B | .711 | .868 | .864 | .990 | 1.173 | 1.177 | 1.183 | 1.227 | 1.279 | 1.248 | 1.280 | 1.487 | 1.563 | 1.607 | 1.755 | 1.739 | 1.824 | 2.229 | 2.614 | 3.041 |
| 68. | Net Income | | $B | .046 | .049 | .027 | .028 | .037 | .026 | .024 | .013 | .026 | .022 | .032 | .054 | .064 | .077 | .081 | .072 | .061 | .090 | .113 | .131 |
| 69. | % of Revenue | 1.310.8 | % | 6.5 | 5.6 | 3.1 | 2.8 | 3.2 | 2.2 | 2.0 | 1.1 | 2.0 | 1.8 | 2.5 | 3.6 | 4.1 | 4.8 | 4.6 | 4.1 | 3.3 | 4.0 | 4.3 | 4.3 |
| | Revenue Anal.–% of Tot. Rev. | | | | | | | | | | | | | | | | | | | | | | |
| 70. | A–Commercial Products, US | | % | 45 | 38 | 38 | 33 | 30 | 32 | 31 | 30 | 30 | 36 | 41 | 43 | 42 | 44 | 45 | 44 | 47 | 46 | 42 | 41 |
| 71. | International | 1.310.8 | % | 17 | 21 | 21 | 19 | 18 | 20 | 20 | 21 | 23 | 28 | 28 | 27 | 27 | 29 | 31 | 34 | 35 | 37 | 41 | 43 |
| 72. | US Govt. Contracts | | % | 38 | 41 | 41 | 48 | 52 | 48 | 49 | 49 | 47 | 36 | 31 | 30 | 31 | 27 | 24 | 22 | 18 | 17 | 17 | 16 |
| 73. | B–Business Machines, etc. | | % | 33 | 31 | 33 | 28 | 28 | 30 | 30 | 29 | 31 | 35 | 35 | 38 | 38 | 41 | 43 | 47 | 48 | 47 | 47 | 46 |
| 74. | Instruments & Controls | 1.310.7 | % | 36 | 40 | 39 | 46 | 50 | 49 | 48 | 48 | 46 | 38 | 36 | 35 | 36 | 32 | 28 | 24 | 23 | 23 | 22 | 22 |
| 75. | Hydraulic & Farm Equip. | 1.310.7 | % | 20 | 18 | 18 | * | * | * | * | * | * | * | * | 21 | 20 | 21 | 23 | 23 | 23 | 23 | 25 | 28 |
| 76. | Other Prod. & Serv. | 1.310.7 | % | 11 | 11 | 10 | 26* | 22* | 21* | 22* | 23* | 23* | 27* | 29* | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 6 | 4 |
| 77. | C–Info. Syst. | 1.310.7 | % | 20 | 21 | 22 | 23 | 23 | 25 | 25 | 24 | 26 | 29 | 29 | 29 | 30.4 | 33.7 | 36.4 | 40.7 | 42.2 | 41.1 | 41 | 39 |
| 78. | Other Business Mach. | 1.310.7 | % | 13 | 10 | 11 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 9 | 8 | 7.7 | 6.7 | 6.1 | 5.7 | 6.2 | 6 | 7 |
| 79. | Office Mach. & Consum. Prod. | | | | | | | | | | | | | 16 | 15 | 13 | 13 | 12 | | | | | |
| 80. | D–Harman "Comp. Operations" | | % | 22.5 | 23.6 | 24.6 | 25.7 | 26.8 | 27.9 | 28.9 | 30.0 | 31.5 | 33.0 | 34.5 | 34.6 | | | | | | | | |
| 81. | Rental Equip. Value–Gross | | $B | | | | | | | | | | | | .307 | .331 | .401 | .448 | .491 | .598 | .608 | .642 | .641 |
| 82. | Net | | $B | | | | | | | | | .161 | .134 | .125 | .119 | .125 | .177 | .211 | .214 | .297 | .241 | .212 | .202 |
| 83. | R & D Expenses | | $B | | | | | | | .025 | .023 | .023 | .027 | .026 | .030 | .035 | .046 | .058 | .052 | .057 | .067 | .146 | .163 |
| 84. | % of Tot. Revenue | 1.310.8 | % | | | | | | | 2.1 | 1.9 | 1.8 | 2.2 | 2.0 | 2.0 | 2.2 | 2.9 | 3.3 | 3.0 | 3.1 | 3.0 | 5.6 | 5.4 |

## TABLES II.1.311 THROUGH II.1.321—NOTES

The data in these tables was collected in a review of annual reports, 10k reports, and prospectuses for the companies covered. In general, the figures given are *as reported at the time*, and have not been restated to make them in some sense comparable to previous years.

**IBM.** With regard to Table II.1.311, the data comes from or is derived directly from IBM annual reports, 10k reports, and prospectuses except for the following:

1. The percentages shown in lines 3, 5, and 7 are the only breakdowns of revenue provided by IBM. Percentages only are given, to the nearest percent. The three entries are identified as "sales, service, and rentals of data processing machines and systems," "other regular products and services," and "special products and services for U.S. government agencies." As far as I could determine, even these percentages were not given for the years 1955, 1957-1960, 1962, and 1964. Where I show figures for those years they are interpolations.

2. The dollar figures on lines 22, 26, and 28 were given by IBM only for the years 1963-1965, 1970, and 1971. The dollar figure for line 24 was given for those years and in addition for the years 1961, 1962, and 1972-1974. To the extent that I provide figures for other years, they are extrapolations and interpolations.

3. The data on lines 125-142 for the years 1958-1966 is from GropA70. The data on line 132 for the years 1970-1972 was made public at the time the Service Bureau Corp. was sold to CDC.

Incidentally, the figures marked with an asterisk in lines 96-124 are *domestic*, not worldwide figures. Worldwide asset data was not provided by IBM for these years, and I have added the asterisks to warn the reader that domestic data is mixed with worldwide data.

**CDC, DEC, XDS, and CalComp.** The "d" preceding a number indicates it is a deficit (i.e. a loss).

Xerox Data Systems revenues for the years 1969 and subsequently were gleaned from Xerox annual reports.

### TABLE II.1.311 INTERNATIONAL BUSINESS MACHINES CORPORATION ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Revenue**—Total | 1.311.3 | $B | .697 | .892 | 1.203 | 1.418 | 1.613 | 1.817 | 2.202 | 2.591 | 2.863 | 3.239 | 3.573 | 4.248 | 5.345 | 6.889 | 7.197 | 7.504 | 8.274 | 9.533 | 10.993 | 12.675 |
| 1a. | Av. 5-Yr. Growth Rate | | % | | | | | | 21.1 | 19.7 | 16.7 | 15.1 | 14.9 | 14.5 | 14.0 | 15.6 | 19.2 | 17.3 | 16.0 | 18.3 | 12.3 | 8.8 | 12.0 |
| 2. | DP Systems | 1.311.3 | $B | | .52 | .73 | .90 | 1.07 | 1.23 | 1.54 | 1.92 | 2.24 | 2.51 | 2.75 | 3.23 | 4.23 | 5.58 | 5.69 | 5.92 | 6.53 | 7.53 | 8.68 | 9.89 |
| 3. | % Total Revenue | 1.311.4 | % | | 58 | 61 | 64 | 66 | 68 | 70 | 74 | 78 | 77.5 | 77 | 76 | 79 | 81 | 79 | 79 | 79 | 79 | 79 | 78 |
| 4. | Other Regular Products | 1.311.3 | $B | | .22 | .26 | .28 | .29 | .31 | .33 | .39 | .43 | .55 | .69 | .85 | .91 | 1.06 | 1.23 | 1.33 | 1.49 | 1.73 | 1.98 | 2.41 |
| 5. | % Total Revenue | 1.311.4 | % | | 25 | 22 | 20 | 18 | 17 | 15 | 15 | 15 | 17 | 19 | 20 | 17 | 15 | 17 | 18 | 18 | 18 | 18 | 19 |
| 6. | Special Products | 1.311.3 | $B | | .15 | .20 | .23 | .26 | .27 | .33 | .28 | .20 | .18 | .14 | .17 | .21 | .25 | .25 | .25 | .25 | .25 | .33 | .38 |
| 7. | % Total Revenue | 1.311.4 | % | | 17 | 17 | 16 | 16 | 15 | 15 | 11 | 7 | 5.5 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 |
| 8. | Sales | 1.311.5 | $B | .236 | .325 | .462 | .513 | .516 | .523 | .715 | .830 | .797 | .928 | .969 | 1.342 | 1.869 | 2.876 | 2.580 | 2.026 | 2.180 | 2.879 | 3.372 | 4.282 |
| 9. | % Total Revenue | | % | 33.9 | 36.0 | 38.3 | 36.2 | 32.1 | 28.7 | 32.3 | 32.0 | 27.9 | 28.7 | 27.2 | 31.5 | 35.0 | 41.8 | 35.8 | 27.0 | 26.4 | 30.2 | 30.7 | 33.8 |
| 10. | Service & Rentals | 1.311.5 | $B | .461 | .567 | .741 | .905 | 1.098 | 1.294 | 1.488 | 1.761 | 2.065 | 2.311 | 2.604 | 2.905 | 3.476 | 4.012 | 4.618 | 5.477 | 6.093 | 6.654 | 7.621 | 8.394 |
| 11. | % Total Revenue | 1.311.5 | % | 66.1 | 64.0 | 61.7 | 63.8 | 67.9 | 71.3 | 67.7 | 68.0 | 72.1 | 71.3 | 72.8 | 68.5 | 65.0 | 58.2 | 64.2 | 73.0 | 73.6 | 69.8 | 69.3 | 66.2 |
| 12. | **Costs**—Sales | | $B | .164 | .229 | .332 | .344 | .347 | .332 | .436 | .449 | .379 | .381 | .438 | .628 | .728 | .934 | .883 | .829 | .932 | 1.155 | 1.242 | 1.427 |
| 13. | % Sales Revenue | 1.311.6 | % | 69.5 | 70.5 | 71.7 | 67.0 | 67.0 | 63.4 | 61.0 | 54.0 | 47.5 | 41.1 | 45.2 | 46.7 | 38.9 | 32.5 | 34.2 | 40.9 | 42.7 | 40.1 | 36.8 | 33.3 |
| 14. | Service & Rentals | | $B | .200 | .250 | .318 | .380 | .439 | .468 | .538 | .659 | .747 | .843 | .925 | 1.128 | 1.532 | 1.742 | 1.810 | 2.059 | 2.259 | 2.603 | 2.952 | 3.327 |
| 15. | % Service Revenue | 1.311.6 | % | 43.4 | 44.0 | 42.9 | 42.0 | 39.9 | 36.2 | 36.2 | 37.3 | 36.2 | 36.5 | 35.5 | 38.8 | 44.1 | 43.5 | 39.2 | 37.6 | 37.1 | 39.1 | 38.7 | 39.6 |
| 16. | Total | 1.311.7 | $B | .364 | .478 | .650 | .724 | .785 | .800 | .975 | 1.108 | 1.126 | 1.225 | 1.363 | 1.756 | 2.260 | 2.676 | 2.693 | 2.888 | 3.191 | 3.758 | 4.194 | 4.754 |
| 17. | % Total Revenue | 1.311.6 | % | 52.2 | 54.0 | 54.1 | 51.0 | 48.8 | 44.2 | 44.1 | 42.9 | 39.4 | 37.8 | 38.1 | 41.4 | 42.4 | 38.9 | 37.4 | 38.5 | 38.6 | 39.4 | 38.2 | 37.5 |
| 18. | Gross Profit | | $B | .333 | .414 | .553 | .694 | .828 | 1.017 | 1.228 | 1.484 | 1.736 | 2.015 | 2.210 | 2.492 | 3.085 | 4.213 | 4.504 | 4.616 | 5.083 | 5.775 | 6.799 | 7.921 |
| 19. | % Total Revenue | | % | 47.8 | 46.0 | 45.9 | 49.0 | 51.3 | 56.4 | 55.9 | 57.1 | 60.6 | 62.2 | 61.9 | 58.6 | 57.6 | 61.1 | 62.6 | 61.5 | 61.4 | 60.6 | 61.8 | 62.5 |

## TABLE II.1.311 INTERNATIONAL BUSINESS MACHINES CORPORATION ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20. | Indirect Costs—Total | | $B | .172 | .221 | .303 | .360 | .442 | .576 | .674 | .824 | .958 | 1.131 | 1.264 | 1.446 | 1.777 | 2.365 | 2.586 | 2.735 | 3.108 | 3.462 | 4.025 | 4.759 |
| 21. | % Total Revenue | | % | 24.7 | 24.8 | 25.2 | 25.4 | 27.4 | 31.8 | 30.5 | 31.8 | 33.4 | 35.0 | 35.4 | 34.0 | 33.2 | 34.4 | 36.0 | 36.4 | 37.6 | 36.3 | 36.6 | 37.5 |
| 22. | Selling, Administrative | 1.311.7 | $B | | .16 | .22 | .26 | .32 | .41 | .46 | .58 | .659 | .765 | .869 | .97 | 1.20 | 1.61 | 1.75 | 1.798 | 2.044 | | | |
| 23. | % Total Revenue | 1.311.8 | % | | 18.0 | 18.3 | 18.4 | 19.8 | 22.6 | 20.9 | 22.4 | 22.9 | 23.7 | 24.3 | 22.8 | 22.4 | 23.4 | 24.3 | 24.1 | 24.8 | | | |
| 24. | Engineering, R & D | 1.311.7 | $B | | .04 | .05 | .06 | .07 | .10 | .123 | .134 | .165 | .209 | .211 | .25 | .30 | .40 | .44 | .500 | .540 | .676 | .730 | .890 |
| 25. | % Total Revenue | 1.311.8 | % | | 4.5 | 4.2 | 4.2 | 4.3 | 5.5 | 5.5 | 5.2 | 5.8 | 6.5 | 5.9 | 5.9 | 5.6 | 5.8 | 6.1 | 6.7 | 6.5 | 7.1 | 6.6 | 7.0 |
| 26. | Depreciation, etc. | | $B | | - | - | - | - | .01 | .02 | .03 | .046 | .060 | .072 | .10 | .116 | .141 | .174 | .213 | .251 | | | |
| 27. | % Total Revenue | | % | | - | - | - | - | .6 | .9 | 1.2 | 1.6 | 1.9 | 2.0 | 2.4 | 2.2 | 2.0 | 2.4 | 2.8 | 3.0 | | | |
| 28. | Taxes and Royalties | | $B | | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .088 | .097 | .112 | .13 | .160 | .221 | .228 | .224 | .273 | | | |
| 29. | % Total Revenue | | % | | 2.2 | 2.5 | 2.8 | 3.1 | 3.3 | 3.2 | 3.1 | 3.1 | 3.0 | 3.1 | 3.1 | 3.0 | 3.2 | 3.0 | 3.0 | 3.3 | | | |
| 30. | Interest, etc. | | $B | .010 | .012 | .016 | .018 | .020 | .022 | .025 | .028 | .028 | .025 | .021 | .027 | .045 | .041 | .035 | .050 | .070 | .078 | .097 | .069 |
| 31. | % Total Revenue | | % | 1.4 | 1.4 | 1.3 | 1.3 | 1.3 | 1.2 | 1.1 | 1.1 | 1.0 | .8 | .6 | .6 | .8 | .6 | .5 | .7 | .8 | .8 | .9 | .5 |
| 32. | Operating Income | | $B | .151 | .181 | .234 | .316 | .365 | .419 | .529 | .631 | .750 | .858 | .924 | 1.019 | 1.262 | 1.806 | 1.884 | 1.832 | 1.903 | 2.234 | 2.676 | 3.094 |
| 33. | % Total Revenue | | % | 21.7 | 20.5 | 19.4 | 22.4 | 22.6 | 23.0 | 24.0 | 24.4 | 26.2 | 26.5 | 25.9 | 24.0 | 23.6 | 26.2 | 26.2 | 24.4 | 23.0 | 23.4 | 24.3 | 24.4 |
| 34. | Other Income | | $B | | .002 | .005 | .008 | .015 | .020 | .017 | .021 | .028 | .039 | .036 | .035 | .035 | .058 | .095 | .180 | .152 | .191 | .270 | .341 |
| 35. | Net Earnings Before Taxes | | $B | | .183 | .239 | .324 | .380 | .438 | .546 | .652 | .778 | .897 | .960 | 1.054 | 1.297 | 1.864 | 1.979 | 2.012 | 2.055 | 2.425 | 2.946 | 3.435 |
| 36. | Net Earnings After Taxes | 1.311.7 | $B | .076 | .087 | .110 | .152 | .176 | .205 | .254 | .305 | .364 | .431 | .477 | .526 | .651 | .871 | .934 | 1.018 | 1.079 | 1.279 | 1.575 | 1.838 |
| 37. | % Total Revenue | 1.311.8 | % | 10.9 | 9.8 | 9.2 | 10.7 | 10.9 | 11.3 | 11.5 | 11.8 | 12.7 | 13.3 | 13.4 | 14.3 | 14.5 | 12.4 | 12.2 | 12.7 | 13.1 | 13.4 | 14.3 | 14.5 |
| 38. | **Employees**—Total | 311.15 | k | 56.4 | 72.5 | 83.8 | 87.8 | 94.9 | 104.3 | 116.3 | 127.5 | 137.6 | 149.8 | 172.4 | 198.2 | 221.9 | 242.0 | 258.7 | 269.3 | 265.5 | 262.2 | 274.1 | 292.4 |
| 39. | Domestic | 311.15 | k | 39.0 | 51.2 | 60.3 | 61.2 | 65.6 | 70.1 | 76.0 | 81.5 | 87.2 | 96.5 | 111.1 | | | | | | | | | |
| 40. | % Tot. Employees | | % | 69.2 | 70.6 | 72.0 | 69.7 | 69.1 | 67.2 | 65.4 | 64.0 | 63.4 | 64.5 | 64.5 | | | | | | | | | |
| 41. | W.T.C. | | k | 17.4 | 21.3 | 23.5 | 25.6 | 29.3 | 34.2 | 40.3 | 46.0 | 50.4 | 53.3 | 61.3 | | | | | | | | | |
| 42. | % Tot. Employees | 311.15 | % | 30.9 | 29.4 | 28.0 | 30.3 | 30.9 | 32.8 | 34.6 | 36.0 | 36.6 | 35.5 | 35.5 | | | | | | | | | |
| 43. | Revenue Per Employee | 311.16 | $k | 12.4 | 12.3 | 14.3 | 16.1 | 17.1 | 17.4 | 18.9 | 20.3 | 20.8 | 21.6 | 20.7 | 21.4 | 24.1 | 28.4 | 27.8 | 27.8 | 31.2 | 36.4 | 40.1 | 43.3 |
| 44. | Deflated | 311.16 | $k | 13.6 | 13.1 | 14.7 | 16.1 | 16.8 | 16.8 | 18.1 | 19.2 | 19.4 | 19.8 | 18.7 | 18.8 | 20.5 | 23.2 | 21.7 | 20.6 | 21.9 | 24.9 | 26.0 | 25.4 |
| 45. | **W.T.C. Revenue**—Total | 1.311.9 | $B | .133 | .168 | .202 | .246 | .297 | .372 | .498 | .653 | .788 | .933 | 1.086 | 1.318 | 1.625 | 2.040 | 2.496 | 2.933 | 3.409 | 4.152 | 5.143 | 5.947 |
| 46. | % Total Revenue | 1.311.9 | % | 19.0 | 17.7 | 16.8 | 17.4 | 18.4 | 20.5 | 22.6 | 25.2 | 27.5 | 28.8 | 30.4 | 31.0 | 30.4 | 29.6 | 34.7 | 39.1 | 41.1 | 43.6 | 46.8 | 46.9 |
| 47. | Av. 5-Yr. Growth Rate | | % | | | | | | 22.8 | 24.3 | 26.4 | 26.2 | 25.6 | 24.9 | 21.4 | 20.0 | 21.0 | 21.8 | 21.9 | 21.0 | 20.6 | 20.5 | 19.0 |
| 48. | Sales | 311.12 | $M | 37.3 | 42.1 | 59.6 | 70.1 | 81.4 | 101.2 | 148.3 | 191.1 | 194.3 | | | | | | | | | | | |
| 49. | % W.T.C. Revenue | | % | 28.1 | 26.7 | 29.5 | 28.5 | 27.4 | 27.3 | 29.8 | 29.3 | 24.7 | | | | | | | | | | | |
| 50. | Service and Rentals | 311.12 | $M | 95.5 | 115.6 | 142.5 | 175.6 | 215.5 | 271.0 | 349.3 | 462.0 | 593.7 | | | | | | | | | | | |
| 51. | % W.T.C. Revenue | 311.12 | % | 71.9 | 73.3 | 70.5 | 71.5 | 72.6 | 72.7 | 70.2 | 70.7 | 75.3 | | | | | | | | | | | |
| 52. | **Costs**—Sales | | $M | 21.7 | 24.8 | 32.9 | 36.4 | 44.5 | 53.4 | 71.7 | 90.4 | 88.2 | | | | | | | | | | | |
| 53. | % of Sales Revenue | 311.14 | % | 58.3 | 58.9 | 55.2 | 51.9 | 54.6 | 52.7 | 48.4 | 47.3 | 45.4 | | | | | | | | | | | |
| 54. | Service and Rentals | | $M | 35.8 | 44.9 | 52.3 | 62.8 | 77.9 | 98.9 | 121.7 | 162.9 | 213.1 | | | | | | | | | | | |
| 55. | % of Service Revenue | 311.14 | % | 37.5 | 38.8 | 36.7 | 35.8 | 36.1 | 36.4 | 34.8 | 35.3 | 35.9 | | | | | | | | | | | |
| 56. | Total Costs | | $M | 57.5 | 69.6 | 85.2 | 99.2 | 122.4 | 152.3 | 193.4 | 253.3 | 301.3 | | | | | | | | | | | |
| 57. | % of W.T.C. Revenue | 311.14 | % | 43.3 | 44.1 | 42.1 | 40.4 | 41.2 | 40.9 | 38.8 | 38.8 | 38.2 | | | | | | | | | | | |
| 58. | Gross Profit | | $M | 75.3 | 88.0 | 116.9 | 146.5 | 174.5 | 220.0 | 304.2 | 399.8 | 486.7 | | | | | | | | | | | |
| 59. | % of W.T.C. Revenue | | % | 56.7 | 55.9 | 57.8 | 59.6 | 58.9 | 59.0 | 61.2 | 61.2 | 61.8 | | | | | | | | | | | |
| 60. | Indirect Costs | | $M | 36.3 | 43.0 | 55.6 | 67.2 | 80.6 | 109.0 | 156.9 | 206.5 | 257.5 | | | | | | | | | | | |
| 61. | % of W.T.C. Revenue | | % | 27.3 | 27.2 | 27.5 | 27.4 | 27.2 | 29.3 | 31.5 | 31.6 | 32.7 | | | | | | | | | | | |
| 62. | Interest, etc. | | $M | 1.8 | 2.1 | 3.4 | 4.2 | 5.1 | 7.8 | 11.3 | 15.6 | 15.7 | | | | | | | | | | | |
| 63. | % of W.T.C. Revenue | | % | 1.4 | 1.4 | 1.7 | 1.7 | 1.7 | 2.1 | 2.3 | 2.4 | 2.0 | | | | | | | | | | | |
| 64. | Operating Income | | $M | 37.2 | 43.2 | 57.9 | 75.1 | 88.8 | 103.1 | 136.1 | 177.7 | 213.6 | | | | | | | | | | | |
| 65. | % of W.T.C Revenue | | % | 28.0 | 27.2 | 28.6 | 30.6 | 29.9 | 27.7 | 27.4 | 27.2 | 27.1 | | | | | | | | | | | |
| 66. | Net Earnings After Taxes | 311.10 | $M | 19.5 | 22.6 | 27.2 | 34.0 | 40.6 | 48.8 | 64.5 | 86.7 | 104.6 | 124.0 | 144.0 | 174.6 | 209.4 | 270.5 | 398.0 | 512.5 | 568.9 | 686.6 | 852.5 | 919.8 |
| 67. | % of W.T.C Revenue | | % | 14.7 | 14.4 | 13.5 | 13.9 | 13.6 | 13.1 | 13.0 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | 12.9 | 13.3 | 15.9 | 17.5 | 16.7 | 16.5 | 16.6 | 15.5 |
| 68. | % of Total Earnings | 311.10 | % | 25.7 | 26.0 | 24.7 | 22.4 | 23.1 | 23.8 | 25.4 | 28.4 | 28.7 | 28.8 | 30.2 | 33.2 | 32.2 | 31.1 | 42.6 | 50.3 | 52.7 | 53.7 | 54.1 | 50.0 |
| 69. | Revenue Per Employee | 311.16 | $k | 7.6 | 7.4 | 8.6 | 9.6 | 10.1 | 10.9 | 12.3 | 14.2 | 15.6 | 17.5 | 17.7 | | | | | | | | | |

## TABLE II.1.311 INTERNATIONAL BUSINESS MACHINES CORPORATION ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70. | **Domestic Revenue–Total** | 1.311.9 | $B | .564 | .734 | 1.000 | 1.172 | 1.316 | 1.445 | 1.704 | 1.938 | 2.075 | 2.306 | 2.487 | 2.930 | 3.720 | 4.848 | 4.701 | 4.571 | 4.864 | 5.381 | 5.850 | 6.728 |
| 71. | % Total Revenue | | % | 81.0 | 82.3 | 83.2 | 82.6 | 81.6 | 79.5 | 77.4 | 74.8 | 72.5 | 71.2 | 69.6 | 69.0 | 69.6 | 70.4 | 65.3 | 60.9 | 58.9 | 56.4 | 53.2 | 53.1 |
| 72. | Av. 5-Yr. Growth Rate | | % | | | | | | 20.6 | 18.3 | 14.1 | 12.1 | 11.9 | 11.5 | 11.4 | 13.9 | 18.5 | 15.4 | 12.9 | 10.7 | 7.7 | 3.8 | 7.4 |
| 73. | Sales | 311.11 | $M | 198.7 | 282.4 | 402.2 | 442.7 | 434.2 | 421.7 | 566.5 | 638.7 | 603.0 | | | | | | | | | | | |
| 74. | % Dom. Revenue | | % | 35.3 | 38.5 | 40.2 | 37.8 | 33.0 | 29.2 | 33.2 | 33.0 | 29.1 | | | | | | | | | | | |
| 75. | Service and Rentals | 311.11 | $M | 364.9 | 451.8 | 598.3 | 729.1 | 882.1 | 1023.0 | 1138.3 | 1299.4 | 1471.7 | | | | | | | | | | | |
| 76. | % Dom. Revenue | 311.11 | % | 64.7 | 61.5 | 59.8 | 62.2 | 67.0 | 70.8 | 66.7 | 67.0 | 70.9 | | | | | | | | | | | |
| 77. | **Costs**–Sales | | $M | 141.8 | 204.1 | 298.9 | 307.6 | 302.1 | 278.2 | 364.5 | 358.4 | 290.8 | | | | | | | | | | | |
| 78. | % of Sales Revenue | 311.13 | % | 71.4 | 72.3 | 74.3 | 69.5 | 69.6 | 66.0 | 64.3 | 56.1 | 48.2 | | | | | | | | | | | |
| 79. | Service and Rentals | | $M | 163.6 | 204.7 | 265.7 | 317.1 | 360.8 | 369.1 | 416.7 | 495.8 | 534.4 | | | | | | | | | | | |
| 80. | % of Service Revenue | 311.13 | % | 44.9 | 45.3 | 44.4 | 43.5 | 39.8 | 36.0 | 36.6 | 38.2 | 36.3 | | | | | | | | | | | |
| 81. | Total Costs | | $M | 305.4 | 408.8 | 564.6 | 624.7 | 663.0 | 647.3 | 781.3 | 854.2 | 875.2 | | | | | | | | | | | |
| 82. | % of Domestic Rev. | 311.13 | % | 54.1 | 55.6 | 56.4 | 53.3 | 50.4 | 44.8 | 45.8 | 44.1 | 42.2 | | | | | | | | | | | |
| 83. | Gross Profit | | $M | 258.1 | 325.6 | 435.8 | 547.1 | 653.3 | 797.3 | 923.6 | 1083.9 | 1250.0 | | | | | | | | | | | |
| 84. | % of Domestic Revenue | | % | 45.7 | 44.4 | 43.5 | 46.7 | 49.6 | 55.2 | 54.2 | 55.9 | 60.2 | | | | | | | | | | | |
| 85. | Indirect Costs | | $M | 135.8 | 177.7 | 247.6 | 292.2 | 361.3 | 467.2 | 516.9 | 617.5 | 700.2 | | | | | | | | | | | |
| 86. | % of Domestic Revenue | | % | 24.1 | 24.2 | 24.8 | 24.9 | 27.5 | 32.4 | 30.3 | 31.9 | 33.7 | | | | | | | | | | | |
| 87. | Interest, etc. | | $M | 8.4 | 10.3 | 12.4 | 13.6 | 15.4 | 14.5 | 13.5 | 12.9 | 12.7 | | | | | | | | | | | |
| 88. | % of Domestic Revenue | | % | 1.4 | 1.4 | 1.2 | 1.2 | 1.2 | 1.0 | 0.8 | 0.7 | 0.6 | | | | | | | | | | | |
| 89. | Operating Income | | $M | 113.9 | 137.6 | 175.8 | 241.3 | 276.6 | 315.7 | 393.1 | 453.6 | 537.1 | | | | | | | | | | | |
| 90. | % of Domestic Revenue | | % | 20.2 | 18.8 | 17.6 | 20.6 | 21.0 | 21.8 | 23.1 | 23.4 | 25.9 | | | | | | | | | | | |
| 91. | Net Earnings After Taxes | 311.10 | $M | 55.9 | 64.6 | 83.3 | 118.2 | 135.9 | 156.1 | 189.6 | 218.0 | 259.7 | 307.2 | 332.9 | 351.5 | 442.1 | 601.0 | 536.0 | 505.0 | 509.9 | 592.4 | 722.5 | 918.2 |
| 92. | % of Domestic Revenue | | % | 9.9 | 8.8 | 8.3 | 10.1 | 10.3 | 10.8 | 11.1 | 11.3 | 12.5 | 13.3 | 13.4 | 12.0 | 11.9 | 12.4 | 11.4 | 11.0 | 10.5 | 11.0 | 12.4 | 50.0 |
| 93. | Revenue Per Employee | 311.16 | $k | 14.4 | 14.3 | 16.6 | 19.1 | 20.0 | 20.6 | 22.4 | 23.8 | 23.8 | 23.9 | 22.4 | | | | | | | | | |

## TABLE II.1.311 INTERNATIONAL BUSINESS MACHINES CORPORATION ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 94. | Assets—Total, WW | 311.17 | $B | | .951 | | | | 1.976 | 2.301 | | 3.073 | 3.309 | 3.745 | 4.661 | 5.594 | 6.743 | 7.390 | 8.539 | 9.576 | 10.792 | 12.289 | 14.027 |
| 95. | Total, Domestic | 311.17 | $B | .630 | .769 | 1.087 | 1.261 | 1.391 | 1.535 | 1.769 | 1.985 | 2.374 | | | | | | | | | | | |
| 96. | Inventories—Total | 311.18 | $B | .022* | .035* | .043* | .034* | .036* | .037* | .042* | .044* | .047* | .118 | .147 | .190 | .214 | .226 | .268 | .374 | .406 | .441 | .518 | .688 |
| 97. | Finished Goods | | $B | | .007* | | | | .008* | .010* | | .012* | .043 | .050 | .059 | .067 | .077 | .094 | .123 | .133 | .125 | .155 | .233 |
| 98. | % Total Inventories | 311.18 | % | | 20.8* | | | | 22.2* | 23.6* | | 25.1* | 35.9 | 34.3 | 31.2 | 31.4 | 33.9 | 35.0 | 32.9 | 32.8 | 28.3 | 29.9 | 33.9 |
| 99. | Work in Process | | $B | | .013* | | | | .016* | .016* | | .019* | .050 | .054 | .079 | .094 | .098 | .115 | .173 | .197 | .249 | .282 | .299 |
| 100. | % Total Inventories | 311.18 | % | | 37.7* | | | | 43.9* | 39.1* | | 41.0* | 42.3 | 37.0 | 41.5 | 43.7 | 43.4 | 42.9 | 46.4 | 48.7 | 56.5 | 54.4 | 43.5 |
| 101. | Raw Materials | | $B | | .012** | | | | .008* | .013* | | .012 | .014 | .021 | .024 | .025 | .029 | .031 | .046 | .031 | .025 | .030 | .070 |
| 102. | % Total Inventories | 311.18 | % | | 33.9* | | | | 22.2* | 31.5* | | 26.2* | 11.9 | 14.5 | 12.6 | 11.9 | 12.7 | 11.7 | 12.4 | 7.5 | 5.7 | 5.8 | 10.2 |
| 103. | Supplies | | $B | | .003* | | | | .004* | .002* | | .004* | .012 | .021 | .028 | .028 | .023 | .028 | .031 | .044 | .042 | .051 | .086 |
| 104. | % Total Inventories | 311.18 | % | | 7.7* | | | | 11.7* | 6.0* | | 7.6* | 9.9 | 14.4 | 14.6 | 13.0 | 10.0 | 10.4 | 8.3 | 11.0 | 9.5 | 9.8 | 12.5 |
| 105. | Total Property, Gross, WW | 311.19 | $B | .724* | .904* | | | | 1.793* | 1.995* | | 2.253* | 3.717 | 4.552 | 5.807 | 6.635 | 6.997 | 8.032 | 9.558 | 10.492 | 11.094 | 12.264 | 14.017 |
| 106. | Land & Buildings—WW | | $B | .089* | .113* | .172* | .197* | .210* | .227* | .246* | .276* | .307* | .433 | .504 | .584 | .663 | .776 | .973 | 1.292 | 1.537 | 1.620 | 1.762 | 2.008 |
| 107. | Office Equipment—WW | | $B | | .027* | | | | .061* | .070* | | .091* | .158 | .186 | | | | | | | | | |
| 108. | Factory Equipment—WW | | $B | | .076* | | | | .150* | .168* | | .222* | .375 | .532 | | | | | | | | | |
| 109. | Factory & Office Equip. | | $B | | .103* | | | | .211* | .238* | | .313* | .533 | .718 | .863 | .984 | 1.132 | 1.335 | 1.600 | 1.758 | 1.808 | 1.988 | 2.374 |
| 110. | Rental Machines & Parts—WW Bal | | $B | | | | | | | | | | | | 3.330 | 4.360 | 4.988 | 5.088 | 5.723 | 6.666 | 7.196 | 7.665 | 8.514 |
| 111. | Added this Year | 311.20 | $B | | | | | | | | | | | | 1.320 | 1.222 | .846 | 1.197 | 1.518 | 1.372 | 1.453 | 1.748 | |
| 112. | Retirements & Sales | 311.20 | $B | | | | | | | | | | | | .290 | .593 | .746 | .562 | .575 | .841 | .984 | .901 | |
| 113. | Closing Balance | 311.20 | $B | | .687* | | | | 1.345* | 1.511* | | 1.632* | 2.751 | 3.330 | 4.360 | 4.988 | 5.088 | 5.723 | 6.666 | 7.196 | 7.665 | 8.514 | 9.634 |
| 114. | Depreciation Balance | | | | | | | | | | | | | | | 2.095 | 2.393 | 2.693 | 3.127 | 3.594 | 3.918 | 4.237 | 4.764 |
| 115. | Chgd. to P & L this Year | | $B | | | | | | | | | | | | | .772 | .863 | .884 | .926 | .971 | 1.111 | 1.268 | |
| 116. | Chgd. to Manufct'ng Overhead | | $B | | | | | | | | | | | | | .007 | .007 | .011 | .017 | .017 | .018 | .018 | |
| 117. | Retirements this Year | | $B | | | | | | | | | | | | | .481 | .570 | .461 | .475 | .664 | .810 | .759 | |
| 118. | Closing Balance | | $B | | | | | | | | | | | | 2.095 | 2.393 | 2.693 | 3.127 | 3.594 | 3.918 | 4.237 | 4.764 | 5.302 |
| 119. | Rent. Mach. & Parts—Net | 311.17 | $B | | | | | | | | | | | | 2.260 | 2.595 | 2.395 | 2.596 | 3.072 | 3.278 | 3.428 | 3.749 | 4.332 |
| 120. | % of Tot. Prop-Land & Build. | 311.19 | % | | 12.5* | | | | 12.6* | 12.4* | | 13.6* | 11.6 | 11.1 | 10.1 | 10.0 | 11.1 | 12.1 | 13.5 | 14.6 | 14.6 | 14.4 | 14.3 |
| 121. | Office Equipment | | % | | 2.9* | | | | 3.4* | 3.5* | | 4.0* | 4.3 | 4.1 | | | | | | | | | |
| 122. | Factory Equipment | | % | | 8.4* | | | | 8.4* | 8.4* | | 9.9* | 10.1 | 11.7 | | | | | | | | | |
| 123. | Factory & Office Equip | 311.19 | % | | 11.3* | | | | 11.8* | 11.9* | | 13.9* | 14.4 | 15.8 | 14.9 | 14.8 | 16.2 | 16.6 | 16.7 | 16.8 | 16.3 | 16.2 | 16.9 |
| 124. | Rental Machines & Parts | 311.19 | % | | 76.1* | | | | 75.0* | 75.6* | | 72.4* | 74.0 | 73.2 | 75.1 | 75.1 | 72.7 | 71.3 | 69.7 | 68.6 | 69.1 | 69.4 | 68.7 |
| | **Domestic Revenue Analysis** | | | | | | | | | | | | | | | | | | | | | | |
| 125. | Computers Sold Outright | | $B | | | | .073 | .039 | .022 | .092 | .184 | .199 | .320 | .345 | .445 | | | | | | | | |
| 126. | Computer Rental Revenue | | $B | | | | .689 | .842 | .978 | 1.093 | 1.241 | 1.407 | 1.504 | 1.665 | 1.781 | | | | | | | | |
| 127. | Military Products | | $B | | | | .225 | .229 | .191 | .254 | .212 | .144 | .110 | .140 | .175 | | | | | | | | |
| 128. | Electric Typewriters | | $B | | | | .075 | .090 | .125 | .125 | .135 | .140 | .150 | .163 | .175 | | | | | | | | |
| 129. | Dictation Equipment | | $B | | | | | | | .005 | .010 | .015 | .018 | .022 | .027 | | | | | | | | |
| 130. | Supplies—Cards & Tape | | $B | | | | .070 | .070 | .075 | .080 | .085 | .090 | .095 | .100 | .110 | | | | | | | | |
| 131. | Science Research Associates | | $B | | | | .004 | .005 | .008 | .009 | .012 | .014 | .020 | .025 | .030 | | | | | | | | |
| 132. | Service Bureau Corp. | | $B | | | | .040 | .040 | .045 | .045 | .058 | .065 | .111 | .125 | .150 | | | | .078 | .062 | .063 | | |
| 133. | Total | | $B | | | | 1.176 | 1.315 | 1.444 | 1.703 | 1.937 | 2.074 | 2.328 | 2.585 | 2.893 | | | | 4.571 | 4.864 | 5.381 | | |
| 134. | % Distribution—Computers Sold | | % | | | | 6.2 | 3.0 | 1.5 | 5.4 | 9.5 | 9.6 | 13.7 | 13.3 | 15.4 | | | | | | | | |
| 135. | Computer Rental Revenue | | % | | | | 58.6 | 64.0 | 67.7 | 64.2 | 64.1 | 67.8 | 64.7 | 64.4 | 61.6 | | | | | | | | |
| 136. | Subtotal DP Revenue | | % | | | | 64.8 | 67.0 | 69.2 | 69.6 | 73.6 | 77.4 | 78.4 | 77.7 | 77.0 | | | | | | | | |
| 137. | Military Products | | % | | | | 19.1 | 17.4 | 13.2 | 14.9 | 10.9 | 7.0 | 4.7 | 5.4 | 6.0 | | | | | | | | |
| 138. | Electric Typewriter | | % | | | | 6.4 | 6.8 | 8.7 | 7.3 | 7.0 | 6.8 | 6.4 | 6.3 | 6.1 | | | | | | | | |
| 139. | Dictation Equipment | | % | | | | | | | 0.3 | 0.5 | 0.7 | 0.8 | 0.9 | 0.9 | | | | | | | | |
| 140. | Supplies—Cards & Tape | | % | | | | 6.0 | 5.3 | 5.2 | 4.7 | 4.4 | 4.3 | 4.1 | 3.9 | 3.8 | | | | | | | | |
| 141. | Science Research Associates | | % | | | | 0.3 | 0.4 | 0.6 | 0.5 | 0.6 | 0.7 | 0.9 | 1.0 | 1.0 | | | | | | | | |
| 142. | Service Bureau Corp. | | % | | | | 3.4 | 3.1 | 3.1 | 2.7 | 3.0 | 3.1 | 4.7 | 4.8 | 5.2 | | | | 1.7 | 1.4 | 1.3 | | |

# TABLE II.1.312 CONTROL DATA CORPORATION

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Revenue** Total | 1.312.3 | $M | | | | .626 | 4.588 | 9.665 | 19.78 | 41.03 | 63.11 | 121.4 | 160.5 | 167.6 | 245.2 | 387.5 | 570.8 | 539.5 | 571.2 | 663.7 | 948.2 | 1101.1 |
| 2. | DP Products | | % | | | | | 49 | 70 | 80 | 88 | 96 | 94 | 93 | | | | | | | | | |
| 3. | Sales | 1.312.3 | $M | | | | .626 | 4.588 | 9.443 | 18.06 | 32.13 | 44.86 | 95.82 | 127.8 | 105.6 | 147.5 | 252.1 | 398.4 | 353.7 | 347.7 | 386.9 | 494.3 | 535.7 |
| 4. | Percent of Revenue | | % | | | | 100 | 100 | 97.7 | 91.3 | 78.3 | 71.1 | 78.9 | 79.6 | 63.0 | 60.2 | 65.1 | 69.8 | 65.6 | 60.9 | 58.3 | 52.1 | 48.7 |
| 5. | Service & Rentals | 1.312.3 | $M | | | | 0 | 0 | .222 | 1.721 | 8.905 | 18.25 | 25.62 | 32.65 | 62.05 | 97.66 | 135.4 | 172.3 | 185.8 | 223.4 | 276.8 | 441.8 | 544.9 |
| 5a. | Percent of Revenue | 1.312.3 | % | | | | 0 | 0 | 2.3 | 8.7 | 21.7 | 28.9 | 21.1 | 20.3 | 37.0 | 39.8 | 34.9 | 30.2 | 34.4 | 39.1 | 41.7 | 46.6 | 49.5 |
| 5b. | Rentals | | % | | | | | | | | | | | | | | | | 14 | 15 | 16 | 14 | 14 |
| 5c. | Services | | % | | | | | | | | | | | | | | | | 21 | 24 | 26 | 33 | 36 |
| 6a. | International Revenue | 1.312.6 | $M | | | | | | | | | | | 12 | 20 | 60 | 86 | 148 | 164 | 204 | 270 | 323 | 341 |
| 6b. | Percent of Tot. Rev. | 1.312.6 | % | | | | | | | | | | 0 | 7.4 | 11.9 | 24.5 | 22.2 | 25.9 | 30.4 | 35.7 | 40.7 | 34.1 | 31. |
| 7. | **Costs**–Sales | | $M | | | | .599 | 3.835 | 6.674 | 11.13 | 22.28 | 28.4 | 52.0 | 73.49 | 76.72 | 104.6 | 163.1 | 266.3 | 285.8 | 260.0 | 280.0 | 341.2 | 425.2 |
| 8. | % of Sales Revenue | 1.312.4 | % | | | | 95.7 | 83.6 | 70.7 | 61.6 | 69.3 | 63.3 | 54.3 | 57.5 | 72.7 | 70.9 | 64.7 | 66.8 | 80.8 | 74.8 | 72.4 | 69.0 | 79.4 |
| 9. | Service & Rentals | | $M | | | | 0 | 0 | .256 | 1.460 | 6.386 | 11.8 | 18.1 | 21.42 | 40.45 | 64.60 | 100.8 | 132.9 | 158.9 | 168.2 | 199.2 | 302.7 | 412.1 |
| 10. | % of Serv. & Rent Rev. | 1.312.4 | % | | | | | | 115.3 | 84.8 | 71.7 | 64.7 | 70.6 | 65.6 | 65.2 | 66.1 | 74.4 | 77.1 | 85.5 | 75.3 | 72.0 | 68.5 | 75.6 |
| 11. | Total Costs | | $M | | | | .599 | 3.835 | 6.930 | 12.59 | 28.67 | 40.16 | 70.12 | 94.91 | 117.2 | 169.2 | 263.8 | 399.2 | 444.7 | 428.2 | 479.2 | 643.9 | 837.2 |
| 12. | % of Total Revenue | 1.312.4 | % | | | | 95.7 | 83.6 | 71.7 | 63.7 | 69.9 | 63.6 | 57.8 | 59.1 | 69.9 | 69.0 | 68.1 | 69.9 | 82.4 | 75.0 | 72.2 | 67.9 | 76.0 |
| 13. | Gross Profit | | $M | | | | .027 | .753 | 2.735 | 7.197 | 12.36 | 22.95 | 51.32 | 66.56 | 50.44 | 75.93 | 125.6 | 171.6 | 94.82 | 143.0 | 184.6 | 304.3 | 263.9 |
| 14. | % of Total Revenue | | % | | | | 4.3 | 16.4 | 28.3 | 36.4 | 30.1 | 36.4 | 42.3 | 41.5 | 30.1 | 31.0 | 32.4 | 30.1 | 17.6 | 25.0 | 27.8 | 32.1 | 24.0 |
| 15. | Indirect Costs–Total | | $M | | | | .145 | .319 | 1.445 | 4.943 | 8.495 | 14.13 | 34.62 | 45.99 | 48.17 | 48.45 | 71.58 | 114.3 | 122.4 | 132.5 | 136.4 | 219.3 | 256.5 |
| 16. | % of Total Revenue | 1.312.5 | % | | | | 23.2 | 7.0 | 15.0 | 25.0 | 20.7 | 22.4 | 28.5 | 28.7 | 28.7 | 19.8 | 18.5 | 20.0 | 22.7 | 23.2 | 20.6 | 23.1 | 23.3 |
| 17. | Selling & Administrative | | $M | | | | .094 | .303 | 1.061 | 3.163 | 5.431 | 8.567 | 21.59 | 30.56 | 33.96 | 31.78 | 51.65 | 81.11 | 84.67 | 90.81 | 106.8 | 171.2 | 201.4 |
| 18. | % of Total Revenue | 1.312.5 | % | | | | 15.0 | 6.6 | 11.0 | 16.0 | 13.2 | 13.6 | 17.8 | 19.0 | 20.3 | 13.0 | 13.3 | 14.2 | 14.8 | 15.9 | 16.1 | 18.1 | 18.3 |
| 19. | Engineering R & D Expenses | | $M | | | | .051 | .016 | .355 | 1.708 | 2.615 | 5.129 | 12.12 | 13.92 | 12.94 | 15.31 | 18.15 | 29.54 | 30.85 | 33.02 | 29.60 | 48.1 | 55.2 |
| 20. | % of Total Revenue | 1.312.5 | % | | | | 8.1 | 0.3 | 3.7 | 8.6 | 6.4 | 8.1 | 10.0 | 8.7 | 7.7 | 6.2 | 4.7 | 5.2 | 5.7 | 5.8 | 4.5 | 5.1 | 5.0 |
| 21. | Total Company Funded | | $M | | | | .051 | .016 | .355 | 1.708 | 2.615 | 5.129 | 12.12 | 16.55 | 17.12 | 18.5 | 23 | 44.1 | 43.6 | 49.9 | | | |
| 22. | % of Total Revenue | | % | | | | 8.1 | 0.3 | 3.7 | 8.6 | 6.4 | 8.1 | 10.0 | 10.3 | 10.2 | 7.5 | 5.9 | 7.7 | 8.1 | 8.7 | | | |
| 23. | Depreciation | | $M | | | | | | .012 | .031 | .332 | .249 | .517 | .732 | .654 | .676 | .903 | 1.373 | 3.559 | 4.828 | – | – | – |
| 24. | % of Total Revenue | | % | | | | 0 | 0 | .1 | .2 | .8 | .4 | .4 | .5 | .4 | .3 | .2 | .2 | .7 | .8 | | | |
| 25. | Taxes | | $M | | | | | | .017 | .041 | .117 | .185 | .393 | .783 | .614 | .677 | .880 | 2.280 | 3.326 | 3.846 | – | – | – |
| 26. | % of Total Revenue | | % | | | | 0 | 0 | .2 | .2 | .3 | .3 | .3 | .5 | .4 | .3 | .2 | .4 | .7 | .7 | | | |
| 27. | Interest | | $M | | | | | .016 | .017 | .115 | .377 | .934 | 1.796 | 3.335 | 5.778 | 9.763 | 13.13 | 22.85 | 43.82 | 44.16 | 43.66 | 43.2 | 65.2 |
| 28. | % of Total Revenue | | % | | | | 0 | .3 | .2 | .6 | .9 | 1.5 | 1.5 | 2.1 | 3.4 | 4.0 | 3.4 | 4.0 | 8.1 | 7.7 | 6.6 | 4.6 | 5.9 |
| 29. | Operating Income | | $M | | | | d.118 | .417 | 1.273 | 2.138 | 3.492 | 7.887 | 14.90 | 16.24 | d3.509 | 17.72 | 38.89 | 34.42 | d71.42 | d33.74 | 4.44 | 41.8 | d57.8 |
| 30. | % of Total Revenue | | % | | | | d18.8 | 9.1 | 13.2 | 10.8 | 8.5 | 12.5 | 12.3 | 10.1 | d2.1 | 7.2 | 10.0 | 6.0 | d13.2 | d5.9 | 0.7 | 4.4 | d5.2 |
| 31. | Other Income | | $M | | | | .011 | .001 | .033 | .060 | .040 | .118 | .220 | .320 | .743 | 1.274 | 4.133 | 7.341 | 10.14 | 10.97 | | | |
| 32. | Net Earnings Before Taxes | | $M | | | | d.115 | .418 | 1.307 | 2.198 | 3.532 | 8.005 | 15.12 | 16.56 | d2.766 | 18.99 | 43.02 | 41.77 | d61.28 | d22.77 | | | |
| 33. | Net Earnings After Taxes | | $M | | | | d.115 | .268 | .531 | .821 | 1.522 | 3.044 | 6.873 | 7.913 | d1.912 | 8.405 | 18.46 | 18.49 | d36.1 | d9.97 | 10.32 | 17.2 | d31.4 |
| 34. | % of Total Revenue | 1.312.5 | % | | | | d18.3 | 5.8 | 5.5 | 4.2 | 3.7 | 4.8 | 5.7 | 4.9 | d1.1 | 3.4 | 4.8 | 3.2 | d6.7 | d1.7 | 1.6 | 1.8 | d2.9 |
| 35. | Including C.C. | | $M | | | | | | | | | | | | | | | 53.34 | d3.2 | 35.78 | 62.40 | 59.3 | 2.1 |
| 36. | **Employees**–Total | 1.312.7 | k | | | | .26 | .38 | .69 | 1.35 | 2.27 | 3.50 | 6.86 | 9.74 | 11.0 | 14.9 | 20.8 | | | | 31.0 | 44.0 | 45.3 |
| 37. | Professional | | k | | | | .02 | .10 | .27 | .56 | .93 | 1.64 | 3.14 | 4.4 | 4.8 | 5.8 | | | | | | | |
| 38. | % of Total Empl. | | % | | | | 7.7 | 26.3 | 39.1 | 41.5 | 41.0 | 46.9 | 45.8 | 45.2 | 43.6 | 38.9 | | | | | | | |
| 39. | Revenue Per Employee | 1.312.7 | $k | | | | 2.41 | 12.1 | 14.0 | 14.65 | 18.07 | 18.03 | 17.70 | 16.48 | 14.59 | 16.46 | 18.63 | | | | 21.41 | 21.55 | 24.3 |
| 40. | **Assets**–Total | 1.312.8 | $M | | | .025 | 1.223 | 2.374 | 7.878 | 18.95 | 40.37 | 71.34 | 133.1 | 208.4 | 273.7 | 350.7 | 465.4 | 1169 | 1273 | 1421 | 1588 | 1779 | 1906 |
| 41. | Inventories | 1.312.8 | $M | | | 0 | .513 | .502 | 2.352 | 8.347 | 11.77 | 23.59 | 47.70 | 58.83 | 71.97 | 131.6 | 136.1 | 299.3 | 282.6 | 258.5 | 245.4 | 282.7 | 325.6 |
| 42. | %–Total Assets | 1.312.8 | % | | | 0 | 41.9 | 21.1 | 29.9 | 44.0 | 29.2 | 33.1 | 35.8 | 28.2 | 26.3 | 37.5 | 29.2 | 25.6 | 22.9 | 18.1 | 15.5 | 15.9 | 17.1 |
| 43. | Serv. Equip. Inven.–Gross | 1.312.8 | $M | | | | | | 1.002 | 3.887 | 13.47 | 26.96 | 32.63 | 65.04 | 100.5 | 124.0 | 174.2 | 203.8 | 254.5 | 309.1 | 366.3 | 422.0 | 509.5 |
| 44. | Added in Year | | $M | | | | | | 1.002 | 2.884 | 9.780 | 14.78 | 13.73 | 38.35 | 40.69 | 43.80 | 57.98 | | | 90.93 | | | |
| 45. | Retired in Year | | $M | | | | | | | | .194 | 1.454 | 8.062 | 5.935 | 5.212 | 20.33 | 12.12 | | | 36.30 | | | |

## TABLE II.1.313 DIGITAL EQUIPMENT CORP.

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Revenue** | | $M | | | | | | | | 6.54 | 9.91 | 10.91 | 14.98 | 22.78 | 38.90 | 57.34 | 87.87 | 135.41 | 146.85 | 187.55 | 265.47 | 421.88 |
| 1a. | Foreign Revenue | | $M | | | | | | | | | | | | | | | 21. | 38. | | 65.0 | 92.9 | 164.5 |
| 1b. | % of Total Revenue | | % | | | | | | | | | | | | | | | 24. | 28. | | 34.6 | 35. | 39. |
| 2. | **Costs**–of Sales | | $M | | | | | | | | | | 4.47 | 7.16 | 11.30 | 19.15 | 28.66 | 45.31 | 67.06 | 76.37 | 98.20 | 142.62 | 227.65 |
| 3. | % of Revenue | | % | | | | | | | | | | 41.0 | 47.8 | 49.6 | 49.2 | 50.0 | 51.6 | 49.5 | 52.0 | 52.4 | 53.7 | 54.0 |
| 4. | Gross Profit | | $M | | | | | | | | | | 6.44 | 7.82 | 11.48 | 19.75 | 28.68 | 42.56 | 68.35 | 70.48 | 89.35 | 122.85 | 194.23 |
| 5. | R & D Expense | | $M | | | | | | | | | | 1.81 | 2.27 | 2.60 | 4.00 | 6.37 | 9.40 | 13.27 | 16.67 | 20.14 | 24.93 | 36.60 |
| 6. | % of Revenue | | % | | | | | | | | | | 16.6 | 15.2 | 11.4 | 10.3 | 11.1 | 10.7 | 9.7 | 11.4 | 10.7 | 9.4 | 8.7 |
| 7. | Selling & Admin. Exp. | | $M | | | | | | | | | | 2.85 | 4.08 | 5.18 | 7.46 | 9.64 | 16.53 | 28.83 | 35.82 | 44.12 | 61.17 | 92.50 |
| 8. | % of Revenue | | % | | | | | | | | | | 26.1 | 27.2 | 22.7 | 19.2 | 16.8 | 18.8 | 21.3 | 24.4 | 23.5 | 23.0 | 21.9 |
| 9. | Interest Expense | | $M | | | | | | | | | | .02 | .08 | .20 | | | .06 | .76 | | | | |
| 10. | % of Revenue | | % | | | | | | | | | | .2 | .5 | .9 | | | .1 | .6 | | | | |
| 11. | Operating Income | | $M | | | | | | | | 1.67 | 2.40 | 1.76 | 1.39 | 3.50 | 8.32 | 12.93 | 17.03 | 25.50 | 18.00 | 25.10 | 37.20 | 66.20 |
| 12. | % of Revenue | | % | | | | | | | | 25.5 | 24.2 | 16.1 | 9.3 | 15.4 | 21.4 | 22.5 | 19.4 | 18.8 | 12.3 | 13.4 | 14.0 | 15.7 |
| 13. | Net Earn. After Taxes | | $M | | | | | | | | .81 | 1.18 | .89 | .74 | 1.95 | 4.54 | 6.86 | 9.33 | 14.40 | 10.6 | 15.30 | 23.50 | 44.40 |
| 14. | % of Revenue | | % | | | | | | | | 12.4 | 11.9 | 8.2 | 4.9 | 8.6 | 11.7 | 12.0 | 10.6 | 10.6 | 7.2 | 8.2 | 8.9 | 10.5 |
| 15. | **Assets**–Total | | $M | | | | | | | | 4.18 | 4.84 | 5.71 | 10.78 | 15.11 | 21.73 | 36.50 | 61.85 | 114.82 | 150.14 | 192.42 | 287.40 | 440.27 |
| 16. | Inventories | | $M | | | | | | | | | | 2.84 | 4.77 | 7.03 | 9.09 | 16.93 | 26.72 | 43.04 | 44.44 | 62.12 | 102.74 | 137.40 |
| 16a. | % of Total Assets | | % | | | | | | | | | | 49.7 | 44.2 | 46.5 | 41.8 | 46.4 | 43.2 | 37.5 | 29.6 | 32.3 | 35.7 | 31.2 |
| 17. | Raw Materials | | $M | | | | | | | | | | | 1.11 | 1.35 | 1.75 | 2.12 | 4.14 | 7.77 | 8.77 | 12.01 | 27.32 | 36.45 |
| 18. | % of Inventories | | % | | | | | | | | | | | 23.3 | 19.2 | 19.3 | 12.5 | 15.5 | 18.1 | 19.7 | 19.3 | 26.6 | 26.5 |
| 19. | Work in Process | | $M | | | | | | | | | | | | | | | | 21.27 | 19.32 | 26.26 | 37.65 | 45.59 |
| 20. | % of Inventories | | % | | | | | | | | | | | | | | | | 49.4 | 43.5 | 42.3 | 36.6 | 33.2 |
| 21. | Finished Goods | | $M | | | | | | | | | | | | | | | | 14.01 | 16.35 | 23.85 | 37.78 | 55.37 |
| 22. | % of Inventories | | % | | | | | | | | | | | | | | | | 32.6 | 36.8 | 38.4 | 36.8 | 40.3 |
| 23. | WIP & Finished Goods | | $M | | | | | | | | | | | 3.66 | 5.68 | 7.34 | 14.81 | 22.58 | 35.28 | 35.67 | 50.11 | 75.43 | 100.96 |
| 24. | % of Inventories | | % | | | | | | | | | | | 76.7 | 80.8 | 80.7 | 87.5 | 84.5 | 82.0 | 80.3 | 80.7 | 73.4 | 73.5 |
| 25. | **Employees** | | k | | | | | | | | | | | | 1.10 | 1.80 | 2.60 | 4.36 | 5.80 | 6.20 | 7.80 | 13.00 | 17.60 |
| 26. | Revenue Per Employee | | $k | | | | | | | | | | | | 20.7 | 21.6 | 22.1 | 20.2 | 23.3 | 23.7 | 24.0 | 20.4 | 24.0 |

## TABLE II.1.314 XEROX DATA SYSTEMS (SDS, XDS)

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Sales & Service Revenue** | | $M | | | | | | | | 1.00 | 7.62 | 20.22 | 43.78 | 54.56 | 70.48 | 98.45 | 125.4 | 83.2 | 65. | 77. | 63. | 82.4 |
| 2. | Net Sales | | $M | | | | | | | | 1.00 | 7.33 | 18.44 | 39.16 | 45.94 | 56.66 | 79.15 | | | | | | |
| 3. | % of Total Revenue | | % | | | | | | | | 100.0 | 96.2 | 91.2 | 89.4 | 84.2 | 80.4 | 80.4 | | | | | | |
| 4. | Rental & Service Income | | $M | | | | | | | | | .29 | 1.78 | 4.62 | 8.62 | 13.82 | 19.30 | | | | | | |
| 5. | % of Total Revenue | | | | | | | | | | | 3.8 | 8.8 | 10.6 | 15.8 | 19.6 | 19.6 | | | | | | |
| 6. | **Cost**–of Sales | | $M | | | | | | | | .45 | 3.32 | 9.48 | 23.45 | 26.49 | 32.61 | 44.82 | | | | | | |
| 7. | % of Total Revenue | | % | | | | | | | | 45.0 | 43.6 | 46.9 | 53.6 | 48.6 | 46.3 | 45.5 | | | | | | |
| 8. | Cost of Products Sold | | $M | | | | | | | | .45 | 3.09 | 8.48 | 21.49 | 23.49 | 27.18 | 37.33 | | | | | | |
| 9. | % of Net Sales | | % | | | | | | | | 45.0 | 42.2 | 46.0 | 54.9 | 51.1 | 48.0 | 47.2 | | | | | | |
| 10. | Cost of Rentals & Service | | $M | | | | | | | | | .23 | 1.00 | 1.96 | 3.00 | 5.43 | 7.49 | | | | | | |
| 11. | % of Rental & Serv. Rev. | | % | | | | | | | | | 79.3 | 56.2 | 42.4 | 34.8 | 39.3 | 38.8 | | | | | | |
| 12. | Marketing & Admin. Costs | | $M | | | | | | | | .53 | 1.60 | 4.20 | 9.17 | 10.11 | 15.27 | 22.27 | | | | | | |
| 13. | % of Total Revenues | | % | | | | | | | | 53.0 | 21.0 | 20.8 | 20.9 | 18.5 | 21.7 | 22.6 | | | | | | |
| 14. | Mktg. Costs Act. Incurred | | $M | | | | | | | | .53 | 1.06 | 2.60 | 3.95 | 5.64 | 7.02 | 10.87 | | | | | | |
| 15. | % of Total Revenue | | % | | | | | | | | 53.0 | 13.9 | 12.9 | 9.0 | 10.3 | 10.0 | 11.0 | | | | | | |
| 16. | Engineering & Development Cost | | $M | | | | | | | | .51 | .57 | 1.79 | 3.79 | 6.48 | 5.99 | 7.87 | | | | | | |
| 17. | % of Total Revenues | | % | | | | | | | | 51.0 | 7.5 | 8.9 | 8.7 | 11.9 | 8.5 | 8.0 | | | | | | |
| 18. | Depreciation, Interest, etc. | | $M | | | | | | | | .02 | .14 | .61 | 2.16 | 4.37 | 5.35 | 6.14 | | | | | | |
| 19. | % of Total Revenues | | % | | | | | | | | 2.0 | 1.8 | 3.0 | 4.9 | 8.0 | 7.6 | 6.2 | | | | | | |
| 20. | Operating Income | | $M | | | | | | | | d.51 | 2.09 | 4.40 | 5.43 | 7.75 | 12.57 | 19.56 | | | | | | |
| 21. | Net Earnings After Taxes | | $M | | | | | | | | d.51 | 1.31 | 2.18 | 3.37 | 4.33 | 6.93 | 10.03 | | | | | | d18.6 |
| 22. | % of Total Revenue | | % | | | | | | | | d51.0 | 17.2 | 10.8 | 7.7 | 7.9 | 9.8 | 10.2 | | | | | | d22.6 |
| 23. | **Assets**–Total | | $M | | | | | | | | | | 18.82 | 42.89 | 65.78 | 97.99 | 113.3 | | | | | | |
| 24. | Inventories–Total | | $M | | | | | | | | .61 | 2.52 | 7.70 | 14.37 | 21.23 | 34.48 | 29.86 | | | | | | |
| 24a. | % of Total Assets | | % | | | | | | | | | | 40.9 | 33.5 | 32.3 | 35.2 | 26.4 | | | | | | |
| 25. | Raw Materials | | $M | | | | | | | | | | 3.06 | 4.33 | 10.58 | | | | | | | | |
| 26. | % of Total Inventory | | % | | | | | | | | | | 39.7 | 30.1 | 49.8 | | | | | | | | |
| 27. | WIP & Finished Goods | | $M | | | | | | | | | | 4.64 | 10.04 | 10.65 | | | | | | | | |
| 28. | % of Total Inventory | | % | | | | | | | | | | 60.3 | 69.9 | 50.2 | | | | | | | | |
| 29. | Rental Equipment–Gross | | $M | | | | | | | | | | | 7.51 | 10.87 | 15.23 | 20.76 | | | | | | |
| 30. | Net | | $M | | | | | | | | | | 1.98 | 6.26 | 8.14 | 10.34 | 13.51 | | | | | | |
| 31. | **Employees** | | k | | | | | | | | .166 | .438 | 1.357 | 2.373 | 2.950 | 3.60 | 4.00 | | | | | | |
| 32. | Revenue Per Employee | | $k | | | | | | | | 6.0 | 17.4 | 14.9 | 18.4 | 18.5 | 19.6 | 24.6 | | | | | | |

## TABLE II.1.321 CALIFORNIA COMPUTER PRODUCTS, INC.

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Revenue.**—Total | | $M | | | | | .029 | .377 | .739 | 1.786 | 2.894 | 5.188 | 4.135 | 6.225 | 11.545 | 16.854 | 20.474 | 27.616 | 44.650 | 53.871 | 80.308 | 129.91 |
| 2. | Proprietary Products | | $M | | | | | | .155 | .099 | .534 | 1.347 | 2.764 | 3.370 | 5.492 | 10.640 | 13.154 | 17.672 | 25.740 | 41.711 | 52.930 | 79.671 | |
| 3. | Percent of Tot. Rev. | | % | | | | | | 41.1 | 13.4 | 29.9 | 46.5 | 53.3 | 81.5 | 88.2 | 92.2 | 78.0 | 86.3 | 93.2 | 93.4 | 98.3 | 99.2 | |
| 4. | Rental Income | | $M | | | | | | | | | | | | .188 | .475 | .863 | 1.379 | 1.181 | 3.274 | 12.008 | 16.295 | 18.55 |
| 5. | Percent of Tot. Rev. | | % | | | | | | | | | | | | 3.0 | 4.1 | 5.1 | 6.7 | 4.3 | 7.3 | 22.3 | 20.3 | 14.3 |
| 6. | Net Sales | | $M | | | | | | .155 | .099 | .534 | 1.347 | 2.764 | 3.370 | 5.304 | 10.165 | 12.291 | 16.293 | 24.559 | 38.437 | 40.922 | 63.376 | 110.75 |
| 7. | Percent of Tot. Rev. | | % | | | | | | 41.1 | 13.4 | 29.9 | 46.5 | 53.3 | 81.5 | 85.2 | 88.0 | 72.9 | 79.6 | 88.9 | 86.1 | 76.0 | 78.9 | 85.3 |
| 8. | Other Income | | $M | | | | | | .015 | .010 | .013 | .022 | .032 | .046 | .052 | .026 | .094 | .075 | .945 | 1.510 | .441 | .637 | .61 |
| 9. | Percent of Tot. Rev. | | % | | | | | | 4.0 | 1.4 | 0.7 | 0.8 | 0.6 | 1.1 | 0.8 | 0.2 | 0.6 | 0.4 | 3.4 | 3.4 | 0.8 | 0.8 | 0.5 |
| 10. | Government Contracts | | $M | | | | | | .207 | .630 | 1.238 | 1.524 | 2.392 | .719 | .680 | .879 | 3.606 | 2.727 | .931 | 1.429 | .5 | | |
| 11. | Percent of Tot. Rev. | | % | | | | | | 54.9 | 85.2 | 69.3 | 52.7 | 46.1 | 17.4 | 10.9 | 7.6 | 21.4 | 13.3 | 3.4 | 3.2 | .9 | | |
| 12. | Foreign Sales—% of Tot. Rev. | | % | | | | | | | | | | 6.4 | | 10.6 | 12.9 | 15.6 | 23. | 31. | 52. | 31. | 28. | 21. |
| 13. | OEM Sales—% of Tot. Rev. | | % | | | | | | | | | | | | 13.2 | 20.3 | 10.1 | | | | | | |
| | **Costs** | | | | | | | | | | | | | | | | | | | | | | |
| 14. | Cost of Products & Services | | $M | | | | | .019 | .259 | .545 | 1.255 | 1.854 | 3.103 | 1.568 | 2.639 | 4.439 | 6.787 | 8.914 | 12.376 | 23.270 | 37.125 | 49.506 | 82.36 |
| 15. | % of Total Revenue | | % | | | | | | 68.7 | 73.7 | 70.3 | 64.1 | 59.8 | 37.9 | 42.4 | 38.4 | 40.3 | 43.5 | 44.8 | 52.1 | 68.9 | 61.6 | 63.4 |
| 16. | Engineering & Develop. Costs | | $M | | | | | | .019 | .017 | .061 | .136 | .304 | .656 | .664 | .941 | 1.351 | 1.556 | 1.736 | 1.846 | 6.188 | 7.647 | 8.20 |
| 17. | % of Total Revenue | | % | | | | | | 5.0 | 2.3 | 3.4 | 4.7 | 5.9 | 15.9 | 10.7 | 8.2 | 8.0 | 7.6 | 6.3 | 4.1 | 11.5 | 9.5 | 6.3 |
| 18. | Marketing, G & A Expenses | | $M | | | | | .025 | .071 | .138 | .300 | .558 | .792 | 1.015 | 1.808 | 3.711 | 6.030 | 7.518 | 10.533 | 10.209 | 16.938 | 17.620 | 20.55 |
| 19. | % of Total Revenue | | % | | | | | | 18.8 | 18.7 | 16.8 | 19.3 | 15.3 | 24.5 | 29.0 | 32.1 | 35.8 | 36.7 | 38.1 | 22.9 | 31.4 | 21.9 | 15.8 |
| 20. | Marketing Expenses | | $M | | | | | | | | | | | | | | | | | 5.017 | 9.380 | | |
| 21. | % of Total Revenue | | % | | | | | | | | | | | | | | | | | 11.2 | 17.4 | | |
| 22. | Total Indirect Costs | | $M | | | | | .025 | .091 | .159 | .364 | .724 | 1.141 | 1.710 | 2.529 | 4.814 | 7.623 | 9.362 | 13.193 | 14.030 | 26.549 | 29.929 | 36.38 |
| 23. | % of Total Revenue | | % | | | | | 86.2 | 24.1 | 21.5 | 20.4 | 25.0 | 22.0 | 41.4 | 40.6 | 41.7 | 45.2 | 45.7 | 47.8 | 31.4 | 49.3 | 37.3 | 28.0 |
| 24. | Income Before Tax | | $M | | | | | d.015 | .027 | .034 | .167 | .316 | .944 | .857 | 1.056 | 2.292 | 2.443 | 2.198 | 2.047 | 7.350 | d9.803 | .873 | 11.17 |
| 25. | Other Gains or Losses | | $M | | | | | | | | | | | | | | | .237 | .357 | 1.353 | d4.942 | d.017 | |
| 26. | Earnings After Taxes | | $M | | | | | d.015 | .023 | .021 | .084 | .144 | .459 | .447 | .556 | 1.175 | 1.187 | 1.127 | .807 | 2.279 | d12.90 | .465 | 8.67 |
| 27. | % of Total Revenue | | % | | | | | | 6.1 | 2.8 | 4.7 | 5.0 | 8.8 | 10.8 | 8.9 | 10.2 | 7.0 | 5.5 | 2.9 | 5.1 | d23.9 | 0.6 | 6.7 |
| 28. | **Assets.**—Total | | $M | | | | | | | | | | 2.467 | 3.713 | 5.197 | 12.284 | 18.386 | 25.756 | 40.505 | 66.609 | 68.063 | 86.142 | 107.81 |
| 29. | Inventories | | $M | | | | | .007 | .024 | .090 | .225 | .545 | .649 | 1.576 | 1.869 | 4.831 | 6.983 | 7.750 | 15.586 | 24.421 | 18.803 | 28.595 | 38.64 |
| 30. | % of Tot. Assets | | % | | | | | | | | | | 26.3 | 42.4 | 36.0 | 39.3 | 38.0 | 30.1 | 38.5 | 36.7 | 27.6 | 33.2 | 35.8 |
| 31. | Raw Materials | | $M | | | | | | | | | | .019 | | .066 | .113 | | 1.665 | 4.181 | 16.740 | 10.431 | 17.837 | 20.02 |
| 32. | % of Tot. Inventories | | % | | | | | | | | | | 2.9 | | 3.5 | 2.3 | | 21.5 | 26.8 | 68.5 | 55.5 | 62.4 | 51.8 |
| 33. | Finished Goods | | $M | | | | | | | | | | .138 | | .590 | .945 | | 2.504 | 3.104 | 2.027 | 3.669 | 3.763 | 9.47 |
| 34. | % of Tot. Inventories | | % | | | | | | | | | | 21.3 | | 31.6 | 19.6 | | 32.3 | 19.9 | 8.3 | 19.5 | 13.2 | 24.5 |
| 35. | Work in Process | | $M | | | | | | | | | | .491 | | 1.213 | 3.772 | | 3.581 | 8.301 | 5.654 | 4.703 | 6.995 | 9.16 |
| 36. | % of Tot. Inventories | | % | | | | | | | | | | 75.7 | | 64.9 | 78.1 | | 46.2 | 53.3 | 23.2 | 25.0 | 24.5 | 23.7 |
| 37. | Equipment on Lease—Gross | | $M | | | | | | | | | | | | | | .815 | 1.270 | 1.353 | 12.795 | 20.483 | 24.548 | 23.00 |
| 38. | Net | | $M | | | | | | | | | | | | | | | .486 | .977 | 11.098 | 14.343 | 16.263 | 14.71 |
| 39. | % of Total Assets | | % | | | | | | | | | | | | | | | 1.9 | 2.4 | 16.7 | 21.1 | 18.9 | 13.6 |
| 40. | **Employees.** | | | | | | | | 30 | 65 | 106 | 194 | 150 | 174 | 258 | 633 | 785 | 857 | 1565 | 1760 | 2365 | 3000 | 4017 |
| 41. | Revenue per Employee | | $k | | | | | | 12.6 | 11.4 | 16.8 | 14.9 | 34.6 | 23.8 | 24.1 | 18.2 | 21.5 | 23.9 | 17.6 | 25.4 | 22.8 | 26.8 | 32.3 |

## TABLE II.1.4.1 USER PERSONNEL ESTIMATES—NOTES

The raw data (lines 1-7) in this three-part table comes from two papers by Gilchrist and Weber (GilcB72-2 and GilcB74) which estimated the number of personnel employed by organizations which use computers. Four major categories were included, and are shown in the table: systems analysts; programmers; computer operators; and keypunch operators. Columns 1-18 are from the 1972 paper, columns 19-27 from the 1974 paper.

Columns 1-10. This data, from the Bureau of Labor Statistics, is derived from surveys conducted from late 1969 through early 1971 covering about 24 million employees. The systems analysts and programmers included were identified as *Business* system systems analysts and programmers, and their scientific equivalents were not included. Column 1 includes the manufacturing organizations covered, and column 2 the non-manufacturing organizations. Columns 3 through 7 break down the non-manufacturing totals into: transportation, communications, and public utilities; wholesale trade; retail trade; real estate, insurance, and finance; and service. Columns 8 and 9 break down the same data by size of the individual establishments (though "large" and "small" are undefined). And column 10 is the total for all non-agricultural, non-government installations. The subtotals in columns 1 through 7 don't add to the total figures because of government limitations on the publication of certain data. The 24 million employees covered by the survey (line 7) were estimated to be about 42% of all those on non-agricultural, non-government payrolls.

Column 11. Dividing column 10 by .42, the percentage of employees covered by the survey, we get column 11, which is an estimate of all the non-government employees in these various categories.

Columns 12-14. Column 12 is the summary of an annual report by the Federal government on its automatic data processing equipment and activities. (Additional data from this source is included in Table II.1.4.2.) The systems analysis and the programming activities are not qualified by the word "business", and therefore presumably include both scientific and business activities. However, the data in this column is given in man-years, rather than in number of employees, and it is assumed that the two terms are equivalent. Though GilcB72-2 doesn't mention it, the totals include man-years for electromechanical punched card systems as well as for computer systems—a problem we will discuss in connection with Table II.1.4.2. Columns 13 and 14 are extrapolations of data covering 36 states and eight major cities.

Columns 15-18. Column 15 is the rounded sum of columns 11 through 14. These totals are low because they neglect four major groups: scientific systems analysts and programmers in the non-government categories; the employees of educational institutions; agricultural employees; and the self-employed. To compensate for failing to include scientific and engineering personnel, Gilchirst and Weber increase systems analysts and programmers by 33%. To compensate for omitting some occupations, an additional 15% correction is made, justified on the grounds that at least 10% of the labor force is included in agricultural and self-employed categories, and that many computer people are employed by universities and colleges. The result of these corrections is given in column 16. Column 17 is an estimate made by the Bureau of Labor Statistics for the year 1968, and column 18 is an estimate based on the *Business Automation* 1971 salary survey, which reported 13.4 system analysts and programmers per installation in the U.S., combined with an IDC estimate of 34,700 installations—both these columns being supplied by GilcB72-2 for purposes of comparison.

Columns 19-21. In their second paper, Gilchrist and Weber start with 1970 data from the Employment and Earnings Surveys and Area Wage Surveys of the Bureau of Labor Statistics. Column 19 shows computer personnel counts for 37 specific U.S. Metropolitan areas, but excluding workers in Agriculture, Mining, Construction, and Government. In column 20, two corrections have been made. The first adjusts the total to include the whole U.S., by multiplying by the ratio of total U.S. employment to total employed in the 37 metropolitan areas. (That multiplier, coincidentally, is 1/.42, the same used in forming column 11). The second correction is the same as that described in connection with column 16 above—the BLS surveys do not enumerate scientific programmers and systems analysts, so those two categories were each increased by 33 percent.

Column 21, provided for comparative purposes, is Census Bureau data for the same year and the same industries. Note that the BLS data shows many more systems analysts and keypunch operators than were counted by the Census, but about the same number of programmers and computer operators. Gilchrist's and Weber's analysis of the differences led them to conclude that the Census count of systems analysts was probably low because it failed to include some employees in categories like "accounting systems analyst". However, in attempting to reconcile the differences in keypunch operator counts, they uncovered a difficulty which made matters worse. The Census data includes "IBM Machine Operators" with keypunch operators. Furthermore, the Census showed its keypunch category as being 10 percent male, where other data indicates only about one percent of keypunch operators are male. Gilchrist and Weber postulate that many of the "IBM Machine Operators" are really computer operators. If about 23,000 male "IBM Machine operators" were transferred from the keypunch to computer operator categories in the Census data, the male-female ratios in both categories would be much more reasonable. Unfortunately, such a transfer worsens the difference between keypunch operator counts in columns 20 and 21, and also introduces questions about the apparent agreement of computer operator counts.

Gilchrist and Weber nevertheless conclude that the BLS data is more likely to be accurate. To include employees working in Agriculture, Mining, Construction, and Government, they multiply by 1.2, which is the Census ratio of total employment in these occupations to employment in the included industries. The result is shown in Column 22.

Columns 23 to 27 show the results of similar analysis for the years 1969 to 1973. (Column 24 is a rounded-off version of Column 22). Gilchrist and Weber believe that the data for later years are better than those for earlier ones, because each year AWS data was available from an increasing number of metropolitan areas.

8-12. These entries show the proportions of each category of personnel to the total personnel in the sample. For example, looking at line 11 in columns 11 and 12, we see that computer operators represent 19.1% of total non-government DP employees, and 40.2% of Federal government DP employees. In each case, the result is

## II.1.4.1 USER PERSONNEL ESTIMATES

| | Column Descriptions: | | Non-Agricultural, Non-Government Users, 1970 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mfg. | Non-Manufacturing | | | | | | Large | Small |
| | | | | Total | TCP | Whol. | Ret'l. | RIF | Serv. | Estab. | Estab. |
| | Column Number: | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1. | No. of Systems Analysts | k | 13.56 | 17.82 | 1.76 | .33 | .23 | 5.63 | .78 | 13.08 | 20.60 |
| 2. | Programmers | k | 15.47 | 28.56 | 3.25 | .79 | .22 | 9.64 | 1.54 | 14.78 | 31.18 |
| 3. | SA & Prog. | k | 29.03 | 46.38 | 5.01 | 1.12 | .45 | 15.27 | 2.32 | 27.86 | 51.78 |
| 4. | Computer Operators | k | 18.35 | 32.98 | 3.12 | 1.77 | 1.14 | 10.41 | 1.98 | 17.45 | 34.62 |
| 5. | Keypunch Operators | k | 47.87 | 94.74 | 13.69 | 8.75 | 10.01 | 17.65 | 3.87 | 43.75 | 99.04 |
| 6. | Total Personnel | k | 95.25 | 174.10 | 21.82 | 11.64 | 11.60 | 43.33 | 8.17 | 89.06 | 185.44 |
| 7. | No. of Covered Employees | M | 11.40 | 12.72 | | | | | | 6.74 | 17.38 |
| | Percentages of Total | | | | | | | | | | |
| 8. | Systems Analysts | % | 14.2 | 10.2 | 8.1 | 2.8 | 2.0 | 13.0 | 9.5 | 14.7 | 11.1 |
| 9. | Programmers | % | 16.2 | 16.4 | 14.9 | 6.8 | 1.9 | 22.2 | 18.8 | 16.6 | 16.8 |
| 10. | SA & Prog. | % | 30.5 | 26.6 | 23.0 | 9.6 | 3.9 | 35.2 | 28.4 | 31.3 | 27.9 |
| 11. | Computer Operators | % | 19.3 | 18.9 | 14.3 | 15.2 | 9.8 | 24.0 | 24.2 | 19.6 | 18.7 |
| 12. | Keypunch Operators | % | 50.3 | 54.4 | 62.7 | 75.2 | 86.3 | 40.7 | 47.4 | 49.1 | 53.4 |
| | Ratios | | | | | | | | | | |
| 13. | Prog. to SA | | 1.14 | 1.60 | 1.85 | 2.39 | .96 | 1.71 | 1.97 | 1.13 | 1.51 |
| 14. | Comp. Oprs. to SA & P | | .63 | .71 | .62 | 1.58 | 2.53 | .68 | .85 | .63 | .67 |
| 15. | Keyp. Oprs. to SA & P | | 1.65 | 2.04 | 2.73 | 7.81 | 22.24 | 1.16 | 1.67 | 1.57 | 1.91 |
| 16. | Keyp. Oprs. to Comp. Oprs. | | 2.61 | 2.87 | 4.39 | 4.94 | 8.78 | 1.70 | 1.95 | 2.51 | 2.86 |
| | Equipment | | | | | | | | | | |
| 17. | No. of GP Computers | k | 18.10 | 24.54 | 3.06 | 2.09 | 1.70 | 7.81 | | | |
| 18. | In Sample | k | 7.51 | 10.18 | 1.27 | .87 | .71 | 3.24 | | | |
| 19. | Data Entry Keyboards | k | | | | | | | | | |
| | Per GP Computer | | | | | | | | | | |
| 20. | SA & P | | 3.87 | 4.56 | 3.94 | 1.29 | .63 | 4.71 | | | |
| 21. | Computer Operators | | 2.44 | 3.24 | 2.46 | 2.03 | 1.61 | 3.21 | | | |
| 22. | Keypunch Operators | | 6.37 | 9.31 | 10.78 | 10.06 | 14.10 | 5.45 | | | |
| 23. | Total Personnel | | 12.68 | 17.10 | 17.18 | 13.38 | 16.34 | 13.37 | | | |

## II.1.4.1 USER PERSONNEL ESTIMATES

| | Column Descriptions: | | Sub- | Non- | Government | | | First | Extrap. | 1968 | 1971 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Govt. | Fed. | State | City | Total | Total | BLS | BA |
| | Column Number: | | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1. | No. of Systems Analysts | k | 33.68 | 80 | 12.92 | 2.51 | 1.35 | 97 | 150 | 150 | |
| 2. | Programmers | k | 45.96 | 110 | 18.55 | 5.01 | 3.04 | 137 | 210 | 175 | |
| 3. | SA & Prog. | k | 79.64 | 190 | 31.47 | 7.52 | 4.39 | 234 | 360 | 325 | 465 |
| 4. | Computer Operators | k | 52.07 | 125 | 36.77 | 6.96 | 3.95 | 173 | 200 | 175 | |
| 5. | Keypunch Operators | k | 142.79 | 340 | 23.13 | 11.41 | 9.31 | 384 | 440 | | |
| 6. | Total Personnel | k | 274.50 | 655 | 91.37 | 25.89 | 17.65 | 791 | 1000 | | |
| 7. | No. of Covered Employees | M | 24.11 | | | | | | | | |
| | Percentages of Total | | | | | | | | | | |
| 8. | Systems Analysts | % | 12.3 | 12.2 | 14.1 | 9.7 | 7.6 | 12.2 | 15.0 | | |
| 9. | Programmers | % | 16.7 | 16.8 | 20.3 | 19.4 | 17.2 | 17.3 | 21.0 | | |
| 10. | S.A. & Prog. | % | 29.0 | 29.0 | 34.4 | 29.0 | 24.9 | 29.6 | 36.0 | | |
| 11. | Computer Operators | % | 19.0 | 19.1 | 40.2 | 26.9 | 22.3 | 21.9 | 20.0 | | |
| 12. | Keypunch Operators | % | 52.0 | 51.9 | 25.3 | 44.1 | 52.7 | 48.5 | 44.0 | | |
| | Ratios | | | | | | | | | | |
| 13. | Prog. to SA | | 1.36 | 1.38 | 1.44 | 2.00 | 2.25 | 1.41 | 1.40 | 1.17 | |
| 14. | Comp. Oprs. to SA & P | | .65 | .66 | 1.17 | .93 | .90 | .74 | .56 | .54 | |
| 15. | Keyp. Oprs. to SA & P | | 1.79 | 1.79 | .73 | 1.52 | 2.12 | 1.64 | 1.22 | | |
| 16. | Keyp. Oprs. to Comp. Oprs. | | 2.74 | 2.72 | .63 | 1.64 | 2.36 | 2.22 | 2.20 | | |
| | Equipment | | | | | | | | | | |
| 17. | No. of GP. Computers | k | 42.63 | 42.63 | 3.64 | 2.23* | * | 48.5 | 48.5 | | |
| 18. | In Sample | k | 17.70 | | | | | | | | |
| 19. | Data Entry Keyboards | k | | | | | | | 337 | | |
| | Per GP Computer | | | | | | | | | | |
| 20. | SA & P | | 4.50 | 4.46 | 8.65 | 5.34* | * | 4.82 | 7.42 | | |
| 21. | Computer Operators | | 2.94 | 2.93 | 10.10 | 4.89* | * | 3.57 | 4.12 | | |
| 22. | Keypunch Operators | | 8.07 | 7.98 | 6.35 | 9.29* | * | 7.92 | 9.07 | | |
| 23. | Total Personnel | | 15.51 | 15.36 | 25.10 | 19.52* | * | 16.31 | 20.62 | | |
| | Per DE Keyboard | | | | | | | | | | |
| 24. | Keypunch Operators | | | | | | | | 1.31 | | |

*State and City Government figures are combined into column 13 for entries marked with asterisk.

obtained by dividing the entry in line 4 by the entry in line 6 and multiplying by 100.

13-16. Ratios can provide useful information in samples where one component of the population is wrong, with the result that all percentages based on that sample are biased. I have computed the ratio of programmers to systems analysts, of keypunch operators to computer operators, and of both computer operators and keypunch operators to the sum of systems analysts and programmers. I use the sum of these two groups rather than computing a ratio to systems analysts alone because I suspect some lack of uniformity in the definitions of these two populations. The ratios are computed in the obvious way. For example, the ratio of programmers to systems analysts in manufacturing companies, shown in column 1 on line 13, is the ratio of the entry in line 2 to that in line 1 of that column.

17-19. The total number of GP computers in each industry classification comes from *EDP/IR* of May 29, 1970 where are given the percentages of all U.S. computers installed in each industry type. The percentages there are for the end of 1969, but I have assumed they applied also to the end of 1970, and have multiplied them by the number of computers installed at the end of 1970 (48,500) to get the numbers in line 17. In columns 11-16, the number of computers installed in the U.S. is applicable to the personnel populations on lines 1 through 6. However, as was stated above, the personnel counts on line 1 through 6, columns 1 through 10, represent a sample of a total of 24.1 million employees (see line 7, column 10) out of a total of 58.1 million employees in the United States. I have assumed that the sample proportion in each subcategory is the same as that for the total, and have thus computed the entries on line 18 by multiplying those on line 17 by the ratio of 24.1 to 58.1. The numbers on line 18 thus represent an estimate of the number of computers used by the personnel shown on lines 1 through 7.

The data entry keyboard population on line 19 is from Table II.1.23.

20-23. These lines show, for each of the columns, the average number of personnel per computer in each category. They were computed by dividing the appropriate number of personnel from line 1 through 6 by the number of computers given either in line 17 or line 18.

24. This line is formed by computing the ratio of line 5 to line 19 in each column.

25-27. Lines 25 and 26 are the quotient of lines 3 and 4, respectively, and the value of all GP systems in use in the U.S., from Table II.1.21. Line 27 is the sum of lines 25 and 26

### II.1.4.1 USER PERSONNEL ESTIMATES (Continued)

| | Column Descriptions: | | BLS | | Census | BLS | Adjusted Totals | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Raw | Corr. | Corr. | Total | 1969 | 1970 | 1971 | 1972 | 1973 |
| | Column Number: | | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 1. | No. of Systems Analysts | k | 30.7 | 98 | 68 | 117 | 110 | 120 | 120 | 135 | 140 |
| 2. | Programmers | k | 41.3 | 132 | 141 | 158 | 150 | 160 | 170 | 180 | 180 |
| 3. | SA & Prog. | k | 72.0 | 230 | 209 | 275 | 260 | 280 | 290 | 315 | 320 |
| 4. | Computer Operators | k | 44.9 | 108 | 104 | 130 | 110 | 130 | 145 | 160 | 165 |
| 5. | Keypunch Operators | k | 131.1 | 316 | 246 | 380 | 360 | 380 | 375 | 380 | 395 |
| 6. | Total Personnel | k | 248.0 | 654 | 559 | 785 | 730 | 790 | 810 | 855 | 880 |
| 7. | No. of Covered Employees | M | | | | | | | | | |
| | Percentages of Total | | | | | | | | | | |
| 8. | Systems Analysts | % | 12.4 | 15.0 | 12.2 | 14.9 | 15.1 | 15.2 | 14.8 | 15.8 | 15.9 |
| 9. | Programmers | % | 16.7 | 20.2 | 25.2 | 20.1 | 20.5 | 20.3 | 21.0 | 21.1 | 20.5 |
| 10. | SA & Prog. | % | 29.0 | 35.2 | 37.4 | 35.0 | 35.6 | 35.4 | 35.8 | 36.8 | 36.4 |
| 11. | Computer Operators | % | 18.1 | 16.5 | 18.6 | 16.6 | 15.1 | 16.5 | 17.9 | 18.7 | 18.8 |
| 12. | Keypunch Operators | % | 52.9 | 48.3 | 44.0 | 48.4 | 49.3 | 48.1 | 46.3 | 44.4 | 44.9 |
| | Ratios | | | | | | | | | | |
| 13. | Prog. to SA | | 1.35 | 1.35 | 2.07 | 1.35 | 1.36 | 1.33 | 1.42 | 1.33 | 1.29 |
| 14. | Comp. Oprs. to SA & P | | .62 | .47 | .50 | .47 | .42 | .46 | .50 | .51 | .52 |
| 15. | Keyp. Oprs. to SA & P | | 1.82 | 1.37 | 1.18 | 1.38 | 1.38 | 1.36 | 1.29 | 1.21 | 1.23 |
| 16. | Keyp. Oprs. to Comp. Oprs. | | 2.92 | 2.93 | 2.37 | 2.92 | 3.27 | 2.92 | 2.59 | 2.38 | 2.39 |
| | Equipment | | | | | | | | | | |
| 17. | No. of GP Computers | k | | | | | 46.00 | 48.50 | 54.40 | 57.73 | 62.25 |
| 18. | In Sample | k | | | | | | | | | |
| 19. | Data Entry Keyboards | k | | | | | 302 | 337 | 374 | 401 | 436 |
| | Per GP Computer | | | | | | | | | | |
| 20. | SA & P | | | | | | 5.65 | 5.77 | 5.33 | 5.46 | 5.14 |
| 21. | Computer Operators | | | | | | 2.39 | 2.68 | 2.67 | 2.77 | 2.65 |
| 22. | Keypunch Operators | | | | | | 7.83 | 7.84 | 6.89 | 6.58 | 6.35 |
| 23. | Total Personnel | | | | | | 15.87 | 16.29 | 14.89 | 14.81 | 14.14 |
| | Per DE Keyboard | | | | | | | | | | |
| 24. | Keypunch Operators | | | | | | 1.19 | 1.13 | 1.00 | .95 | .91 |
| | Per $100k US GP Value | | | | | | | | | | |
| 25. | SA & P | | | | | | 1.21 | 1.19 | 1.15 | 1.18 | 1.17 |
| 26. | Computer Operators | | | | | | .51 | .55 | .58 | .60 | .60 |
| 27. | SA & P Plus Comp. Oprs. | | | | | | 1.73 | 1.74 | 1.73 | 1.78 | 1.77 |

## TABLE II.1.4.2 PERSONNEL—NOTES

**User Personnel.** Table II.1.4.1 supplied two recent estimates of user personnel. I will now present some data which will be used to estimate how the population of user personnel has changed over the history of the industry.

1-9. This data comes from GSAInv, and from GilcB72-2. As stated in connection with Table II.1.4.1, the figures on lines 1-6 are for man-years, not personnel. Total man-years includes administration, equipment selection, and maintenance as well as the categories shown in lines 1 through 5. The "operations" category on line 5 is actually a miscellaneous catch-all, labelled "other ADP operations". It certainly includes computer and peripheral equipment operators, and undoubtably other personnel as well. The total on line 7 includes man-years both for computer units, defined as digital, programmed systems including a CPU; and punched card accounting machines, primarily electromechanical in operation, and using punched cards to record, verify, sort, list, tabulate, select, collate, merge, interpret, and total data. Lines 8 and 9 distinguish the man-years devoted to these two activities. (Another category included in the 1966 GSA report which is the source of line 8 and 9 is "ADP Management Staffs"; it represents the difference between line 7 and the sum lines 8 and 9.)

10-14. These figures are from various issues of CvSrvOccu. The figures marked with an asterisk on lines 12 and 14 are for the year 1954, though they appear in the 1955 column. Computer operators include digital computer systems and peripheral computer operators. System analysts and programmers include, in addition to those specific categories, computer specialists and computer aids and technicians. Accounting and tabulating machine operators, on line 14, includes electric accounting machine operation and planning. Note that in 1954 no computer operators or systems analysts and programmers were identified.

15-16. The tally of U.S. government computers also comes from GSAInv. The total on line 15 includes control systems, classified equipment, and mobile systems as well as general management systems. The latter are distinguished on line 16. (The 1955-66 figures on line 16 are my own extrapolations of the later data, and are based on the assumption that a decreasing proportion of the computer count were used in special applications as we go back in time.)

17-20. This information is from various issues of LabSPT. This survey, of a large sample of non-government, non-agricultural employees (the number of employees included is shown on line 19) identifies two categories of keypunch operators and three of tabulating machine operators. The count of total non-government, non-agricultural employees on line 20 is from CenStatAb.

21-24. The count of total civilian labor force 16 years and older on line 21 and the percentage of that force included in professional, technical, and kindred workers, and in clerical and kindred workers, are from the Department of Labor's "Handbook of Labor Statistics".

25-31. In reviewing data about the history of the computer industry, we frequently find statistics which apply not only to computers, but also to the data processing equipment which preceeded computers and is still today used in many places. This equipment, which is variously called tabulating machine or unit record or punched card or ADP (automatic data processing, as compared with EDP, which stands for electronic data processing) equipment, consisted of electromechanical card punches, card readers, printers, tabulators, and sorters employed to process files stored on punched cards. One indication of the importance of this older equipment is given on line 25, which gives the total of the U.S. government's computer system man-years as a percentage of all data processing man-years. These figures, which are the ratio of line 8 to line 7, provide one direct indication that non-computer data processing applications must be taken into account in interpreting statistics about the whole data processing industry.

Next look at line 12 above. We see that, in 1954 (when the Federal government operated only 10 computers) there were over 6,000 keypunch operators. If we assume that virtually all these operators were punching data for the tabulating machines operated by the people identified on line 14, we conclude that it took about 0.65 keypunch operators to prepare information for one tabulating machine operator in 1954. The ratio of line 12 to line 14 is given on line 26, and line 27 shows the same ratio for the U.S. clerical worker sample on lines 17 and 18. Note that the ratios are surprisingly consistent with one another.

The ratio increases, of course, because the ratio of computers to tabulating machine installations increased, and more and more keypunch operators were assigned to provide data to computers. On lines 28 and 29 I estimate the number of keypunch operators of the samples on lines 12 and 18, respectively, who were supplying data to computers. I base this estimate on the assumption that the number of keypunch operators per tabulating machine operator has remained constant since 1954 at 0.65. I can thus compute the number of keypunch operators supplying data for tabulating machines by multiplying 0.65 times the number of tabulating machine operators; and I find the number of keypunch operators on computers by subtracting the tab machine keypunch operators from total keypunch operators. For example, the number of keypunch operators on line 28 for the year 1964 was found by multiplying .65 by 7.35 from line 14, and subtracting the result from 12.28 on line 12. The entries on line 29 for the bigger U.S. clerical sample are calculated using the same constant (0.65) applied to lines 17 and 18.

30-31. We get a cross check of sorts by computing the percentage of all keypunch operators who are supplying data to computer installations. Line 30 is the quotient of lines 28 and 12, and line 31 the quotient of lines 29 and 18. Note that the figures, which are of course from two entirely different sources, agree fairly well for the years after 1964; but that they are in substantial disagreement for 1960. Line 31a is my assumption about the ratio of computer-input keypunch operators to total keypunch operators for the period since 1955.

32-34. The ratio of lines 19 and 21 is shown on line 32, and gives us a rough way to correct line 29 in order to take into account the fact that the keypunch operators identified on lines 18 and 29 represent only a sample of the total population. Line 33 is the adjusted figure—the quotient of lines 29 and 32. And line 34 is line 33 divided by the number of GP computers in use in the United States in each of the years in question. The figures on line 33 are, for reasons which will be clearer when we discuss line 55 below, too high. In part this is because of the character of the U.S. clerical sample, which does not consider small establishments. Since such establishments (having less than 250 employees, in general) probably have less data processing equipment and fewer keypunch operators per thousand employees than the bigger organizations, the correction factor on line 32 is probably too small. In addition, of course, my tabulting machine correction may be wrong.

35-40. On line 28, we computed a corrected value for the number of keypunch operators in the U.S. government civil service sample. If we substitute that line for line 12 in this table, and recompute line 13 by adding together lines 10, 11, and 28, we have a "corrected" U.S. government employee sample, line 35a. Lines 35 to 37 show the proportions of system analysts and programmers, computer operators, and keypunch operators of this corrected sample; and lines 38 to 40 show various ratios for that sample.

41-48. Next we compare the man-years of government data processing activities, given on lines 1 through 8, with the number of "general management" government computers from line 16. Line 41 is based on line 7, and thus includes punched card as well as computer operations. Lines 42 and 48 are based on lines 8 and 6, respectively, and presumably are comparable as ratios of computer man-years per computer. Lines 43 through 47 are the ratios of lines 1 through 5 to line 16. Line 48a is the ratio of line 35a to line 16, and thus takes into account the correction for ADP keypunch operators.

49-50. These ratios are based on the same U.S. government man-year population, lines 1-4.

**User Personnel–Summary.** 51-56. We now have more then enough data with which to attempt an estimate of the number of user personnel in each major category as a function of time. I will begin by estimating the levels in the period 1969-1973, in the light of Gilchrist's analysis; and I will base estimates for other years on the computer population in those years and on the other data which appears in the table.

Let us first compare some ratios from two time series: The U.S. Government figures in lines 43-50 above; and the "Adjusted totals" from the Gilchrist-Weber study, columns 23-27, lines 13-16 and 20-24 of Table II.1.4.1. The two sources have one striking factor in common—a substantial reduction, between 1969 and 1973, of the recorded number of keypunch operators per computer. But their differences are even more striking. Average government man-years per computer ranged from 24 to 30, while the average U.S. figures ranged between 14 and 16. And while the "operations" category in government fell from 12 to less than 10 man-years per computer, the U.S. operators per computer were increasing from 2.4 to 2.7. The greater number of total employees per computer in government computing is understandable because the government employs large computers to a greater extent than does the U.S. in general. In 1972, for example, the average government "general management" computer cost $660K, while the average U.S. computer cost $460K (Tables II.1.21 and II.3.11.6). Furthermore, we know that the government category "Operations" is a catch-all, which includes personnel other than the computer operators we (and Gilchrist) want to count.

Because of these difficulties, I will reject the government figures and base my estimate principally on columns 23-27 of Table II.1.4.1. Furthermore, because the various ratios of systems analysts, programmers, and computer operators to one another and to number of computers seem plausible and reasonable, I accept them without change for the period 1969-1973. The count of keypunch operators, however, I believe is inappropriate. Actually, we want to count the people who operate data entry keyboards, including keypunches, and key-tape and key-disk systems. It seems likely that the drop in "keypunch operators" shown in both Gilchrist's and the government figures reflects some sort of reclassification of personnel rather than an actual decrease in the number of people entering data. I will therefore assume that there are 1.2 keyboard operators for every keyboard, and thus will compute "keypunch operators" from the keyboard count in Table II.1.23.

For the years previous to and subsequent to the period 1969-1973, the only relevant data we have is that provided by the U.S. government figures of lines 41-48 above. The trend for total personnel per computer, from lines 42 and 48, indicates a steep drop between 1960 and 1965, a stable level of about 30 man-years per computer between 1965 and 1969, and a subsequent further fall to the level of about 20. However, as we have seen there is reason to believe these figures are not representative of all computer usage, and do not count the same personnel classifications we are trying to identify.

On the other hand, the ratios at the bottom of Table II.1.4.1 provide us with a clue which I propose to use to estimate personnel trends over the years. When we count average personnel per computer, we do not take into account differences in the size of the computers being used. If all computers were IBM System/3's, we would expect a much smaller number of personnel per computer than we would expect if all systems were CDC Star's. One way of accounting for this effect is to compute personnel per $100k of installed value, and this ratio is shown on lines 25 to 27 of Table II.1.4.1. Because the computed ratios seem fairly stable and because it seems reasonable that they should be, I adopt them as a means of computing personnel counts for years other than those estimated by Gilchrist. Furthermore, as system usage (in terms of hours per week and of number of applications) has increased over the years, I will assume that personnel employed per $100k of systems value has also increased moderately. Specifically, I assume computer operators per $100k have increased from 0.45 to 0.60 between 1955 and 1974, and that systems analysts and programmers (counted together) have increased from 1.15 to 1.20. Furthermore, I assume a constant 1.4 programmers per system analyst over the entire period. Lines 49 of this table and 13 of Table II.1.4.1 give some indication of a drop in that ratio over the years, but the trend is not altogether obvious in Gilchrist's data, and the government data is presumably not representative.

With these assumptions, we are able to estimate the population of system analysts, programmers, and computer operators from the value of U.S. GP computers in use, and the population of keypunch operators (more accurately called data entry keyboard operators) from the number of data entry keyboards in use. The results are shown in lines 51 to 55, and the sum of lines 53 to 55 is given on line 56.

**Supplier Personnel.** 57-59. Line 57 comes from GilcB73, which gives the U.S. Department of Labor as the source. The figures given are averages for the year, except for the last,

## TABLE II.1.4.2 PERSONNEL ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **User Personnel** | | | | | | | | | | | | | | | | | | | | | | |
| | U.S. Government Man-Years | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Systems Analysts | | k | | | | | | | | | | | | 6.61 | 8.03 | 10.53 | 12.01 | 12.92 | 13.55 | 12.75 | 14.16 | 14.11 |
| 2. | Programmers | | k | | | | | | | | | | | | 13.89 | 15.49 | 16.75 | 17.09 | 18.55 | 18.91 | 19.65 | 18.78 | 18.84 |
| 3. | SA & P | | k | | | | | | | | | | | | 20.50 | 23.52 | 27.28 | 29.10 | 31.47 | 32.46 | 32.40 | 32.94 | 32.95 |
| 4. | Keypunch Operators | | k | | | | | | | | | | | | 20.17 | 23.54 | 25.06 | 22.83 | 23.13 | 20.45 | 18.49 | 16.70 | 12.59 |
| 5. | Operations | | k | | | | | | | | | | | | 29.40 | 33.67 | 35.59 | 34.59 | 36.77 | 34.14 | 33.21 | 33.00 | 30.23 |
| 6. | Total | | k | | | | | | | | | | | | 70.07 | 80.73 | 87.93 | 86.52 | 91.37 | 87.05 | 84.10 | 82.64 | 75.77 |
| 7. | Total–All ADP Man-Yrs. | | k | | | | | | 48.70 | 54.40 | 58.80 | 67.40 | 72.30 | 76.20 | 89.63 | 105.93 | 118.81 | 118.87 | 127.49 | 122.19 | 124.29 | 118.80 | 114.29 |
| 8. | Computer Units | | k | | | | | 24.40 | 29.60 | 34.90 | 39.00 | 47.40 | 58.90 | 63.70 | 71.20 | | | | | | | | |
| 9. | Punched-Card Units | | k | | | | | | 19.10 | 19.50 | 19.80 | 17.50 | 9.90 | 8.60 | 8.20 | | | | | | | | |
| | U.S. Govt. Employees | | | | | | | | | | | | | | | | | | | | | | |
| 10. | Systems Anal. & Programmers | | k | | | | 1.72 | 2.48 | 3.92 | | 6.11 | | 8.79 | | 13.00 | 16.88 | 19.98 | 18.60 | 20.06 | | | | |
| 11. | Computer Operators | | k | | | | .96 | 1.45 | 2.06 | | 3.30 | | 4.33 | | 6.29 | 7.49 | 8.96 | 13.14 | 14.49 | | | | |
| 12. | Keypunch Operators | | k | 6.42* | | | 8.66 | 9.49 | 10.22 | | 11.56 | | 12.28 | | 16.07 | 17.15 | 16.17 | 14.82 | 13.11 | | | | |
| 13. | Total | | k | | | | 11.34 | 13.42 | 16.20 | | 20.97 | | 25.40 | | 35.36 | 41.52 | 45.11 | 46.56 | 47.66 | | | | |
| 14. | Acctg. & Tab. Mach. Opers. | | k | 9.93* | | | 12.06 | 11.17 | 10.71 | | 9.98 | | 7.35 | | 5.29 | 4.47 | 3.89 | 3.51 | 2.40 | | | | |
| | U.S. Govt. Computers | | | | | | | | | | | | | | | | | | | | | | |
| 15. | Total | | k | .045 | .090 | .160 | .250 | .403 | .531 | .730 | 1.030 | 1.326 | 1.862 | 2.412 | 3.007 | 3.692 | 4.232 | 4.666 | 5.277 | 5.934 | 6.731 | 7.149 | 7.830 |
| 16. | General Management | | k | .045 | .09 | .16 | .25 | .4 | .5 | .7 | 1.0 | 1.3 | 1.7 | 2.1 | 2.4 | 2.685 | 2.805 | 2.882 | 3.404 | 3.389 | 3.433 | 3.432 | 3.487 |
| | U.S. Clerical Worker Sample | | | | | | | | | | | | | | | | | | | | | | |
| 17. | Tabul'ng Mach. Opers. | | k | | | | | | 39.2 | | | | | 36.1 | | | 26.1 | 20.5 | 15.8 | | | | |
| 18. | Keypunch Operators | | k | | | | | | 45.1 | | | | | 84.0 | | | 100.6 | 108.4 | 113.7 | – | – | 109.2 | |
| 19. | No. of Covered Employees | | M | | | | | | 11.3 | | | | | 16.7 | | | 18.7 | 19.7 | 19.9 | – | – | 19.7 | |
| 20. | Total Non-Govt. Employees | | M | 43.8 | | | | | 45.9 | | | | | 50.8 | | 54.5 | 56.1 | 58.1 | 58.1 | 57.8 | – | 61.9 | |
| | U.S. Labor Force | | | | | | | | | | | | | | | | | | | | | | |
| 21. | All Occupations | 1.4.1 | M | 65.5 | 67.2 | 67.6 | 68.2 | 69.0 | 70.2 | 71.0 | 71.3 | 72.4 | 73.6 | 75.0 | 76.5 | 76.9 | 78.3 | 80.3 | 82.2 | 83.5 | 85.9 | 88.1 | |
| 22. | Prof. Techn., etc. | 1.4.1 | % | 8.9 | 9.2 | 9.7 | 10.4 | 10.5 | 10.8 | 11.1 | 11.5 | 11.6 | 11.8 | 12.0 | 12.5 | 13.0 | 13.3 | 13.6 | 13.8 | 13.7 | 13.7 | 13.7 | |
| 23. | Clerical, etc. | 1.4.1 | % | 13.1 | 13.5 | 13.9 | 14.0 | 14.0 | 14.5 | 14.6 | 14.8 | 14.8 | 15.0 | 15.4 | 15.9 | 16.6 | 16.8 | 17.2 | 17.4 | 17.0 | 17.4 | 17.2 | |
| 24. | Subtotal | 1.4.1 | % | 22.0 | 22.7 | 23.6 | 24.4 | 24.5 | 25.3 | 25.6 | 26.3 | 26.4 | 26.8 | 27.4 | 28.2 | 29.6 | 30.1 | 30.8 | 31.2 | 30.7 | 31.1 | 30.9 | |
| | Inferences & Deductions | | | | | | | | | | | | | | | | | | | | | | |
| 25. | Computer Man-Yrs.–% of Total | | | | | | | | 60.7 | 64.1 | 66.3 | 70.3 | 81.5 | 83.6 | 79.4 | | | | | | | | |
| | Keyp. Opr. Per Tab. Mach. Opr. | | | | | | | | | | | | | | | | | | | | | | |
| 26. | U.S. Govt. | | | .647* | | | .72 | .85 | .95 | | 1.16 | | 1.67 | | 3.04 | 3.84 | 4.16 | 4.22 | 5.46 | | | | |
| 27. | U.S. Clerical Sample | | | | | | | | 1.15 | | | | | 2.33 | | | 3.85 | 5.29 | 7.20 | | | | |
| | Keyp. Oprs. on Computers | | | | | | | | | | | | | | | | | | | | | | |
| 28. | U.S. Govt. | | k | | | | .86 | 2.27 | 3.30 | | 5.11 | | 7.52 | | 13.65 | 14.26 | 13.66 | 12.55 | 11.56 | | | | |
| 29. | U.S. Clerical | | k | | | | | | 19.8 | | | | | 60.7 | | | 8.37 | 95.1 | 103.5 | | | | |
| | Comp. Keyp. Oprs.–% of Tot. | | | | | | | | | | | | | | | | | | | | | | |
| 30. | Corr. U.S. Govt. Employees | | % | | | | 10 | 24 | 32 | | 44 | | 61 | | 85 | 83 | 84 | 85 | 88 | | | | |
| 31. | U.S. Clerical Sample | | % | | | | | | 44 | | | | | 72 | | | 83 | 88 | 91 | | | | |
| 31a. | Assumed Correct value | | % | 2 | 5 | 10 | 18 | 28 | 38 | 46 | 53 | 60 | 66 | 72 | 76 | 80 | 83 | 88 | 91 | 93 | 95 | 97 | 98 |
| | U.S. Clerical Sample | | | | | | | | | | | | | | | | | | | | | | |
| 32. | Corr. Factor–US Cler. Keyp. Oper. | | | | | | | | .161 | | | | | .222 | | | .239 | .245 | .241 | | | .223 | |
| 33. | Tot. US Cler Keyp. Oper. on Comp. | | k | | | | | | 123 | | | | | 273 | | | 350 | 388 | 429 | | | | |
| 34. | Per GP. Computers | | | | | | | | 28.0 | | | | | 12.6 | | | 8.5 | 8.4 | 8.8 | | | | |
| | Corrected U.S. Govt. | | | | | | | | | | | | | | | | | | | | | | |
| 35a. | Total Employees | | k | | | | 3.54 | 6.20 | 9.28 | | 14.52 | | 20.65 | | 32.94 | 38.63 | 42.60 | 44.29 | 46.11 | | | | |
| 35. | Percent–SA & Programmers | | % | | | | 48.6 | 40.0 | 42.2 | | 42.1 | | 42.6 | | 39.5 | 43.7 | 46.9 | 42.0 | 43.5 | | | | |
| 36. | Computer Operators | | % | | | | 27.1 | 23.4 | 22.2 | | 22.7 | | 21.0 | | 19.1 | 19.4 | 21.0 | 29.7 | 31.4 | | | | |
| 37. | Keypunch Operators | | % | | | | 24.3 | 36.6 | 35.6 | | 35.2 | | 36.5 | | 41.4 | 36.9 | 32.1 | 28.3 | 25.1 | | | | |

which is given as "employment for August 1972". The authors point out that other employees are concealed in other SIC Codes, and speculate that total employment by computer manufacturers is over 300,000. The U.S. Department of Commerce figures for total employees in SIC Code 3573 and its predecessor 3571 are given on lines 58 and 59. Gilchirst provided no explanation for the difference between Department of Labor and Department of Commerce figures–lines 57 and 58.

**Manufacturing Direct Labor.** 60-63. The first category of supplier personnel we will look at in detail is the biggest–the people directly involved in fabricating and assembling products. Line 60 provides the U.S. Department of Commerce estimate of production workers in establishments classified under SIC Code 3573–electronic computing equipment. These employees are, of course, included in the total employees from line 58 above. Line 61, which estimates direct labor cost as a percent of shipments, is derived from Table II.4.10.1. The figures for 1967 through 1972 are the Department of Commerce ratios of direct labor wages to total shipment value. Those for the years 1957 through 1966 are based on the direct labor percentage of SIC 3571, "computing and related equipment". However, labor costs in that industry are a higher percentage of shipments than in SIC 3573; and I have therefore estimated the numbers on line 61 by multiplying SIC 3571 direct labor percentages by the ratio of 8.3 to 11.9–the direct labor ratios of the two industries in 1967. The direct labor percentages for the years 1955 through 1957 are my own extrapolation of the later figures.

Line 62 is the total direct labor cost of the computer business, including shipments of general purpose systems, minisystems, and peripheral equipment. It is computed by multiplying the direct labor percentages of line 61 by the total shipments of GP's, minis, and peripherals from Table II.1.20, line 5. It does *not* include foreign shipments by U.S. firms, and therefore does not include overseas production workers of those firms, or domestic labor producing equipment to be shipped overseas. Line 63 is computed from line 62 by dividing total direct labor by the wages of production personnel, from Table II.1.4.3. As is explained in connection with that table, the direct labor dollars per hour are based on man hours actually worked, excluding vacations. I therefore used a 50-week year in computing annual wages and deriving line 63. In comparing lines 60 and 63, remember that SIC Code 3573 includes production of some equipment other than computing equipment; and that some other computing equipment is shipped under different SIC codes. Line 63a is computed, in the same way as was line 63, starting with the U.S. shipments of GP systems alone (line 1 of Table II.1.20 instead of line 5). It thus estimates the number of direct labor manufacturing personnel involved in producing GP systems.

**Development Personnel.** In the paragraphs which follow, I estimate the number of professional personnel engaged in developing hardware and software for the manufacturers of GP computer equipment in the United States. I exclude personnel developing minicomputers and peripheral equipment for the independent manufacturers; and I exclude software development people in the software industry (discussed in connection with Tables II.1.25 and II.1.26) and in the minicomputer business. The great majority of professional people working for suppliers do of course work for the GP system manufacturers.

In each development category–hardware and software–I begin by estimating the number of IBM personnel, and then apply the same estimating techniques to the other system companies. Lines 64 through 88, then, deal with IBM; lines 89 through 108 with other system companies; and lines 109 through 115 summarize the results.

64-66. Line 64 lists the number of CPU models IBM added to its line each year; and line 65 is the cumulative sum of all models introduced. The source for this data is the same as that given for the industry-wide figures shown on Table II.1.21, lines 156 through 203. The two CPU's introduced before 1955 were shipped in 1953 and 1954. The number of CPU's "in the product line", on line 66, makes the arbitrary assumpting that a CPU is dropped ten years after its first shipment. Thus for example the 28 CPU's in the product line in 1969 are computed by subtracting the eight machines introduced through 1959 from the 36 introduced through 1969.

67. The amount of software provided as standard programming support (operating systems, data management systems, utility programs, system generators, assemblers, compilers, sort-merge routines, etc.) has been growing steadily. This estimate of the average number of lines of machine language code required for each CPU in the product line is my own interpretation of a graph by R.M. McClure (NaurP69, p.66)–here reproduced as Figure 1.25.5. Note particularly that this does not include application programs, or special programs for individual customers.

68-69. The amount of software completed each year, and the cumulative total amount completed are computed from lines 64 and 67, using the following assumptions. The software for each CPU is developed over a period of six years. One sixth of the total is completed each year, starting with the year before the shipment of the first system, and ending the fourth year afterward. Thus I assume, for the five machines first shipped in 1965 (the 360/20, 30, 40, 50, and 65), that each machine required 1.4 million lines of code (the software per CPU shown for the year 1969), and that one sixth of that 7 million lines was developed in each of the six years 1964-69. The totals on line 69 are computed by summing these various individual development requirements. Line 68 is the cumulative sum of line 69.

70-70a. To compute the number of professional programmers required to develop the amount of code on line 69, we need to know how many lines of code an individual programmer produces in one year. The figures on line 70 assume that all programs are written in machine language, that programming productivity has increased by a uniform 3.5% per year, and that the 1964 average productivity was as given by NelsE67 (See Notes to Table II.4.22.3). Line 70a is computed by multiplying line 70 by 12.

71. The number of development programmers required is computed by dividing line 69 by line 70a. Because of the oscillations in the raw data on line 69 for the years since 1966, I have arbitrarily adjusted some of the numbers on line 71 (marked by an asterisk) to provide what seems to be a reasonable result, leaving unchanged the total number of lines of code developed.

72-74. In addition to the programmers assigned to develop new software, an increasing proportion of total programming personnel must be given the job of sustaining–that

## TABLE II.1.4.2 PERSONNEL ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | Ratios–Comp. Opr to SA & P | | | | | | .56 | .58 | .53 | | .54 | | .49 | | .48 | .44 | .45 | .71 | .72 | | | | |
| 39. | Keyp Oprs. to SA & P | | | | | | .50 | .92 | .84 | | .84 | | .86 | | 1.05 | .84 | .68 | .67 | .58 | | | | |
| 40. | Keyp. Opr. to Comp. Opr. | | | | | | .89 | 1.57 | 1.60 | | 1.55 | | 1.74 | | 2.17 | 1.90 | 1.52 | .96 | .80 | | | | |
| | Govt. Man-Yrs. Per GM Comp. | | | | | | | | | | | | | | | | | | | | | | |
| 41. | All ADP | | | | | | | | 97.4 | 77.7 | 58.8 | 51.8 | 42.6 | 36.3 | 37.3 | 39.45 | 42.36 | 41.25 | 37.45 | 36.05 | 36.20 | 34.62 | 32.78 |
| 42. | Computer Units | | | | | | | | 59.2 | 49.9 | 39.0 | 36.5 | 34.6 | 30.3 | 29.7 | | | | | | | | |
| 43. | Systems Analysts | | | | | | | | | | | | | | 2.75 | 2.99 | 3.75 | 4.17 | 3.80 | 4.00 | 3.71 | 4.13 | 4.05 |
| 44. | Programmers | | | | | | | | | | | | | | 5.79 | 5.77 | 5.97 | 5.93 | 5.45 | 5.58 | 5.72 | 5.47 | 5.40 |
| 45. | SA & P | | | | | | | | | | | | | | 8.54 | 8.76 | 9.73 | 10.10 | 9.25 | 9.58 | 9.44 | 9.60 | 9.45 |
| 46. | Keypunch Operators | | | | | | | | | | | | | | 8.40 | 8.77 | 8.93 | 7.92 | 6.79 | 6.03 | 5.39 | 4.87 | 3.61 |
| 47. | Operations | | | | | | | | | | | | | | 12.25 | 12.54 | 12.69 | 12.00 | 10.80 | 10.07 | 9.67 | 9.62 | 8.67 |
| 48. | Total | | | | | | | | | | | | | | 29.20 | 30.07 | 31.35 | 30.02 | 26.84 | 25.69 | 24.50 | 24.08 | 21.73 |
| 48a | Corrected U.S. Government | | | | | | 14.2 | 15.5 | 18.6 | | 14.5 | | 12.1 | | 13.7 | 14.4 | 15.2 | 15.4 | 13.5 | | | | |
| | U.S. Govt. Man-Years Ratios | | | | | | | | | | | | | | | | | | | | | | |
| 49. | Prog. to SA | | | | | | | | | | | | | | 2.10 | 1.93 | 1.59 | 1.42 | 1.44 | 1.40 | 1.54 | 1.33 | 1.34 |
| 50. | Keypunch Opr. to SA & P | | | | | | | | | | | | | | .98 | 1.00 | .92 | .84 | .73 | .63 | .57 | .51 | .38 |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| 51. | No. of–Systems Analysts | 1.4.2 | k | .86 | 1.5 | 2.6 | 4.4 | 6.5 | 9.1 | 13 | 17 | 23 | 30 | 39 | 54 | 70 | 88 | 110 | 120 | 120 | 135 | 140 | 150 |
| 52. | Programmers | 1.4.2 | k | 1.21 | 2.2 | 3.7 | 6.0 | 9.1 | 12.7 | 18 | 24 | 31 | 41 | 55 | 76 | 95 | 122 | 150 | 160 | 170 | 180 | 180 | 210 |
| 53. | SA & Programmers | | k | 2.07 | 3.7 | 6.3 | 10.4 | 15.7 | 21.8 | 31 | 41 | 54 | 71 | 94 | 130 | 165 | 210 | 260 | 280 | 290 | 315 | 320 | 360 |
| 54. | Computer Operators | 1.4.2 | k | .81 | 1.5 | 2.5 | 4.2 | 6.3 | 9.0 | 13 | 17 | 22 | 30 | 39 | 54 | 69 | 88 | 110 | 130 | 145 | 160 | 165 | 180 |
| 55. | Keypunch Operators | 1.4.2 | k | 1.80 | 5.2 | 9.2 | 15.6 | 23.2 | 32.8 | 47 | 61 | 89 | 128 | 166 | 218 | 280 | 310 | 360 | 405 | 450 | 480 | 525 | 520 |
| 56. | Total User Personnel | 1.4.2 | k | 4.68 | 10.4 | 18.0 | 30.2 | 45.2 | 63.6 | 91 | 119 | 165 | 229 | 299 | 402 | 514 | 608 | 730 | 815 | 885 | 955 | 1010 | 1060 |
| | **Supplier Personnel** | | | | | | | | | | | | | | | | | | | | | | |
| 57. | SIC 3573–U.S. Dept. of Labor | | k | | | | | | | | | | | | | 145.1 | 160.6 | 182.7 | 190.3 | 170.1 | 172.3 | | |
| 58. | U.S. Dept. of Commerce | | k | | | | | | | | | | | | | 98 | 109 | 140 | 146 | 153 | 145 | | |
| 59. | SIC 3571–U.S. Dept. of Comm'r. | | k | | | | 80.9 | 78.2 | 95.1 | 98.3 | 100.5 | 96.4 | 102.8 | 115.1 | 136.4 | 137.3 | | | | | | | |
| | Manufacturing Direct Labor | | | | | | | | | | | | | | | | | | | | | | |
| 60. | SIC 3573–Production Workers | | k | | | | | | | | | | | | | 50.7 | 55.4 | 69.8 | 67.0 | 72.3 | 64.5 | | |
| 61. | D.L. as Percent of Shipments | | % | 20. | 19. | 18. | 17.1 | 14.8 | 15.9 | 15.3 | 13.9 | 13.5 | 9.2 | 9.4 | 7.8 | 8.3 | 9.1 | 9.8 | 9.5 | 9.5 | 8.5 | 9.0 | 9.0 |
| 62. | Total Direct Labor | | $B | .015 | .034 | .050 | .076 | .084 | .110 | .151 | .170 | .195 | .169 | .210 | .274 | .353 | .464 | .511 | .448 | .453 | .543 | .641 | .774 |
| 63. | Total D.L. Employees | | k | 3.1 | 6.8 | 9.9 | 14.6 | 15.9 | 19.7 | 26.6 | 29.8 | 34.2 | 29.7 | 35.0 | 46.3 | 58.1 | 71.8 | 73.2 | 59.7 | 54.9 | 64.8 | 74.5 | 86.9 |
| 63a. | US GP D.L. Employees | 1.4.3 | k | 2.5 | 5.8 | 8.3 | 12.5 | 13.3 | 15.9 | 22.8 | 25.8 | 28.9 | 25.3 | 29.9 | 42.3 | 53.6 | 65.5 | 65.2 | 51.6 | 45.8 | 52.4 | 56.6 | 62.9 |
| | Development Personnel–IBM | | | | | | | | | | | | | | | | | | | | | | |
| 64. | CPU–Models Added | | | 3 | 0 | 1 | 1 | 1 | 3 | 3 | 1 | 5 | 2 | 5 | 5 | 2 | 1 | 1 | 2 | 5 | 1 | 3 | 2 |
| 65. | Cumulative CPU's | | | 5 | 5 | 6 | 7 | 8 | 11 | 14 | 15 | 20 | 22 | 27 | 32 | 34 | 35 | 36 | 38 | 43 | 44 | 47 | 49 |
| 66. | CPU's in Product Line | | | 5 | 5 | 6 | 7 | 8 | 11 | 14 | 15 | 19 | 20 | 22 | 27 | 28 | 28 | 28 | 27 | 29 | 29 | 27 | 27 |
| 67. | Software Per CPU | 1.25.5 | kli | 11 | 16 | 25 | 37 | 57 | 86 | 130 | 200 | 300 | 460 | 660 | 850 | 1040 | 1220 | 1400 | 1575 | 1750 | 1920 | 2090 | 2260 |
| 68. | Cum. Software Written | | Mli | .09 | .15 | .24 | .38 | .75 | 1.4 | 2.2 | 3.9 | 5.9 | 9.0 | 13.3 | 17.7 | 22.4 | 26.5 | 31.0 | 36.4 | 40.8 | 46.0 | 51.9 | 58.4 |
| 69. | Completed This Year | | Mli | .04 | .06 | .09 | .14 | .36 | .67 | .81 | 1.7 | 2.0 | 3.1 | 4.2 | 4.5 | 4.7 | 4.1 | 4.5 | 5.3 | 4.5 | 5.2 | 5.9 | 6.5 |
| 70. | Programmer Productivity | | li/mo | 125 | 129 | 133 | 138 | 143 | 148 | 153 | 158 | 164 | 170 | 176 | 182 | 188 | 195 | 202 | 209 | 216 | 224 | 231 | 239 |
| 70a. | –Annual Productivity | | kl/yr | 1.49 | 1.55 | 1.60 | 1.66 | 1.72 | 1.78 | 1.84 | 1.90 | 1.97 | 2.04 | 2.11 | 2.18 | 2.26 | 2.34 | 2.42 | 2.50 | 2.59 | 2.68 | 2.78 | 2.87 |
| 71. | No. Develop. Programmers | | | 26 | 39 | 59 | 84 | 212 | 374 | 443 | 869 | 1028 | 1540 | 2002 | *2020 | *1960 | *1900 | 1853 | *1900 | *1935 | *1970 | 2111 | 2272 |
| 72. | Sustaining Progrs.–New. Rel. | | | 4 | 4 | 6 | 9 | 13 | 32 | 56 | 66 | 130 | 154 | 231 | 300 | 303 | 294 | 285 | 278 | 285 | 290 | 296 | 317 |
| 73. | Older Releases | | | 1 | 2 | 3 | 4 | 7 | 13 | 23 | 35 | 59 | 86 | 127 | 180 | 232 | 282 | 320 | 355 | 395 | 413 | 433 | 472 |
| 74. | Tot. Dev/Sust. Prog. | | | 31 | 45 | 68 | 97 | 232 | 419 | 522 | 970 | 1217 | 1780 | 2360 | 2500 | 2495 | 2476 | 2458 | 2533 | 2615 | 2673 | 2840 | 3061 |
| 75. | Hardware Model Nos. in Line | | | 40 | 90 | 180 | 320 | 480 | 640 | 850 | 1070 | 1300 | 1540 | 1780 | 2020 | 2260 | 2500 | 2740 | 2990 | 3230 | 3470 | 3720 | 3980 |
| 76. | Model Nos. Per CPU in Line | | | 8 | 18 | 30 | 46 | 60 | 58 | 61 | 71 | 68 | 77 | 81 | 75 | 81 | 91 | 98 | 110 | 111 | 120 | 138 | 147 |
| 77. | Model Nos. Dev. This Year | | | 30 | 50 | 90 | 140 | 160 | 160 | 210 | 220 | 230 | 240 | 270 | 310 | 330 | 380 | 400 | 410 | 440 | 460 | 480 | 500 |
| 78. | Engineering Productivity | | Eng/n | 8 | 7.8 | 7.6 | 7.4 | 7.2 | 7 | 6.8 | 6.6 | 6.4 | 6.2 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5.9 | 5.9 | 5.8 |
| 79. | No. Develop. Engrs. | | | 240 | 390 | 684 | 1036 | 1152 | 1120 | 1428 | 1452 | 1472 | 1488 | 1620 | 1860 | 1980 | 2280 | 2400 | 2460 | 2640 | 2714 | 2832 | 2900 |

is, correcting errors in and adding improvements to—existing software. I have estimated the total sustaining activity by dividing it into two parts. The first, shown on line 72, represents the manpower needed to maintain programs released the previous year, and I estimated that at 15% of the previous year's total number of development programmers (see the discussion in Section 4.22 on Programming Costs for a justification of this figure). To estimate the sustaining activity required for older releases, I assumed that an amount of code equivalent to 3% of the total amount written in the preceeding nine years had to be written to correct errors and add improvements; and I divided that amount of code by the current year's productivity. For example, the 355 programmers required in 1970 was computed by subtracting the cumulative amount of code completed in 1960 (1.4 million lines) from the amount completed by the end of 1969 (31 million lines), multiplying the result by 3%, and dividing that product by 2.50 thousand lines per year per programmer. The 3% figure is quite arbitrary, and represents a concensus of opinions of knowledgeable friends. Line 74 is the sum of lines 71, 72, and 73.

75-77. To estimate the number of engineers required to develop hardware, I begin with the number of model numbers offered for sale or lease by IBM. I have counted model numbers in the IBM GSA (General Services Administration) price catalogs for the years since 1960, and estimated model numbers available in 1955 by examining WeikM55. The 1956 to 1960 figures are interpolations. The numbers on lines 75 and 77 were chosen so that line 75 approximates the model number count, so that line 77 provides a reasonably smooth curve of model numbers developed per year, and so that line 75 is the sum of the last ten entries in line 77—it represents the number of model numbers currently in the product line, not the total number ever developed. Line 76 is the quotient of lines 75 and 66, and indicates how many model numbers are available for each CPU in the product line.

78-79. I argue that every product or product option identified by a model number and offerred at an incremental price must have been developed, documented, and sustained by engineering personnel (see discussion under development costs in Section 4.21).

To compute the number of engineers required to develop the model numbers in line 77, we must make an assumption about the engineering man-years required to release a model number by IBM. My estimate, shown on line 78, is based on my own personal (non-IBM) experience in development, on the knowledge that the complexity of an average model number dropped between 1955 and 1965 as manufacturers developed the concept of offering a variety of options, and on the belief that IBM's development budget supports, and IBM's product reliability demonstrates, the thesis that IBM employs a third more man-years per model number than do the other system manufacturers. Line 79 is simply the product of lines 77 and 78.

80-82. The sustaining problem for hardware engineers is quite comparable to that for programmers. The number of sustaining engineers required for model numbers released during the previous year, shown on line 80, was estimated at 15% of the number of development engineers required during the previous year. And the number of sustaining engineers required for older model numbers assumes that a single engineer is required to sustain every 15 model numbers in the product line. Thus the 183 engineers shown on line 81 for the year 1970 was found by dividing the 2,740 model numbers in the product line at the end of 1969 by 15 model numbers per engineer. Line 82 is the sum of lines 79 through 81.

83-84. The development cost per engineer and programmer, including not only the salaries of those individuals, but also all salaries of supporting personnel and other costs, are documented in Tables 4.21.1 and 4.22.1, where development costs are described.

85-87. Total engineering costs are the product of development cost per engineer on line 83 and the number of engineering personnel from line 82. Programming costs on line 86 similarly is the product of the cost per programmer on line 84 and the number of programmers on line 74. Line 87 is the sum of lines 85 and 86.

88. IBM's reported research and development expenses are shown here. Note that these are expenses for the entire corporation, and must include research and development in areas other then data processing—office products, supplies, and education and data processing services, for example. Note also that the numbers we have derived on line 87 exclude important data processing development activities, including basic research on software, products, and materials; the development of products which were never released; and the development of the electronic technologies from which the hardware is built.

89-108. Generally speaking, I followed the same approach in estimating non-IBM development personnel as I did in formulating the IBM estimates. Comments on various specific entries are given below, but for the lines not mentioned, calculations in this part of the table were carried out just like the IBM calculations.

92. The software in use per CPU I estimated at one quarter of the software per CPU for IBM machines. One small piece of data supports that estimate—note the CDC 1604 shown on Figure 1.25.5. But basically this ratio is based on the fact that other manufacturers have not had the financial resources that IBM has had to devote to development, and on a guess that 4:1 is a reasonable ratio.

95. The number of development programmers is computed from the number of lines of software completed per year (line 94) under the assumption that the productivity of non-IBM programmers is the same as for IBM programmers.

99. A cursory review of GSA catalogs of the non-IBM system manufacturers led me to conclude that they generally have offered about one-third as many model numbers per CPU as IBM offered. In part, this is a reflection of the fact that the other manufacturers provide less variety in their peripheral and terminal equipment offerings; in part, it occurs because IBM permits many more low cost options than do the other manufacturers—in the late sixties and early seventies, more than a quarter of IBM's model numbers had selling prices less than $1000; a sampling of other system companies indicated that, for their product lines, the figure was less than 10%. Line 99, then, is computed by multiplying the number of CPU's in non-IBM product lines (line 91) by roughly one third of IBM's model numbers per CPU (line 76). For the years 1950-1954, the assumed number of model numbers are 3, 6, 12, 30, and 45.

100. The non-IBM model numbers developed in each year is

## TABLE II.1.4.2 PERSONNEL ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80. | Sustaining Engrs.—New Rel. | | | 30 | 36 | 59 | 103 | 155 | 173 | 168 | 214 | 218 | 221 | 223 | 243 | 279 | 294 | 342 | 360 | 369 | 396 | 407 | 435 |
| 81. | Older Model Nos. | | | 1 | 3 | 6 | 12 | 21 | 32 | 43 | 57 | 71 | 87 | 103 | 119 | 135 | 151 | 167 | 183 | 199 | 215 | 231 | 248 |
| 82. | Total Dev/Sust Engrs. | | | 271 | 429 | 749 | 1151 | 1328 | 1325 | 1639 | 1723 | 1761 | 1796 | 1946 | 2222 | 2394 | 2725 | 2909 | 3003 | 3208 | 3325 | 3470 | 3583 |
| 82a. | Total Development Personnel | | | 302 | 474 | 817 | 1248 | 1560 | 1744 | 2161 | 2693 | 2978 | 3576 | 4306 | 4722 | 4889 | 5201 | 5367 | 5536 | 5823 | 5998 | 6310 | 6644 |
| 83. | Development Cost—Per Engr. | | k$/yr | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 41 | 42 | 44 | 46 | 48 | 50 | 52 | 55 | 58 | 61 | 65 |
| 84. | Per Programmer | | k$/yr | 14 | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 32 | 33 | 36 | 38 | 40 |
| 85. | Engineering Costs | | $M | 8.4 | 13.7 | 24.7 | 39.1 | 46.5 | 47.7 | 60.6 | 65.5 | 68.7 | 73.6 | 81.7 | 97.8 | 110. | 131. | 145. | 156. | 176. | 193. | 212. | 233. |
| 86. | Programming Costs | | $M | .4 | .6 | 1.0 | 1.5 | 3.7 | 7.1 | 8.9 | 17.5 | 23.1 | 37.4 | 54.3 | 62.5 | 67.4 | 71.8 | 76.2 | 81.1 | 86.3 | 96.2 | 107.9 | 122.4 |
| 87. | Total Dev. Cost | | $M | 8.8 | 14.3 | 25.7 | 40.6 | 50.2 | 54.8 | 69.5 | 83.0 | 91.8 | 111. | 136.0 | 160.3 | 177. | 203. | 221. | 237. | 262. | 289. | 320. | 355. |
| 88. | IBM Reported R & D Exp. | | $M | 20 | 30 | 40 | 55 | 70 | 90 | 123 | 134 | 165 | 209 | 211 | 250 | 300 | 400 | 440 | 500 | 540 | 676 | 730 | 890 |
| | Development Personnel—Non-IBM | | | | | | | | | | | | | | | | | | | | | | |
| 89. | CPU—Models Added | | | 6 | 6 | 6 | 5 | 8 | 10 | 11 | 9 | 7 | 18 | 13 | 9 | 12 | 8 | 15 | 10 | 20 | 17 | 11 | 6 |
| 90. | Cumulative CPU's | | | 21 | 27 | 33 | 38 | 46 | 56 | 67 | 76 | 83 | 101 | 114 | 123 | 135 | 143 | 158 | 168 | 188 | 205 | 216 | 222 |
| 91. | CPU's in Prod. Lines | | | 21 | 27 | 33 | 38 | 46 | 55 | 65 | 72 | 73 | 86 | 93 | 96 | 102 | 105 | 112 | 112 | 121 | 129 | 133 | 121 |
| 92. | Software Per CPU | 1.25.5 | kli | 3 | 4 | 6 | 9 | 14 | 22 | 33 | 50 | 75 | 115 | 165 | 212 | 260 | 305 | 350 | 394 | 437 | 480 | 523 | 565 |
| 93. | Cum. Software Written | | Mli | .10 | .18 | .31 | .52 | .93 | 1.6 | 2.6 | 3.9 | 6.0 | 8.8 | 12.0 | 15.7 | 19.8 | 24.9 | 30.0 | 36.4 | 44.0 | 52.0 | 60.2 | 70.0 |
| 94. | Completed This Year | | Mli | .05 | .08 | .12 | .22 | .40 | .69 | .99 | 1.3 | 2.1 | 2.8 | 3.2 | 3.8 | 4.1 | 5.1 | 5.1 | 6.4 | 7.6 | 8.0 | 8.2 | 9.8 |
| 95. | No. Development Programmers | | | 34 | 54 | 77 | 131 | 234 | 388 | 536 | 662 | 1082 | 1368 | 1512 | 1726 | 1807 | 2174 | 2113 | 2548 | 2937 | 2980 | 2960 | 3399 |
| 96. | Sustaining Progrs—New Rel. | | | 3 | 5 | 8 | 12 | 20 | 35 | 58 | 80 | 99 | 162 | 205 | 227 | 259 | 271 | 326 | 317 | 382 | 441 | 447 | 444 |
| 97. | Older Releases | | | 1 | 2 | 3 | 6 | 9 | 16 | 26 | 41 | 59 | 88 | 124 | 162 | 204 | 247 | 298 | 341 | 392 | 449 | 496 | 538 |
| 98. | Tot. Dev/Sust Progrs. | | | 38 | 61 | 88 | 149 | 263 | 439 | 620 | 783 | 1240 | 1618 | 1841 | 2115 | 2270 | 2692 | 2737 | 3206 | 3711 | 3870 | 3903 | 4381 |
| 99. | Hardware Model Nos. in Prodn. | | | 63 | 162 | 330 | 570 | 828 | 1100 | 1430 | 1656 | 1752 | 2150 | 2418 | 2592 | 2858 | 3150 | 3696 | 4032 | 4477 | 5160 | 6118 | 5929 |
| 100. | Model Nos. Dev. This Year | | | 18 | 99 | 168 | 240 | 258 | 275 | 285* | 280* | 260* | 267* | 286 | 273 | 434 | 532 | 715* | 700* | 730 | 750* | 760* | 750* |
| 101. | Engineering Productivity | | Eng/n | 6 | 5.9 | 5.8 | 5.6 | 5.4 | 5.2 | 5.1 | 4.9 | 4.7 | 4.6 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| 102. | No. Devlop. Engrs. | | k | 108 | 584 | 974 | 1344 | 1393 | 1430 | 1454 | 1372 | 1222 | 1228 | 1287 | 1229 | 1953 | 2394 | 3217 | 3150 | 3285 | 3375 | 3420 | 3375 |
| 103. | Sustaining Engrs.—New Rel. | | k | 14 | 16 | 88 | 146 | 202 | 209 | 215 | 218 | 206 | 183 | 184 | 193 | 184 | 293 | 359 | 483 | 472 | 493 | 506 | 513 |
| 104. | Older Model Nos. | | k | 3 | 4 | 11 | 22 | 38 | 55 | 73 | 95 | 110 | 117 | 143 | 161 | 173 | 191 | 210 | 246 | 269 | 298 | 344 | 408 |
| 105. | Total Dev/Sust. Engrs. | | k | 125 | 604 | 1073 | 1512 | 1633 | 1694 | 1742 | 1685 | 1538 | 1528 | 1614 | 1583 | 2310 | 2878 | 3586 | 3879 | 4026 | 4166 | 4270 | 4296 |
| 105a. | Total Development Personnel | | | 163 | 665 | 1161 | 1661 | 1896 | 2133 | 2362 | 2468 | 2778 | 3146 | 3455 | 3698 | 4580 | 5570 | 6323 | 7085 | 7737 | 8036 | 8173 | 8677 |
| | Development Cost—Non-IBM | | | | | | | | | | | | | | | | | | | | | | |
| 106. | Engineering Costs | | $M | 3.9 | 19.3 | 35.4 | 51.4 | 57.1 | 61.0 | 64.5 | 64.0 | 60.0 | 62.6 | 67.8 | 69.6 | 106. | 138. | 179. | 202. | 221. | 242. | 260. | 279. |
| 107. | Programming Costs | | $M | .5 | .9 | 1.3 | 2.2 | 4.2 | 7.5 | 10.5 | 14.1 | 23.6 | 34.0 | 42.3 | 52.9 | 61.3 | 78.1 | 84.8 | 103. | 122. | 139. | 148. | 175. |
| 108. | Total Dev. Cost | | $M | 4.4 | 20.2 | 36.7 | 53.6 | 61.3 | 68.5 | 75.0 | 78.1 | 83.6 | 96.6 | 110.1 | 122.5 | 167. | 216. | 264. | 305. | 343. | 381. | 408. | 454. |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| 109. | Total Hardware Dev. Cost | | $M | 12.3 | 33.0 | 60.1 | 90.5 | 103.6 | 108.7 | 125.1 | 129.5 | 128.7 | 136.2 | 149.5 | 167.4 | 216. | 269. | 324. | 358. | 397. | 435. | 472. | 512. |
| 110. | Total Software Dev. Cost | | $M | .9 | 1.5 | 2.3 | 3.7 | 7.9 | 14.6 | 19.4 | 31.6 | 46.7 | 71.4 | 96.6 | 115.4 | 128.7 | 149.9 | 160.0 | 184. | 208. | 235. | 256. | 297. |
| 111. | Total Dev. Cost | | $M | 13.2 | 34.5 | 62.4 | 94.2 | 111.5 | 123.3 | 144.5 | 161.1 | 175.4 | 208. | 246.1 | 282.8 | 345. | 419. | 484. | 542. | 605. | 670. | 728. | 809. |
| 112. | Dev. Cost as Percent of GP Rev. | | % | 44 | 43 | 33 | 43 | 38 | 29 | 17 | 13 | 10 | 9.2 | 9.1 | 7.6 | 7.0 | 6.1 | 6.8 | 7.1 | 7.2 | 6.9 | 7.1 | 6.9 |
| 113. | Total Dev. Engineers | 1.4.3 | k | .40 | 1.03 | 1.82 | 2.66 | 2.96 | 3.02 | 3.38 | 3.41 | 3.30 | 3.32 | 3.56 | 3.81 | 4.70 | 5.60 | 6.50 | 6.88 | 7.23 | 7.49 | 7.74 | 7.88 |
| 114. | Total Dev. Programmers | 1.4.3 | k | .07 | .11 | .16 | .25 | .50 | .86 | 1.14 | 1.75 | 2.46 | 3.40 | 4.20 | 4.62 | 4.77 | 5.17 | 5.20 | 5.74 | 6.33 | 6.54 | 6.74 | 7.44 |
| 115. | Total Dev. Professionals | | | .46 | 1.14 | 1.98 | 2.91 | 3.46 | 3.88 | 4.52 | 5.16 | 5.76 | 6.72 | 7.76 | 8.42 | 9.47 | 10.77 | 11.69 | 12.62 | 13.56 | 14.03 | 14.48 | 15.32 |
| | Sales Personnel | | | | | | | | | | | | | | | | | | | | | | |
| 116. | Pers. per $1M Ordered | | | 4 | 4 | 4 | 4 | 3.9 | 3.7 | 3.5 | 3.3 | 3.1 | 3 | 3 | 3 | 3 | 2.9 | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 | 2.7 |
| 117. | U.S. Orders | | $B | .108 | .194 | .308 | .428 | .518 | .705 | .955 | 1.140 | 1.395 | 1.740 | 2.555 | 3.550 | 4.275 | 4.646 | 4.358 | 4.024 | 4.573 | 5.288 | 5.813 | 5.910 |
| 118. | Sales Personnel | 1.4.4 | k | .43 | .78 | 1.23 | 1.71 | 2.02 | 2.61 | 3.34 | 3.76 | 4.32 | 5.22 | 7.67 | 10.65 | 12.83 | 13.47 | 12.64 | 11.67 | 12.80 | 14.81 | 16.28 | 15.96 |
| | Maintenance Personnel | | | | | | | | | | | | | | | | | | | | | | |
| 119. | CE's per $1M In Use | | | 1.41 | 1.26 | 1.10 | .94 | .77 | .64 | .60 | .56 | .52 | .49 | .47 | .46 | .47 | .48 | .49 | .50 | .50 | .49 | .49 | .48 |
| 120. | Maintenance Personnel | 1.4.4 | k | .25 | .40 | .59 | .85 | 1.03 | 1.19 | 1.56 | 1.95 | 2.37 | 2.94 | 3.67 | 4.92 | 6.49 | 8.40 | 10.49 | 11.80 | 12.60 | 13.03 | 13.38 | 14.50 |

computed from line 99, taking into account the assumption that model numbers developed more than ten years earlier have been dropped from the product line. (Remember that line 99 lists the number of models in the line, net of new models added, and old ones dropped.) For example, the 434 model numbers developed in 1967 is computed by finding the net additions to the product lines (2858 model numbers in 1967 minus 2592 in 1966), and adding to that difference the 168 model numbers which had been developed in 1957 and were assumed dropped. The entries marked with asterisks have been smoothed to eliminate unlikely-looking fluctuations.

101. I estimate that 4.5 to 6 man-years of engineering are required per model number for the average system company, excluding IBM.

103-104. Although I estimate that the "other" companies require two-thirds as many engineers as IBM to develop a model number, I assume that their sustaining ratios—the percentage of last year's engineers who are assigned to sustain a product during its first year of production, and the number of engineers per model number assigned for older products—are the same as IBM's.

109-111. The total hardware development cost on line 109 is the sum of lines 85 and 106. The total software cost is the sum of lines 86 and 107; and total development costs on line 111 is the sum of lines 109 and 110.

112. The development cost as a percent of GP revenue is the quotient of line 111 and the U.S. GP revenue figures from line 1 of Table II.1.30.

113-115. Total development engineers is the sum of lines 82 and 105; total development programmers is the sum of lines 74 and 98; and total development personnel is the sum of lines 113 and 114.

**Sales Personnel.** 116-118. Line 116 is an unsupported estimate of the number of salesmen and sales analysts used per million dollars of order each year. See Section 4.3 for a discussion of this parameter. U.S. orders for GP systems is derived from GP shipment data in Table II.1.21 (line 108) assuming each year's orders is the average of that year's and next year's shipments. Total selling personnel on line 118 is then the product of lines 116 and 117.

**Maintenance Personnel.** 119-120. Customer engineers per million dollars worth of GP systems in use is an interpolation of data from line 25 of Table II.4.4.5. Total maintenance personnel is the product of line 119 and the value of GP systems in use each year in the U.S., from line 109 of Table II.1.21.

**Summary.** 121-125. Lines 121 to 124 are copied from the corresponding lines 63a, 115, 118, and 120. Line 125 is the sum of lines 121-124.

**Gilchrist study.** 126-130. These figures are from GilcB74-2, where they are derived from various U.S. Government statistical reports on the industry group having Standard Industrial Classification 3573—Electronic Computer Equipment. The various categories are manufacturing, auxiliary (mainly R & D and administrative employees), wholesale (all sales and marketing employees at manufacturers' sales offices and branches), and services (maintenance, repair, data handling, programming, and other personnel who provide services to other companies).

## TABLE II.1.4.3 SALARIES AND WAGES—NOTES

At various points in a review of the data processing industry, it is useful to have available some figures on average wages and salaries. In this table, I present some source data, along with my assumed averages, for user personnel, equipment supplier personnel, and general clerical personnel.

**User Personnel.** 1-8. *Business Automation* Magazine for some years published an annual survey of data processing salaries, and some of the data is reproduced here. Unfortunately, there is a substantial lack of uniformity from year to year. For the years 1958-1960, "machine accounting" salaries were estimated, while for subsequent years the estimate was for "EDP" salaries. The magazine generally presented three salaries for each job title: two were minimum and maximum salaries; the other, which I reproduce here, was variously known as "medium", "average", "midpoint", "median", or "actual salary". Furthermore, though the surveys generally were published in the July issue of the magazine, there was no indication as to exactly when the survey was taken. The 1973 and 1974 data is from *Datamation* magazine (McLaR74). It shows the results of surveys conducted in those years.

9-14. These figures are from CvSrvOccu. The $61 figure in line 14 marked with as asterisk actually represents a 1954 salary, though it appears in the 1955 column. In the source publication, these figures are given as average annual salaries; I have converted them to weekly figures by dividing by 52 and rounding to the nearest dollar.

15-16. These figures come from LabSPT. They were computed by dividing "mean annual salaries" by 52. The precise date of each sample varies, sometimes being reported as "winter", sometimes as "March" or "June". I have copied the figures in a column which seemed to me to be the most appropriate year for the sample.

17-20. These estimates of average salaries are my interpretations, interpolations, and extrapolations of the data given above, and of additional private data, where available. It is these numbers we will use in calculations in various parts of this book.

## TABLE II.1.4.2 PERSONNEL ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| 121. | No. of–Mfg. Employees | | k | 2.5 | 5.8 | 8.3 | 12.5 | 13.3 | 15.9 | 22.8 | 25.8 | 28.9 | 25.3 | 29.9 | 42.3 | 53.6 | 65.5 | 65.2 | 51.6 | 45.8 | 52.4 | 56.6 | 62.9 |
| 122. | Development Personnel | | k | .5 | 1.1 | 2.0 | 2.9 | 3.5 | 3.9 | 4.5 | 5.2 | 5.8 | 6.7 | 7.8 | 8.4 | 9.5 | 10.8 | 11.7 | 12.6 | 13.6 | 14.0 | 14.5 | 15.3 |
| 123. | Sales Personnel | | k | .4 | .8 | 1.2 | 1.8 | 2.0 | 2.6 | 3.3 | 3.7 | 4.3 | 5.2 | 7.7 | 10.7 | 12.8 | 13.5 | 12.6 | 11.7 | 12.8 | 14.8 | 16.3 | 16.0 |
| 124. | Maintenance Pers. | | k | .3 | .4 | .6 | .9 | 1.0 | 1.2 | 1.6 | 2.0 | 2.4 | 2.9 | 3.7 | 4.9 | 6.5 | 8.4 | 10.5 | 11.8 | 12.6 | 13.0 | 13.4 | 14.5 |
| 125. | Total | 1.4.5 | k | 3.7 | 8.1 | 12.1 | 18.1 | 19.8 | 23.6 | 32.2 | 36.7 | 41.4 | 40.1 | 49.1 | 66.3 | 82.4 | 98.2 | 100.0 | 87.7 | 84.8 | 94.2 | 100.8 | 108.7 |
| | Gilchrist Study | | | | | | | | | | | | | | | | | | | | | | |
| 126. | Employment–Mfg. | | k | | | | | | | | | | | | | 99 | | | 146 | 139 | 145 | | |
| 127. | Services | | k | | | | | | | | | | | | | 64 | | | 86 | 95 | 104 | | |
| 128. | Wholesale | | k | | | | | | | | | | | | | 49 | | | 72 | 71 | 78 | | |
| 129. | Auxiliary | | k | | | | | | | | | | | | | 19 | | | 22 | 20 | 21 | | |
| 130. | Total | 1.4.5 | k | | | | | | | | | | | | | 231 | | | 326 | 325 | 348 | | |

## TABLE II.1.4.3 SALARIES AND WAGES

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **User Personnel** | | | | | | | | | | | | | | | | | | | | | | |
| | *Business Automation* Magazine | | | | | | | | | | | | | | | | | | | | | | |
| 1. | System Analysts–Lead | | $/wk | | | | | 169 | | 183 | | 204 | 216 | | 212 | | | | | | | 338 | 362 |
| 2. | Grade A | | $/wk | | | | | 158 | | 155 | | 164 | 168 | | | | | | | | | 272 | 295 |
| 3. | Programmer–Lead | | $/wk | | | | | 168 | | 160 | | 180 | 185 | | 192 | | | | | | | 307 | 320 |
| 4. | Grade A | | $/wk | | | | | 118 | | 132 | | 143 | 140 | | | | | | | | | 232 | 246 |
| 5. | Computer Operator–Lead | | $/wk | | | | 102 | 135 | 113 | 132 | | 133 | 139 | | 147 | | | | | | | 228 | 251 |
| 6. | Grade A | | $/wk | | | | | 105 | 98 | 104 | | 106 | 106 | | | | | | | | | 171 | 181 |
| 7. | Keypunch Operator–Lead | | $/wk | | | | 82 | | 91 | | | 95 | 95 | | 102 | | | | | | | 158 | 161 |
| 8. | Grade A | | $/wk | | | | | | 80 | | | 84 | 84 | | | | | | | | | 136 | 142 |
| | U.S. Govt. Employees | | | | | | | | | | | | | | | | | | | | | | |
| 9. | Dig. Comp. Systems Admin. | | $/wk | | | | 167 | 166 | | | | | | | | 287 | 311 | 346 | 368 | | | | |
| 10. | Computer Specialist | | $/wk | | | | 125 | 128 | | | | | | | | 210 | 229 | 259 | 280 | | | | |
| 11. | Computer Operator | | $/wk | | | | 100 | 105 | | | | | | | | 151 | 157 | 165 | 174 | | | | |
| 12. | Periph. Equip. Operator | | $/wk | | | | 81 | 81 | | | | | | | | 108 | 111 | | - | | | | |
| 13. | Comp. Aid & Techn'n. | | $/wk | | | | - | - | | | | | | | | 129 | 133 | 146 | 159 | | | | |
| 14. | Card Punch Operator | | $/wk | 61* | | | 73 | 74 | | | | | | | | 94 | 99 | 107 | 114 | | | | |
| | U.S. Clerical | | | | | | | | | | | | | | | | | | | | | | |
| 15. | Keypunch Operators I | | | | | | | | | | | | | 78 | | | 88 | 92 | 98 | | | | |
| 16. | Keypunch Operators II | | | | | | | | 74 | | | | | 90 | | | 100 | 105 | 112 | | | | |
| | Estimated Averages | | | | | | | | | | | | | | | | | | | | | | |
| 17. | System Analysts | 1.4.6 | $/wk | 154 | 156 | 159 | 163 | 170 | 176 | 187 | 195 | 206 | 218 | 229 | 240 | 257 | 272 | 287 | 300 | 315 | 329 | 340 | 360 |
| 18. | Programmers | 1.4.6. | $/wk | 120 | 123 | 125 | 128 | 131 | 135 | 139 | 145 | 152 | 160 | 169 | 179 | 191 | 204 | 217 | 231 | 245 | 258 | 270 | 280 |
| 19. | Computer Operators | 1.4.6 | $/wk | 88 | 89 | 91 | 96 | 100 | 105 | 110 | 115 | 121 | 126 | 132 | 137 | 143 | 150 | 158 | 166 | 175 | 184 | 200 | 215 |
| 20. | Keypunch Operators | 1.4.6 | $/wk | 62 | 64 | 66 | 68 | 71 | 73 | 75 | 77 | 79 | 81 | 84 | 87 | 90 | 94 | 100 | 106 | 111 | 125 | 140 | 150 |

**Supplier Personnel.** 21-24. These Department of Commerce figures come from surveys of the various manufacturing classifications (CenSurMan). They are hourly figures, and were computed by dividing total production worker wages by the man-hours worked. They are therefore higher than hourly wages actually quoted and contracted, for the wages paid include premiums for over-time pay, and the hours worked exclude vacations and sick leaves.

25-29. The source for this data is the same as that for lines 15 and 16 above, and the same comments apply. Eight categories of engineer were included, and although categories III and IV contained more than half of all engineers in the sample, the higher salary of the less numerous Engineer V is typical of the computer industry, in my experience. Draftsman II and Engineering Technician III were the middle groups of draftsmen and technicians.

30. Average manufacturing direct labor is taken to be that of SIC Code 3573 (line 22 above) for 1967 and later. For the period before 1967, I formed an estimate based on the average wages in SIC Code 3571 ("computing and related machines", line 21 above) and the ratios of SIC Code 3573 and SIC Code 3571 wages for the years 1967 and 1968—assuming that that ratio remained more or less constant.

31. I could find no public data on the average salary of the programmers who work for equipment manufacturers. The numbers given here are based on private data, my own experience, and the belief that programmer salaries were once lower than those for engineers, but have recently become equal to engineering salaries.

32. My estimate of the average development engineer's salary is based on an extrapolation of the "Engineer V" given in line 25 above.

33-34 Similarly, the average draftsman's and technician's salary is assumed to be equivalent to that given in lines 28 and 29 above.

35. The computer serviceman, often called a Customer Engineer, must combine the expertise of an engineering technician with the ability to deal firmly, politely, and effectively with the customer. I have taken his average salary as 20% higher than that of the Engineering Technician, given on line 33 above.

36-37. I assume that a system analyst working with a salesman earns the same salary as his opposite number, working for the customer. Therefore, line 37 is the same as line 17. The salesman's pay, including commissions, I assume to be one third higher than that of the systems analyst.

**Clerical Personnel.** 38-41. The source for this data is the same as that for lines 9 through 14 above, and the same comments apply. The figures marked with an asterisk are for the year 1954, though they appear in the 1955 column.

42-47. These figures come from the same source as do lines 15 and 16. There are three categories of file clerks, and clerks II has the intermediate salary, though clerks I is slightly more numerous. Secretary II was, in 1970, the most numerous secretarial classification. There were only two typist categories, and typist I was substantially the more numerous.

48-50. In developing these averages, I attempted to take into account the relative frequency of occurence of different categories in the U.S. Clerical sample. Note my results are substantially lower, in general, than the U.S. Government figures.

## TABLE II.1.4.3 SALARIES AND WAGES ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Supplier Personnel** | | | | | | | | | | | | | | | | | | | | | | |
| | Manufacturing Direct Labor | | | | | | | | | | | | | | | | | | | | | | |
| 21. | Prodn. Wages–SIC 3571 | | $/hr | | | | 2.73 | 2.80 | 2.94 | 3.05 | 3.09 | 3.09 | 3.07 | 3.24 | 3.19 | 3.28 | 3.47 | | | | | | |
| 22. | Electronic Comp'ng (3573) | | $/hr | | | | | | | | | | | | | 3.02 | 3.23 | 3.49 | 3.75 | 4.12 | 4.19 | | |
| 23. | Calc & Acctg Mach (3574) | | $/hr | | | | | | | | | | | | | 3.75 | 3.74 | 3.60 | 4.09 | 4.02 | 4.58 | | |
| 24. | Radio & TV Receivers (365x) | | $/hr | | | | | | | | | | | | 2.37 | 2.42 | 2.51 | 2.69 | 2.96 | 3.15 | | | |
| | Development Personnel | | | | | | | | | | | | | | | | | | | | | | |
| 25. | U.S. White-Collar–Eng. V | | $/wk | | | | | | 222 | | | | | 265 | | | 293 | 310 | 327 | | | 377 | |
| 26. | Engineer I | | | | | | | | 126 | | | | | 149 | | | 173 | 186 | 196 | | | 216 | |
| 27. | Engineer VIII | | | | | | | | 366 | | | | | 405 | | | 448 | 462 | 488 | | | 567 | |
| 28. | Draftsman II | | | | | | | | 122 | | | | | 134 | | | 145 | 155 | 161 | | | 189 | |
| 29. | Eng. Technician III | | | | | | | | | | | | | 134 | | | 146 | 154 | 164 | | | 192 | |
| | Estimated Averages | | | | | | | | | | | | | | | | | | | | | | |
| 30. | M'fctng. Direct Labor | 1.4.7 | $/hr | 2.50 | 2.50 | 2.55 | 2.60 | 2.65 | 2.80 | 2.85 | 2.85 | 2.85 | 2.85 | 3.00 | 2.95 | 3.02 | 3.23 | 3.49 | 3.75 | 4.12 | 4.19 | 4.30 | 4.45 |
| 31. | Dev. Programmers | 1.4.7 | $/wk | 170 | 175 | 179 | 185 | 192 | 200 | 209 | 219 | 228 | 240 | 252 | 265 | 279 | 293 | 310 | 327 | 344 | 356 | 377 | 390 |
| 32. | Engineers | 1.4.7 | $/wk | 193 | 198 | 203 | 208 | 215 | 222 | 230 | 238 | 246 | 255 | 265 | 273 | 283 | 293 | 310 | 327 | 344 | 356 | 377 | 390 |
| 33. | Technicians | | $/wk | 113 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 129 | 132 | 134 | 137 | 140 | 145 | 155 | 161 | 170 | 178 | 190 | 200 |
| 34. | Draftsmen | | $/wk | 113 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 129 | 132 | 134 | 137 | 140 | 145 | 155 | 161 | 170 | 178 | 190 | 200 |
| 35. | Customer Engr. | 1.4.7 | $/wk | 136 | 137 | 139 | 142 | 144 | 146 | 149 | 151 | 155 | 158 | 161 | 164 | 168 | 174 | 186 | 193 | 204 | 214 | 228 | 240 |
| 36. | Sales–Salesmen | | $/wk | 205 | 208 | 212 | 217 | 227 | 235 | 249 | 260 | 275 | 291 | 305 | 320 | 343 | 363 | 383 | 400 | 420 | 439 | 453 | 480 |
| 37. | System Analysts | | $/wk | 154 | 156 | 159 | 163 | 170 | 176 | 187 | 195 | 206 | 218 | 229 | 240 | 257 | 272 | 287 | 300 | 315 | 329 | 340 | 360 |
| | **Clerical Personnel** | | | | | | | | | | | | | | | | | | | | | | |
| | U.S. Government | | | | | | | | | | | | | | | | | | | | | | |
| 38. | File Clerk | | $/wk | 62* | | | 75 | 76 | | | | | | | | 100 | 103 | | | | | | |
| 39. | Stenographer | | $/wk | 63* | | | 77 | 78 | | | | | | | | 109 | 113 | | | | | | |
| 40. | Secretary | | $/wk | 72* | | | 87 | 89 | | | | | | | | 129 | 134 | | | | | | |
| 41. | Clerk-Typist | | $/wk | 60* | | | 72 | 72 | | | | | | | | 95 | 99 | | | | | | |
| | U.S. Clerical | | | | | | | | | | | | | | | | | | | | | | |
| 42. | File Clerk I | | $/wk | | | | | | | | | | | 61 | | | 71 | 75 | | | | 93 | |
| 43. | File Clerk II | | $/wk | | | | | | 58 | | | | | 69 | | | 79 | 83 | | | | 103 | |
| 44. | Stenographers, General | | $/wk | | | | | | 78 | | | | | 84 | | | 93 | 100 | | | | 125 | |
| 45. | Secretary II | | $/wk | | | | | | | | | | | | | | 120 | 127 | | | | 158 | |
| 46. | Typist I | | $/wk | | | | | | 63 | | | | | 71 | | | 81 | 86 | | | | 105 | |
| 47. | Typist II | | $/wk | | | | | | 75 | | | | | 84 | | | 94 | 99 | | | | 122 | |
| | Estimated Averages | | | | | | | | | | | | | | | | | | | | | | |
| 48. | File Clerk | 1.4.8 | $/wk | 48 | 49 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 67 | 71 | 75 | 79 | 83 | 88 | 93 | 99 | 103 | 110 |
| 49. | Clerk Typist | 1.4.8 | $/wk | 53 | 55 | 57 | 59 | 61 | 63 | 66 | 69 | 72 | 74 | 77 | 81 | 84 | 88 | 93 | 98 | 103 | 109 | 114 | 121 |
| 50. | Secretary | 1.4.8 | $/wk | 70 | 73 | 76 | 80 | 84 | 88 | 92 | 95 | 99 | 103 | 107 | 112 | 116 | 121 | 127 | 135 | 142 | 147 | 158 | 170 |

## II.2.10 THE IMPORTANT COMPUTERS—NOTES

**GP System Populations.** 1-35. For every year since 1956 I selected the two computers whose total installed value (the product of number of computers in use and their average value) was greatest in each year. For each of these thirteen machines, I record the number in use each year, from Table II.1.31.1. The average rental value of each computer comes from the source indicated on line 1. (The initials 'MP' for the years 1958 and 1960 indicate that I estimated values for those years.) The total monthly rental for each computer is then the product of the number in use and the average rental.

36-41a. These seven computers were added to the list in order to include the first and second most numerous GP systems over the period since 1956. The data once again comes from Table II.1.31.1.

42-45. Finally, these four computers were added to include the systems representing the first and second greatest installed *performance* for the period since 1956. (See lines 53-62 below.)

**Minisystem Populations.** 46. The number of minisystems in use in the United States comes from Table II.1.21.

47-52b. These eight computers were selected by reviewing the minicomputer censuses in each year and selecting the most numerous and second most numerous machine in each year. Once again the census figures come from Table II.1.31.1

**GP System Performance.** 53-62b. The performance measure I adopted is that invented by Ken Knight (KnigK66,68. See Figure II.2.11 for a definition and discussion of this performance measure). Knight described both a "commerical" and a "scientific" measure, and I have used the commercial one. System performance in thousands of operations per second (kops) is shown in the heading for each computer; and installed performance in millions of operations per second (Mops) is computed by multiplying unit performance by the individual computer populations shown on lines 3 through 45. For a few systems whose performance improved over the years (e.g. the IBM 705 which evolved to the 705III) I varied the performance measure.

**Greatest Value in Use.** 63. The total value of all GP systems in use, in millions of dollars per month, is computed from total system value in use shown in Table II.1.21 by dividing that total value by 44, the assumed ratio of purchase price to total system rental.

65-75a. The indicated percentages are determined by dividing the total installed value of each computer (lines 5 through 35c) by the system value in use on line 63.

76. Each entry in this line is the sum of the two largest percentages from lines 65 through 75a.

**Greatest Number of systems in Use.** 77-85a. These percentages are found by dividing the appropriate system populations from lines 3 through 41a by the total GP population for the given year in line 2.

86. Each entry in this line is the sum of the two greatest entries for each year on lines 77 through 85a.

87-93. These percentages were found by dividing individual populations on lines 47 through 52b by total minisystem population on line 46. Once again each entry in the last line is the sum of the largest two entries in the associated previous lines.

**Greatest Performance in Use** 94-99. For each of the years 1956, 1959, 1961, 1963, 1965, 1968, 1970, 1972, and 1974, I took the computer censuses published in *C&A* or *EDP/IR* (worldwide GP systems in use), and multiplied each by the appropriate Knight commercial performance index, in thousands of operations per second. For the years since 1968, when Knight's last paper was published, I estimated the index myself, using Knight's formula, for the principal computers. I then summed these products, in each year, in two groups, one including all the IBM systems, the other all other systems. I thus had a measure of the number of operations per second performed at year end by all IBM computers and by all other computers. Dividing by the number of IBM and non-IBM computers, I computed an average computer power for each category. These are reproduced as lines 96 and 97.

I was unable to find or to compute performance indices for every computer on the census. The number of computers included in my calculations so far is shown on line 94, and the number not included on line 95. The machines on line 95 were virtually all *non*-IBM machines, for I had indices for all IBM systems. I next made an assumption, shown on line 98, for the average performance of the missing, non-IBM systems. For the years up to and including 1968, I assumed the missing non-IBM systems had the same performance as the included non-IBM systems. However, in 1970 and later I had systematically eliminated the *newer* non-IBM systems, whose indices I did not take the trouble to compute. I therefore made an estimate of the performance of those systems in such a way that the average performance of *all* non-IBM systems was suitably larger than that of IBM systems—thus continuing the trend observed in lines 96 and 97 for the years 1961-1968.

100. This is the resulting average performance index for all systems in use. It was found by multiplying entries on line 98 by those on line 95, adding the previously-calculated year-end operations per second of identified IBM and non-IBM systems, and dividing by the sum of the entries on lines 94 and 95. For the years not included in the above calculations, I made a reasonable-seeming interpolation.

101. This is the product of the average index and the US GP population on line 2 of this table.

102-114. These percentages are the quotient of individual installed system peformance figures on lines 53 through 62b and total installed performance on line 101.

115. As usual, this entry is the sum of the two greatest percentages in each year from lines 102 through 114.

# TABLE II.2.10 THE IMPORTANT COMPUTERS •

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **GP System Populations, US** | | | | C&A | C&A | MP | C&A | MP | C&A | C&A | C&A | C&A | C&A | EDP/IR | EDP/IR | EDP/IR | EDP/IR | EDP/IR | EDP/IR | EDP/IR | EDP/IR | EDP/IR |
| 2. | GP Systems in Use | | k | .240 | .700 | 1.260 | 2.100 | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 28.300 | 35.600 | 41.000 | 46.000 | 48.500 | 54.400 | 57.730 | 62.247 | 65.036 |
| 3. | IBM 650–No. in Use | | k | | .470 | .803 | 1.350 | 1.554 | 1.300 | .988 | .815 | .490 | .300 | .207 | .133 | .108 | .082 | .025 | .008 | .004 | | | |
| 4. | Average Rental | | $k/mo | | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.31 | 4.95 | 4.83 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | | | |
| 5. | Total Monthly Rental | | $M/mo | | .259 | .442 | 7.43 | 8.50 | 7.15 | 5.43 | 4.33 | 2.42 | 1.45 | .99 | .64 | .52 | .39 | .12 | .04 | .02 | | | |
| 6. | Univac I–No. in Use | | k | | .036 | .038 | .056 | .085 | .080 | .060 | .051 | .034 | .025 | .023 | .019 | .018 | .017 | .017 | .013 | .003 | .004 | .003 | .003 |
| 7. | Average Rental | | $k/mo | | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 8. | Total Monthly Rental | | $M/mo | | .90 | .95 | 1.63 | 2.13 | 2.00 | 1.50 | 1.28 | .85 | .63 | .58 | .48 | .45 | .43 | .43 | .33 | .08 | .10 | .075 | .075 |
| 9. | IBM 704–No. in Use | | k | | .025 | .077 | .130 | .127 | .110 | .091 | .073 | .051 | .033 | .033 | .025 | .022 | .018 | .009 | .006 | .002 | .001 | .001 | .001 |
| 10. | Average Rental | | $k/mo | | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| 11. | Total Monthly Rental | | $M/mo | | .80 | 2.46 | 4.16 | 4.06 | 3.52 | 2.91 | 2.34 | 1.63 | 1.06 | 1.06 | .80 | .70 | .58 | .29 | .19 | .06 | .03 | .03 | .03 |
| 12. | IBM 705 & 705 III–No. in Use | | k | | .028 | .078 | .140 | .175 | .170 | .167 | .131 | .094 | .065 | .050 | .040 | .035 | .029 | .022 | .019 | .010 | .005 | .003 | .003 |
| 13. | Average Rental | | $k/mo | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| 14. | Total Monthly Rental | | $M/mo | | .84 | 2.34 | 4.20 | 5.25 | 5.10 | 5.01 | 3.93 | 2.82 | 1.95 | 1.50 | 1.52 | 1.33 | 1.10 | .84 | .72 | .38 | .19 | .11 | .11 |
| 15. | IBM 7090–No. in Use | | k | | | | | .002 | .065 | .127 | .174 | .210 | .038 | .037 | .035 | .020 | .030 | .034 | .028 | ,023 | .021 | .018 | .014 |
| 16. | Average Rental | | $k/mo | | | | | 64 | 64 | 64 | 64 | 64 | 64 | 63.5 | 63.5 | 63.5 | 63.5 | 63.5 | 63.5 | 63.5 | 63.5 | 63.5 | 63.5 |
| 17. | Total Monthly Rental | | $M/mo | | | | | .13 | 4.16 | 8.13 | 11.14 | 13.44 | 2.43 | 2.35 | 2.22 | 1.27 | 1.91 | 2.16 | 1.78 | 1.46 | 1.33 | 1.14 | .89 |
| 18. | IBM 1401–No. in Use | | k | | | | | | .260 | 1.773 | 3.148 | 5.227 | 6.295 | 5.487 | 6.000 | 4.700 | 2.970 | 2.123 | 1.808 | 1.618 | 1.350 | 1.100 | .870 |
| 19. | Average Rental | | $k/mo | | | | | | 2.5 | 2.5 | 2.5 | 3.5 | 4.5 | 4.5 | 6.6 | 6.48 | 6.2 | 6.2 | 6.2 | 6.2 | 3.7 | 3.7 | 3.7 |
| 20. | Total Monthly Rental | | $M/mo | | | | | | .65 | 4.43 | 7.87 | 18.29 | 28.33 | 24.69 | 39.60 | 30.46 | 18.41 | 13.16 | 11.21 | 10.03 | 5.00 | 4.07 | 3.22 |
| 21. | IBM 7094 I & II–No. in Use | | k | | | | | | | | .001 | .073 | .248 | .185 | .191 | .229 | .200 | .092 | .092 | .082 | .066 | .054 | .044 |
| 22. | Average Rental | | $k/mo | | | | | | | | 70 | 70 | 70 | 72.5 | 72.5 | 75.5 | 75.5 | 73.4 | 73.4 | 73.4 | 73.4 | 73.4 | 73.4 |
| 23. | Total Monthly Rental | | $M/mo | | | | | | | | .07 | 5.11 | 17.36 | 13.41 | 13.85 | 17.29 | 15.10 | 6.75 | 6.75 | 6.02 | 4.84 | 3.96 | 3.23 |
| 24. | IBM 1460–No. in Use | | k | | | | | | | | | .093 | .706 | 1.748 | 1.391 | 1.061 | .616 | .173 | .130 | .087 | .065 | .055 | .050 |
| 25. | Average Rental | | $k/mo | | | | | | | | | 9.8 | 9.8 | 9.0 | 11.5 | 10.93 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 | 10 |
| 26. | Total Monthly Rental | | $M/mo | | | | | | | | | .91 | 6.92 | 15.73 | 16.00 | 11.60 | 6.04 | 1.70 | 1.27 | .85 | .64 | .54 | .50 |
| 27. | IBM 360/30–No. in Use | | k | | | | | | | | | | | .325 | 1.950 | 3.520 | 5.360 | 7.960 | 7.270 | 6.000 | 4.300 | 3.104 | 2.685 |
| 28. | Average Rental | | $k/mo | | | | | | | | | | | 7.2 | 7.5 | 8.5 | 8.8 | 10.5 | 12.3 | 12.3 | 11.0 | 11.0 | 11.4 |
| 29. | Total Monthly Rental | | $M/mo | | | | | | | | | | | 2.34 | 14.63 | 29.92 | 47.17 | 83.58 | 89.42 | 73.80 | 47.30 | 34.14 | 30.61 |
| 30. | IBM 360/40–No. in Use | | k | | | | | | | | | | | .285 | 1.055 | 1.907 | 2.524 | 3.022 | 3.576 | 3.146 | 2.550 | 1.510 | 1.275 |
| 31. | Average Rental | | $k/mo | | | | | | | | | | | 14.5 | 15.0 | 15.0 | 16.8 | 19.3 | 22.0 | 22.0 | 19.6 | 19.4 | 20.4 |
| 32. | Total Monthly Rental | | $M/mo | | | | | | | | | | | 4.13 | 15.83 | 28.60 | 42.40 | 58.32 | 78.67 | 69.21 | 49.98 | 29.29 | 26.01 |
| 32a. | IBM 370/145–No. in Use | | k | | | | | | | | | | | | | | | | | .450 | 1.270 | 1.700 | 1.925 |
| 32b. | Average Rental | | $k/mo | | | | | | | | | | | | | | | | | 28.9 | 24.7 | 27.8 | 31.7 |
| 32c. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | | | | | 13.01 | 31.37 | 47.26 | 61.02 |
| 33. | IBM 370/155–No. In Use | | k | | | | | | | | | | | | | | | | 0 | .49 | 1.045 | 1.190 | .695 |
| 34. | Average Rental | | $k/mo | | | | | | | | | | | | | | | | | 50.9 | 51.7 | 53.35 | 60.3 |
| 35. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | | | | | 24.94 | 54.03 | 63.49 | 41.91 |
| 35a. | IBM 370/135–No. in Use | | k | | | | | | | | | | | | | | | | | | .970 | 2.200 | 2.750 |
| 35b. | Average Rental | | $k/mo | | | | | | | | | | | | | | | | | | 13.5 | 16.2 | 17.5 |
| 35c. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | | | | | | 13.10 | 35.64 | 48.13 |
| | Number in Use | | | | | | | | | | | | | | | | | | | | | | |
| 36. | Burroughs 205 | | k | .017 | .046 | .087 | .120 | .127 | .120 | .103 | .071 | .056 | .050 | .042 | .033 | .030 | .022 | .006 | .001 | .001 | | | |
| 37. | IBM 305 | | k | | · | .021 | .250 | .610 | .950 | 1.064 | .756 | .514 | .350 | .138 | .109 | .082 | .060 | .008 | .002 | .001 | .001 | | |
| 38. | IBM 1620 | | k | | | | | | .050 | .415 | 1.103 | 1.138 | 1.263 | 1.382 | 1.305 | 1.017 | .866 | .746 | .440 | .430 | .390 | .325 | .280 |
| 39. | Univac 1004 | | k | | | | | | | | | .548 | 1.787 | 2.600 | 2.500 | 1.932 | 1.712 | 1.383 | 1.174 | 1.100 | .975 | .900 | .815 |
| 40. | IBM 360/20 | | k | | | | | | | | | | | .002 | .940 | 3.470 | 5.622 | 7.348 | 8.440 | 8.390 | 6.500 | 3.402 | 2.400 |
| 41. | IBM System 3/10 | | k | | | | | | | | | | | | | | | | 1.568 | 3.496 | 8.700 | 15.500 | 16.825 |
| 41a. | IBM System 3/6 | | k | | | | | | | | | | | | | | | | .005 | 1.618 | 1.800 | 3.015 | 3.100 |
| 42. | IBM 707x | | k | | | | | | | .192 | .200 | .379 | .428 | .276 | .252 | .200 | .155 | .191 | .176 | .138 | .113 | .101 | .097 |
| 42a. | BGH 5000/5500 | | k | | | | | | | | | .019 | .031 | .039 | .047 | .067 | .085 | .127 | .139 | .137 | .105 | .082 | .082 |

## TABLE II.2.10 THE IMPORTANT COMPUTERS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43. | CDC 6600 | | k | | | | | | | | | | .001 | .006 | .016 | .026 | .045 | .062 | .066 | .061 | .059 | .058 | .059 |
| 44. | IBM 360/65 | | k | | | | | | | | | | | .001 | .022 | .269 | .490 | .563 | .660 | .610 | .460 | .482 | .430 |
| 45. | Univac 1108 | | k | | | | | | | | | | | .003 | .023 | .067 | .120 | .116 | .137 | .148 | .140 | .135 | .130 |
| | **Mini System Popul'ns, U.S.** | | | | | | | | | | | | | | | | | | | | | | |
| 46. | Mini Systems in Use | | k | - | .050 | .240 | .450 | .700 | 1.000 | 1.400 | 1.800 | 2.100 | 2.500 | 3.100 | 4.000 | 6.000 | 9.500 | 16.100 | 25.560 | 34.615 | 49.345 | 71.000 | 100.00 |
| 47. | CDC Bendix G-15 | | k | | .025 | .102 | .200 | .284 | .370 | .419 | .432 | .323 | .358 | .383 | .340 | .357 | .432 | .270 | .265 | | | | |
| 48. | CDC Librascope LGP-30 | | k | | | .100 | .220 | .356 | .450 | .530 | .497 | .531 | .480 | .300 | .134 | .145 | .160 | .295 | .290 | | | | |
| 49. | CDC 160, 160A | | k | | | | | | .030 | .143 | .267 | .381 | .430 | .518 | .504 | .569 | .740 | .249 | | | | | |
| 50. | DEC PDP-8 | | k | | | | | | | | | | | .112 | .603 | 1.350 | 1.814 | 1.189 | 1.185 | .950 | .900 | .777 | .758 |
| 51. | DEC PDP-8L | | k | | | | | | | | | | | | | | | 1.955 | 3.320 | 3.190 | 2.600 | | |
| 52. | DEC PDP-8/E,F,M | | k | | | | | | | | | | | | | | | | | 2.365 | 4.654 | 7.233 | 10.336 |
| 52a. | DEC PDP-11/05,10 | | k | | | | | | | | | | | | | | | | | | 1.392 | 2.902 | 4.691 |
| 52b. | HP 2100-A | | k | | | | | | | | | | | | | | | | | | .450 | 3.073 | 4.871 |
| | **GP System Performance** | | | | | | | | | | | | | | | | | | | | | | |
| 53. | IBM 650 at .291 Kops | | Mops | | .136 | .234 | .466 | .452 | .378 | .288 | .237 | .143 | .087 | .060 | .039 | .031 | .024 | .007 | .002 | .001 | | | |
| 54. | IBM 704 at 3.785 Kops | | Mops | | .095 | .291 | .492 | .481 | .416 | .344 | .276 | .193 | .125 | .125 | .095 | .083 | .068 | .034 | .023 | .008 | .004 | | |
| 55. | IBM 705III at 7.47 Kops | | Mops | | .059 | .163 | .560 | 1.31 | 1.27 | 1.25 | .979 | .702 | .486 | .374 | .299 | .261 | .217 | .164 | .142 | .075 | .037 | | |
| 55a. | IBM 709 at 10.23 Kops | | Mops | | | | | .542 | .409 | .307 | .379 | .133 | .092 | .092 | .072 | .051 | .031 | .020 | | | | | |
| 56. | IBM 7090 at 45.47 Kops | | Mops | | | | | .091 | 2.956 | 5.775 | 7.912 | 9.549 | 1.728 | 1.682 | 1.591 | .909 | 1.364 | 1.546 | 1.273 | 1.046 | .955 | 0.8 | 0.6 |
| 57. | IBM 1401 at 1.2 Kops | | Mops | | | | | | .312 | 2.128 | 3.778 | 6.272 | 7.554 | 6.584 | 7.200 | 5.640 | 3.564 | 2.548 | 2.170 | 1.942 | 1.620 | 1.3 | 1.0 |
| 58. | IBM 7094II at 95.9 Kops | | Mops | | | | | | | | .096 | 7.00 | 23.8 | 17.7 | 18.3 | 22.0 | 19.2 | 8.82 | 8.82 | 7.86 | 6.33 | 5.2 | 4.2 |
| 59. | CDC 6600 at 4091.3 Kops | | Mops | | | | | | | | | | 4.091 | 24.55 | 65.46 | 106.4 | 184.1 | 253.7 | 270.0 | 249.6 | 241.4 | 237.3 | 241.4 |
| 60. | BGH 5000/5500 at 544.2 Kops | | Mops | | | | | | | | | .304 | 6.26 | 21.2 | 25.6 | 36.5 | 46.3 | 69.1 | 75.6 | 74.6 | 57.1 | 44.6 | 44.6 |
| 61. | IBM 360/65 at 809.7 Kops | | Mops | | | | | | | | | | | .810 | 17.81 | 217.8 | 396.7 | 455.9 | 534.4 | 493.9 | 372.5 | 390.3 | 348.2 |
| 62. | Univac 1108 at 2088.1 Kops | | Mops | | | | | | | | | | | 6.264 | 48.03 | 139.9 | 250.6 | 242.2 | 286.1 | 309.0 | 292.3 | 281.9 | 271.5 |
| 62a. | IBM 370/155 at 1203 Kops | | Mops | | | | | | | | | | | | | | | | | 589.5 | 1257.1 | 1431.6 | 836.1 |
| 62b. | IBM 370/145 at 445.8 Kops | | Mops | | | | | | | | | | | | | | | | | 200.6 | 566.2 | 757.9 | 858.2 |
| | **Greatest Value in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 63. | GP System Value in Use, US | | $M/mo | 4.09 | 7.27 | 12.27 | 20.45 | 30.45 | 42.39 | 59.20 | 79.20 | 103.4 | 136.4 | 177.3 | 243.2 | 313.6 | 397.7 | 486.4 | 536.4 | 572.7 | 604.5 | 620.5 | 686.4 |
| | Percent of Total GP Value, US | | | | | | | | | | | | | | | | | | | | | | |
| 65. | IBM 650 | 2.10.4 | % | | 35.6 | 36.0 | 36.3 | 27.9 | 16.9 | 9.2 | 5.5 | 2.3 | 1.1 | 0.6 | 0.3 | 0.2 | 0.1 | | | | | | |
| 66. | Univac I | 2.10.5 | % | | 12.3 | 7.7 | 8.0 | 7.0 | 4.7 | 2.5 | 1.6 | 0.8 | 0.5 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | | | | | |
| 67. | IBM 704 | 2.10.5 | % | | 11.0 | 20.0 | 20.3 | 13.3 | 8.3 | 4.9 | 3.0 | 1.6 | 0.8 | 0.6 | 0.3 | 0.2 | 0.1 | | | | | | |
| 68. | IBM 705 | 2.10.5 | % | | 11.6 | 19.1 | 20.5 | 17.2 | 12.0 | 8.5 | 5.0 | 2.7 | 1.4 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.1 | | | | |
| 69. | IBM 7090 | 2.10.4 | % | | | | | 0.4 | 9.8 | 13.7 | 14.1 | 13.0 | 1.8 | 1.3 | 0.9 | 0.4 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 70. | IBM 1401 | 2.10.4 | % | | | | | | 1.5 | 7.5 | 9.9 | 17.7 | 20.8 | 13.9 | 16.3 | 9.7 | 4.6 | 2.7 | 2.1 | 1.8 | 0.8 | 0.7 | 0.5 |
| 71. | IBM 7094 | 2.10.5 | % | | | | | | | | | 4.9 | 12.7 | 7.6 | 5.7 | 5.5 | 3.8 | 1.4 | 1.3 | 1.1 | 0.8 | 0.6 | 0.5 |
| 72. | IBM 1460 | 2.10.5 | % | | | | | | | | | 0.8 | 5.1 | 8.9 | 6.6 | 3.7 | 1.5 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| 73. | IBM 360/30 | 2.10.4 | % | | | | | | | | | | | 1.3 | 6.0 | 9.5 | 11.9 | 17.2 | 16.7 | 12.9 | 7.8 | 5.5 | 4.5 |
| 74. | IBM 360/40 | 2.10.5 | % | | | | | | | | | | | 2.3 | 6.5 | 9.1 | 10.7 | 12.0 | 14.7 | 12.1 | 8.3 | 4.7 | 3.8 |
| 74a. | IBM 370/145 | 2.10.5 | % | | | | | | | | | | | | | | | | | 2.3 | 5.2 | 7.6 | 8.9 |
| 75. | IBM 370/155 | 2.10.4 | % | | | | | | | | | | | | | | | | | 4.4 | 8.9 | 10.2 | 6.1 |
| 75a. | IBM 370/135 | 2.10.5 | % | | | | | | | | | | | | | | | | | | 2.2 | 5.7 | 7.0 |
| 76. | Sum of Two Greatest | | % | | 47.9 | 56.0 | 56.8 | 45.1 | 28.9 | 22.9 | 24.0 | 30.7 | 33.5 | 22.8 | 22.9 | 19.2 | 22.6 | 29.2 | 31.4 | 25.0 | 17.2 | 17.8 | 15.9 |
| | **Greatest Number in Use** | | | | | | | | | | | | | | | | | | | | | | |
| | % of Tot. GP Syst. in Use, US | | | | | | | | | | | | | | | | | | | | | | |
| 77. | IBM 650 | 2.10.1 | % | | 67.1 | 63.7 | 64.3 | 50.0 | 29.5 | 16.1 | 10.1 | 4.2 | 1.8 | 1.0 | 0.5 | 0.3 | 0.2 | 0.1 | | | | | |
| 78. | Burroughs 205 | 2.10.2 | % | | 6.6 | 6.9 | 5.7 | 4.1 | 2.7 | 1.7 | 0.9 | 0.5 | 0.3 | 0.2 | 0.1 | | | | | | | | |
| 79. | IBM 305 | 2.10.2 | % | | | 1.7 | 11.9 | 19.6 | 21.6 | 17.3 | 9.3 | 4.4 | 2.1 | 0.6 | 0.4 | 0.2 | 0.1 | | | | | | |
| 80. | IBM 1401 | 2.10.1 | % | | | | | | 5.9 | 28.8 | 38.9 | 44.7 | 37.7 | 25.4 | 21.2 | 13.2 | 7.2 | 4.6 | 3.7 | 3.0 | 2.3 | 1.8 | 1.3 |
| 81. | IBM 1620 | 2.10.2 | % | | | | | | 1.1 | 6.7 | 13.6 | 9.7 | 7.6 | 6.4 | 4.6 | 2.9 | 2.1 | 1.6 | 0.9 | 0.8 | 0.7 | 0.5 | 0.4 |

## TABLE II.2.10 THE IMPORTANT COMPUTERS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82. | Univac 1004 | 2.10.2 | % | | | | | | | | | 4.7 | 10.7 | 12.0 | 8.8 | 5.4 | 4.2 | 3.0 | 2.4 | 2.0 | 1.7 | 1.4 | 1.3 |
| 83. | IBM 360/30 | 2.10.1 | % | | | | | | | | | | | 1.5 | 6.9 | 9.9 | 13.1 | 17.3 | 15.0 | 11.0 | 7.4 | 5.0 | 4.1 |
| 84. | IBM 360/20 | 2.10.1 | % | | | | | | | | | | | · | 3.3 | 9.7 | 13.7 | 16.0 | 17.4 | 15.4 | 11.3 | 5.5 | 3.7 |
| 85. | IBM System 3/10 | 2.10.1 | % | | | | | | | | | | | | | | | | 3.2 | 6.4 | 15.1 | 24.9 | 25.9 |
| 85a. | IBM System 3/6 | 2.10.2 | % | | | | | | | | | | | | | | | | | 3.0 | 3.1 | 4.8 | 4.8 |
| 86. | Sum of Two Greatest | | % | | 73.7 | 70.6 | 76.2 | 69.6 | 51.1 | 45.1 | 52.5 | 54.4 | 48.4 | 37.4 | 30.0 | 22.9 | 26.8 | 33.3 | 32.4 | 26.4 | 26.4 | 30.4 | 30.7 |
| | % of Tot. Mini Syst in Use, US | | | | | | | | | | | | | | | | | | | | | | |
| 87. | CDC Bendix G-15 | 2.10.3 | % | | 50.0 | 42.5 | 44.4 | 40.6 | 37.0 | 29.9 | 24.0 | 15.4 | 14.3 | 12.4 | 8.5 | 6.0 | 4.5 | 1.7 | 1.0 | | | | |
| 88. | CDC LGP-30 | 2.10.3 | % | | | 41.7 | 48.9 | 50.9 | 45.0 | 37.9 | 27.6 | 25.3 | 19.2 | 9.7 | 3.4 | 2.4 | 1.7 | 1.8 | 1.1 | | | | |
| 89. | CDC 160, 160A | 2.10.3 | % | | | | | | 3.0 | 10.2 | 14.8 | 18.1 | 17.2 | 16.7 | 12.6 | 9.5 | 7.8 | 1.5 | | | | | |
| 90. | DEC PDP-8 | 2.10.3 | % | | | | | | | | | | | 3.6 | 15.1 | 22.5 | 19.1 | 7.4 | 4.6 | 2.7 | 1.8 | | |
| 91. | DEC PDP-8L | 2.10.3 | % | | | | | | | | | | | | | | | 12.1 | 13.0 | 9.2 | 5.3 | | |
| 92. | DEC PDP-8/E,F,M | 2.10.3 | % | | | | | | | | | | | | | | | | | 6.8 | 9.4 | 10.2 | 10.3 |
| 92a. | DEC PDP-11/05,10 | 2.10.3 | % | | | | | | | | | | | | | | | | | | 2.8 | 4.1 | 4.7 |
| 92b. | HP 2100-A | 2.10.3 | % | | | | | | | | | | | | | | | | | | 0.9 | 4.3 | 4.9 |
| 93. | Sum of Two Greatest | | % | | | 84.2 | 93.3 | 91.5 | 82.0 | 67.8 | 51.6 | 43.4 | 36.4 | 29.1 | 27.7 | 32.0 | 26.9 | 19.5 | 17.6 | 16.0 | 14.7 | 14.5 | 15.2 |
| | **Greatest Perform. In Use** | | | | | | | | | | | | | | | | | | | | | | |
| 94. | Population–Included | | k | | .599 | | | 2.86 | | 5.99 | | 13.756 | | 26.360 | | | 60.033 | | 77.106 | | 93.144 | | 99.579 |
| 95. | Missing | | k | | 0 | | | .07 | | .08 | | .114 | | .210 | | | 2.74 | | 1.154 | | 5.376 | | 12.265 |
| 96. | Average Performance–IBM | | kops | | .598 | | | 1.128 | | 2.31 | | 4.04 | | 6.58 | | | 32.9 | | 39.9 | | 88.8 | | 105.1 |
| 97. | Non-IBM Systems | | kops | | .812 | | | .727 | | 2.77 | | 4.08 | | 16.29 | | | 67.0 | | 73.9 | | 69.2 | | 78.2 |
| 98. | Missing Systems (Assumed) | | kops | | · | | | .727 | | 2.77 | | 4.08 | | 16.29 | | | 67.0 | | 78.0 | | 280.0 | | 238.0 |
| 99. | Total Non-IBM | | kops | | .812 | | | .727 | | 2.77 | | 4.08 | | 16.29 | | | 67.0 | | 74.1 | | 100.0 | | 125.0 |
| 100. | Average System Performance | | kops | .50 | .639 | .70 | .85 | 1.063 | 1.7 | 2.399 | 3.1 | 4.048 | 6.5 | 9.860 | 20.0 | 32.5 | 42.98 | 48.1 | 52.73 | 70. | 93.03 | 102. | 112.6 |
| 101. | Total US GP Operations/Sec | | Mops | .120 | .447 | .882 | 1.785 | 3.31 | 7.48 | 14.8 | 25.1 | 47.4 | 108.6 | 213.0 | 566 | 1,157 | 1,762 | 2,213 | 2,557 | 3,808 | 5,371 | 6,350 | 7,324 |
| | % of Tot. Perf. In Use By: | | | | | | | | | | | | | | | | | | | | | | |
| 102. | IBM 650 | 2.10.6 | % | | 30.4 | 26.5 | 26.1 | 13.7 | 5.1 | 2.0 | 0.9 | 0.3 | 0.1 | | | | | | | | | | |
| 103. | IBM 704 | 2.10.6 | % | | 21.2 | 33.0 | 27.6 | 14.5 | 5.6 | 2.3 | 1.1 | 0.4 | 0.1 | 0.1 | | | | | | | | | |
| 104. | IBM 705 III | 2.10.6 | % | | 13.2 | 18.5 | 31.4 | 39.6 | 17.0 | 8.5 | 3.9 | 1.5 | 0.4 | 0.2 | 0.1 | | | | | | | | |
| 105. | IBM 709 | 2.10.7 | % | | | | | 16.4 | 5.5 | 2.1 | 1.5 | 0.3 | 0.1 | | | | | | | | | | |
| 106. | IBM 7090 | 2.10.6 | % | | | | | 2.7 | 39.5 | 39.0 | 31.5 | 20.1 | 1.6 | 0.8 | 0.3 | 0.1 | | | | | | | |
| 107. | IBM 1401 | 2.10.7 | % | | | | | | 4.2 | 14.4 | 15.1 | 13.2 | 7.0 | 3.1 | 1.3 | 0.5 | 0.2 | 0.1 | 0.1 | | | | |
| 108. | IBM 7094 II | 2.10.6 | % | | | | | | | | 0.4 | 14.8 | 21.9 | 8.3 | 3.2 | 1.9 | 1.1 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 |
| 109. | CDC 6600 | 2.10.6 | % | | | | | | | | | | 3.9 | 11.5 | 11.6 | 9.2 | 10.4 | 11.5 | 10.6 | 6.6 | 4.5 | 3.7 | 3.3 |
| 110. | BGH 5500 | 2.10.7 | % | | | | | | | | | 0.6 | 5.8 | 10.0 | 4.5 | 3.2 | 2.6 | 3.1 | 3.0 | 2.0 | 1.1 | 0.7 | 0.6 |
| 111. | IBM 360/65 | 2.10.6 | % | | | | | | | | | | | 0.4 | 3.1 | 18.8 | 22.6 | 20.6 | 20.9 | 13.0 | 6.9 | 6.1 | 4.8 |
| 112. | Univac 1108 | 2.10.7 | % | | | | | | | | | | | 2.9 | 8.5 | 12.1 | 14.2 | 10.9 | 11.2 | 8.1 | 5.4 | 4.4 | 3.7 |
| 113. | IBM 370/155 | 2.10.6 | % | | | | | | | | | | | | | | | | | 15.5 | 23.4 | 22.5 | 11.4 |
| 114. | IBM 370/145 | 2.10.7 | % | | | | | | | | | | | | | | | | | 5.3 | 10.5 | 11.9 | 11.7 |
| 115. | Sum of the Two Greatest | | % | | 51.6 | 59.5 | 59.0 | 56.0 | 56.5 | 53.4 | 46.6 | 34.9 | 28.9 | 21.5 | 20.1 | 30.9 | 36.8 | 32.1 | 32.1 | 28.5 | 33.9 | 34.4 | 23.1 |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS—NOTES

This table presents comparable data on a number of different GP and mini computers. I include all of the GP systems, and many of the minis, which were identified in Table II.2.10 as being "important", either in the sense that their number in use, value in use, or total operations per second carried out ranked them first or second amongst all U.S. computers. In addition, I have added some IBM computers, and all the non-IBM computers whose *number or value* in use exceeded 1% of total worldwide GP installations in some year. It was this criterion which brought in such machines as the CDC 1103, the NCR 315, the Honeywell 200, and the Univac 9200 and 9300. Obviously, including so many machines on the basis of number installed tends to bias the sample in the direction of small machines. The systems are presented in sequence by manufacturer, with IBM first and other system manufacturers following in alphabetical order. For each manufacturer, systems appear in the sequence they were first installed.

1. My primary source of information on the date first installed is the computer census in *EDP/IR*. For systems which have not appeared in those censuses, I used the predecessor *C & A* census, and if that source failed also, I used KnigK66,68.

**Processor Performance.** 2. This line specifies whether the hardware performs binary or decimal arithmetic. If the decimal performance is optional at extra cost, I have listed the machine as a binary machine. If both decimal and binary arithmetic are standard, I list "both".

3. The machine's fundamental word length, given in bits, does not include parity bits, marker bits, or sign bits. Where a machine has a variable word length which is an integer multiple of some number of bits per character, I have shown the number of bits per character followed by D.

4-6. Memory cycle time, in microseconds, is the average time between successive instruction fetches from the computer's internal memory. For machines with a hierarchy of internal memory, I thus list the faster memory speed. For drum memories, it is one-half the maximum access time. Addition and multiplication times given here are the times required to perform an addition and a multiplication command, including memory accesses. For variable word-length machines, it is assumed that both operands are the equivalent of five decimal digits in length, at least. For machines with no hardware multiplication, the time required for a programmed multiplication is given. The source for this information was AuerCTR, or WeikM.

7-8. These addition and multiplication times come from GillF61, and are supplied for comparative purposes. Generally, Gille provides the time required to add 555,555 to itself, and to multiply 555,555 by 5,555.

9-10. This data, from AuerCTR, is the time required to add (or multiply) two numbers from two different places in internal memory, and store the result in a third location. For 3-address machine, these functions might each be carried out with one command. For a 1-address machine, they typically require at least three commands. Once again, 5-decimal-digit precision or its equivalent is assumed.

11-12. The rate at which additions can be performed is the inverse of the addition time, converted to thousands of operations per second. For addition time I used line 9, line 7, or line 5, (in that order) depending on which piece of data was available. The weighted addition rate is the computing speed in thousands of operations per second, assuming that 95% of all operations are additions and the other 5% are multiplications.

13-17. The Knight indices, from KnigK66,68, are discussed in the note following this one, in reference to Figure II.2.11. Scientific and commercial operations per dollar are computed by multiplying lines 13 and 14, respectively, by line 15.

18. The memory bit rate is the number of bits read out from the memory in one access divided by the memory cycle time—line 70 divided by line 71. It thus represents the maximum rate at which bits can be read from or written into memory. However, it understates that rate for drum memories by ignoring the possibility that many words can be read in sequence from adjacent sectors on the drum. It understates the core memory rate by ignoring the fact that some computers have interleaved memories which increase the transfer rate by allowing independent portions of memory to operate simultaneously. And it understates the rate for systems having a heierarchy of internal memory because it is based on the data rate of the slower, bulk memory.

19-38. The Auerbach performance measures are discussed in some detail in connection with Table II.2.23.1 below. The data shown here is a selected set of performance figures for a small and a large configuration.

39. This line is intended to show how many raw computer additions can be purchased with $1.00 spent in CPU rental. It is found by dividing additions per second, in millions, by CPU rental in dollars per second. Additions per second is the reciprocal of line 5 (or line 7, if line 5 is blank). Dollars per second is found by dividing line 89 by 624,000, the number of seconds in a month of 40-hour weeks.

40. In the late fifties and early sixties, Cresap, McCormick, and Paget published a number of papers in *Control Engineering* magazine on computer systems and their peripherals (CresM). The January, March, and April issues in 1963 summarized CPU performance by taking the weighted average operation time for each of a number of processors. The weights used are given in Table 2.21.8. The operation times to which the weights were applied are generally the times required to read six-digit operands from memory, carry out an indicated operation, and (if necessary) store the result or results back in memory.

41. Adams' *Computer Characteristics Quarterly* (AdamA) has always published a "complete add time" defined as the length of time required to execute one fixed-point addition command, taking into account all the features including overlapped memory banks, instruction look-ahead, and parallel execution of instructions. The figure on line 41 is the reciprocal of the addition time, converted into thousands of additions per second.

41a. Processor operations per dollar is computed by dividing Knight's commercial speed, on line 14, by the rent of a central processor (without memory), from line 89. The quotient is then multiplied by 624 to get the results in kilo-operations per dollar.

42-68. These entries in the table compare the performance of each computer to that of the IBM 360/30. They are ratios of various entries on lines 5 through 41 of the table for each computer and corresponding numbers for the 360/30. The ratios are taken in such a way as to present a uniform picture of relative performance, with large numbers corresponding to high performance and small numbers to low. This required that ratios be computed differently for different parts of the table. For example, line 43 is found by dividing 360/30 multiplication time (235 microseconds) by the given computer's multiplication time on line 6. Line 44, on the other hand, was found by dividing the given computer's weighted addition rate, on line 12, by the 360/30's rate of 9.013Kops. The Auerbach performance ratios were all computed with reference to the performance of the 360/30 configuration III. (See Table II.2.23.1.)

**Memory.** Lines 3 and 4 described the characteristics of the memory from which instructions are executed. Lines 69/80 describe the bulk main memory. For early machines, there is only one internal memory and lines 3-4 describe the same memory as do lines 69-80. For machines with two levels of internal memory (cache memory), lines 69-80 describe the *lower-speed* portion of the memory.

69. Most memories described by the table employ magnetic core technology; for those memories this line is blank. The other technologies represented are magnetic drums, mercury delay lines (Hg Line) for the Univac I, and integrated circuits (IC).

70. This line shows the number of data bits which are read when internal memory is accessed. For most processors, the number of bits is the same as the word length; but for some low-performance processors the number is less, and for some high-performance the number is greater.

71. The cycle time is the average time between the beginning of successive accesses to data located randomly in memory.

72-75. These lines show the minimum and maximum size of internal memories available with each processor. Size is given both in thousands of words and thousands of bytes. I have, at this point, used the word "byte" to mean an alphanumeric character rather than a fixed number of bits. The number of bits per byte can be inferred by comparing the word length in line 3 with the number of bytes per word found by dividing line 73 by line 72. The IBM 650, for example, has five bytes per word and 50 bits per word—ten bits are required to represent an alphanumeric character. The IBM 1401, in comparison, uses 6 bits to represent a byte; and the 360 family of machines uses 8. For these entries, K = 1.024.

76-82. These lines provide data on memory economics. Line 76 gives the size of a memory increment, and lines 77 through 79 show the sales price, monthly rental, and monthly maintenance cost of that increment. For some systems, a memory increment is offered as a separate item having a separate model number, and I have used that data whenever it was available. For other systems, and particularly for the early ones, central processors were offered in several configurations, each having a different memory size. For these systems, the price, rental, and maintenance costs given are differences between the prices for different processors having a memory increment of the amount shown on line 76.

System prices vary with time. In general, I have attempted to record the prices quoted roughly two years after a model was introduced. My sources for price information, in order of preference, were: General Services Administration (GSA) Annual Price Lists published by the various manufacturers; AuerCTR; GillF; and WeikM. The GSA catalogs provide the most complete and accurate information, but infortunately are not generally accessible. However, all the early IBM prices came from GSA catalogs of the following years: 1960, 1963, 1964, 1967, 1968, 1969. Later IBM prices are from the IBM Consultants' Manual.

The price per byte shown on line 80 is the ratio of line 77 to 76. In interpreting it, one must keep in mind the fact that the number of bits per byte varies from system to system—see the comment in connection with lines 72-75 above. The maintenance cost per $100,000 of sales price is found by dividing line 79 by line 77 and multiplying the result by 100. The price/rent ratio is the ratio of line 77 to line 78.

**Processor and System Prices.** 84-87. These are the prices for a central processor having a memory of the size shown on line 87. The sources of data are the same as those discussed in connection with lines 77-79 above. In computing processor prices, I have included power supplies and consoles whenever those items were called out as being required with the processor.

88-92. The inferred prices of a processor having no memory were computed from lines 84-86 and 77-79, taking into account lines 87 and 76. For example, the price of an IBM 650 without memory was found by subtracting $35,000, the price of ten kbytes of memory shown on line 77, from $157,400, the price of a processor with ten kbytes of memory on line 84. Maintenance per $100k, on line 91, is the ratio of line 90 to line 88, multiplied by 100. The price/rental ratio on line 92 is the ratio of line 88 to line 89.

93-94. The figure on line 93 is the average system rental from *EDP/IR*, or its predecessor *C & A*. Wherever possible, I used the rental figures published roughly two years after the processor was introduced. The rental figure on line 94 comes from *Computer Characteristics Quarterly* (AdamA). Where a range of prices was given, I computed an average of the minimum and maximum.

95-98b. These figures are ratios to the corresponding figures for the IBM 360/30. The Auerbach ratios, on lines 98a and 98b, are ratios to the 360/30 configuration III.

**Physical Characteristics.** 99-106. This data pertains to the processor alone or to the processor including the memory increment shown on line 76. If line 107 contains contains the letters "incl.", the memory is included in the figures on lines 99-106. The weight of the processor needs no explanation. The floor space is that occupied by the processor cabinets themselves, not including space necessary for doors to swing open and for operators and maintenance men to access the equipment. The volume is floor space multiplied by equipment height. Electrical load and heat dissipation would seem to require no further explanation. The sources for this table, in order of preference are: Manufacturers' Installation Manuals; AuerCTR; GillF; and WeikM.

Lines 104 and 105 are the ratio of lines 99 and 103, respectively, to line 101. Line 106 is the ratio of either line 84 or line 88 to line 99, depending on whether memory is included with the processor, as specified on line 107.

107-116. These lines provide information on the physical

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item | Units | System | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturers: | | IBM | IBM | IBM | IBM | IBM | IBM | IBM | IBM |
| | Model Numbers: | | 650 | 704 | 705 | 305 | 709 | 7090 | 7070 | 1401 |
| 1. | **Date 1st Installed** | mo/yr | 11/54 | 12/55 | 11/55 | 12/57 | 8/58 | 11/59 | 3/60 | 9/60 |
| 2. | **Processor Performance** | | dec. | bin. | dec. | dec. | bin. | bin. | dec. | dec. |
| 3. | Word Length | bits | 50 | 36 | 6D | 6D | 36 | 36 | 50 | 6D |
| 4. | Memory Cycle Time | μsec. | 2400 | 12 | 17 | 10000 | 12 | 2.18 | 6 | 12 |
| 5. | Raw Speed—Add | μsec. | 5200 | 24 | 85 | 30000 | 24 | 4.36 | 72 | 230 |
| 6. | Multiply | μsec. | 11600 | 240 | 749 | 125,000 | 132 | 17.4 | 1070 | 2085 |
| 7. | Add (Gille) | μsec. | 1440 | 72 | 272 | 60000 | 72 | 4.8 | 168 | 264 |
| 8. | Multiply (Gille) | μsec. | 6720 | 288 | 816 | 90000 | 144 | 38 | 708 | 12000 |
| 9. | Five Dec. Dig.—c=a+b | μsec. | - | 72 | - | - | 72 | 13.1 | 156 | 437 |
| 10. | c=ab | μsec. | - | 288 | - | - | 238 | 34.0 | 660 | 21216 |
| 11. | Addition Rate | Kops | .694 | 13.89 | 3.676 | .017 | 13.88 | 76.3 | 6.41 | 2.29 |
| 12. | Weighted Opns/sec. | Kops | .586 | 12.1 | 3.34 | .016 | 12.5 | 70.7 | 5.52 | .68 |
| 13. | Knight Index—Scientific | Kops | .111 | 10.67 | .734 | .095 | 1.87 | 97.35 | 2.81 | .497 |
| 14. | Commercial | Kops | .291 | 3.79 | 2.087 | .097 | 10.23 | 45.47 | 5.14 | 1.626 |
| 15. | Time Per Dollar | Sec/$ | 155.9 | 13.18 | 13.27 | 163.0 | 8.882 | 9.742 | 23.98 | 83.14 |
| 16. | Ops./$—Scientific | Kop/$ | 17.3 | 141 | 9.74 | 15.5 | 46.6 | 948.4 | 67.38 | 41.32 |
| 17. | Commercial | Kop/$ | 45.4 | 50.0 | 27.69 | 15.8 | 90.9 | 443.0 | 123.3 | 135.2 |
| 18. | Memory Bit Rate | bit/μsec | .021 | 3.0 | .353 | .0006 | 3.0 | 16.5 | 8.33 | 0.5 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.—Type | | | VI | | | VIIB | VIIB | III | I |
| 20. | Rental | $k/mo | - | 28.45 | - | - | 53.77 | 66.77 | 119.40 | 4.33 |
| 21. | Performance—F1 | min | - | - | - | - | 1.6 | .47 | 1.3 | - |
| 22. | F3 | min | - | - | - | - | 9.4 | 1.9 | 67 | 100 |
| 23. | Random Access | min | - | - | - | - | - | - | - | - |
| 24. | Sorting | min | - | - | - | - | 11 | 3.2 | 5.7 | - |
| 25. | Matrix Inv.—10 | min | - | - | - | - | .009 | .001 | .037 | .33 |
| 26. | Matrix Inv.—40 | min | - | - | - | - | .58 | .062 | 2.1 | - |
| 27. | P1 | ms | - | 180 | - | - | 35 | 8.5 | | 520 |
| 28. | P3 | ms | - | 1700 | - | - | 1800 | 270 | | 50K |
| 29. | Largest Config.—Type | | | VIIB | | | VIIIB | VIIIB | VIIIB | IV |
| 30. | Rental | $k/mo | - | 48.16 | - | - | 69.05 | 89.22 | 45.03 | 11.54 |
| 31. | Performance—F1 | min | - | - | - | - | 1.6 | .21 | .38 | 2.0 |
| 32. | F3 | min | - | - | - | - | 9.4 | 1.6 | 4.5 | 20 |
| 33. | Random Access | min | - | - | - | - | - | - | - | - |
| 34. | Sorting | min | - | - | - | - | 4.7 | 1.5 | 2.0 | 10. |
| 35. | Matrix Inv.—10 | min | - | - | - | - | .009 | .001 | .037 | .33 |
| 36. | Matrix Inv.—40 | min | - | - | - | - | .58 | .062 | 2.1 | - |
| 37. | P1 | ms | - | 67 | - | - | 35 | 7.7 | 63 | - |
| 38. | P3 | ms | - | 1500 | - | - | 1800 | 270 | 6000 | - |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | .051 | 2.68 | .650 | .013 | 2.60 | 7.43 | 2.89 | .230 |
| 40. | Datamation (CresM63) | Kops | .101 | 11.74 | - | - | - | 67.84 | 5.12 | 1.50 |
| 41. | Adams Addition Rate | Kops | - | - | - | - | - | 227.3 | 16.7 | 4.35 |
| 41a. | Processor Ops./$ | kop/$ | 77.3 | 243.8 | 115.3 | 38.4 | 638.4 | 1472 | 1069 | 859.1 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed—Add | | .0057 | 1.250 | .353 | .0010 | 1.25 | 6.881 | .417 | .130 |
| 43. | Multiply | | .0203 | .979 | .314 | .0019 | 1.78 | 13.51 | .220 | .113 |
| 44. | Weighted Opns/sec. | | .0650 | 1.343 | .371 | .0018 | 1.387 | 7.844 | .612 | .0038 |
| 45. | Knight Index—Scientific | | .0140 | 1.344 | .092 | .012 | .236 | 12.26 | .354 | .063 |
| 46. | Commercial | | .0170 | .222 | .122 | .0057 | .598 | 2.66 | .301 | .095 |
| 47. | Time Per Dollar | | .467 | 5.530 | 5.492 | .447 | 8.205 | 7.48 | 3.04 | .877 |
| 48. | Scientific Opns/$ | | .0299 | .244 | .0168 | .0268 | .0287 | 1.639 | .116 | .0714 |
| 49. | Commericial Opns/$ | | .0364 | .0401 | .0222 | .0127 | .0729 | .355 | .099 | .108 |
| 50. | Memory Bit Rate | | .0039 | .563 | .0662 | .0001 | .563 | 3.094 | 1.562 | .0938 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.—F1 | | | | | | .938 | 3.191 | 1.154 | - |
| 52. | F3 | | | | | | 2.128 | 10.53 | .299 | .200 |
| 53. | Random Access | | | | | | - | - | - | - |
| 54. | Sorting | | | | | | .836 | 2.875 | 1.614 | - |
| 55. | Matrix Inv.—10 | | | | | | 2.778 | 25.0 | .676 | .0758 |
| 56. | Matrix Inv.—40 | | | | | | 2.069 | 19.35 | .571 | - |
| 57. | P1 | | | .556 | | | 2.857 | 11.76 | - | .192 |
| 58. | P3 | | | 2.488 | | | 2.350 | 15.67 | - | .0846 |
| 59. | Large Config.—F1 | | | | | | .938 | 7.143 | 3.947 | .750 |
| 60. | F3 | | | | | | 2.128 | 12.50 | 4.444 | 1.000 |

characteristics of the memory increment described by line 76-79. Floorspace and volume are computed here the same as they were for lines 100 and 101. Lines 112 and 113 are the ratios of lines 107 and 111 to 109. Lines 114 and 115 are the ratio of line 76 to lines 108 and 109, respectively. And line 116 is the ratio of line 77 to line 107.

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item | Units | System | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Manufacturers:** | | **IBM** | **IBM** | **IBM** | **IBM** | **IBM** | **IBM** | **IBM** | **IBM** |
| | **Model Numbers:** | | **650** | **704** | **705** | **305** | **709** | **7090** | **7070** | **1401** |
| 61. | Random Access | | | | | - | - | - | - | |
| 62. | Sorting | | | | | | 1.957 | 6.133 | 4.600 | .120 |
| 63. | Matrix Inv.—10 | | | | | | 2.778 | 25.0 | .676 | .0758 |
| 64. | Matrix Inv.—40 | | | | | | 2.069 | 19.35 | .571 | - |
| 65. | P1 | | | 1.493 | | | 2.857 | 12.99 | 1.587 | - |
| 66. | P3 | | | 2.820 | | | 2.350 | 15.67 | .705 | - |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | .0020 | .106 | .026 | .0005 | .103 | .294 | .114 | .0091 |
| 68. | Adams Addition Rate | | - | - | - | - | - | 9.092 | .668 | .174 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | drum | | | drum | | | | |
| 70. | Bits Per Access | | 50 | 36 | 6 | 6 | 36 | 36 | 50 | 6 |
| 71. | Cycle Time | μsec. | 2400 | 12 | 17 | 10000 | 12 | 2.18 | 6.0 | 11.5 |
| 72. | Minimum Size | kwords | 2 | 4K | - | - | 4K | 32K | 5.0 | 1.4 |
| 73. | Bytes | kbytes | 10 | 24K | 20 | 2.9 | 24K | 196.6 | 25.0 | 1.4 |
| 74. | Maximum Size | kwords | 4 | 32K | - | - | 32K | 32K | 9.9 | 16.0 |
| 75. | Bytes | kbytes | 20 | 192K | 40 | 3.3 | 192K | 196.6 | 49.5 | 16.0 |
| 76. | Increment Size | kbytes | 10 | 168K | 20 | - | 168K | 196.6 | 25 | 4.0 |
| 77. | Price | $k | 35 | 940 | 90 | | 940 | 840 | 234.0 | 22.35 |
| 78. | Rental | $k/mo | .85 | 19.7 | 2.5 | | 19.7 | 17.5 | 5.1 | .625 |
| 79. | Maintenance | $/mo | 97 | 960 | 204 | | 960 | 580 | 62 | 15.5 |
| 80. | Price Per Byte | $/by | 3.50 | 5.46 | 4.50 | - | 5.46 | 4.27 | 9.36 | 5.59 |
| 81. | Maint. Cost Per $100k | $/mo | 277 | 102 | 227 | - | 102 | 69.0 | 26.5 | 69.4 |
| 82. | Price: Rental Ratio | | 41.2 | 47.7 | 36.0 | - | 47.7 | 48.0 | 45.9 | 35.8 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 157.4 | 450 | 562.4 | 92.7 | 500 | 817.5 | 138.1 | 70.5 |
| 85. | Rental | $k/mo | 3.2 | 9.7 | 12.85 | 1.575 | 10.0 | 19.275 | 3.0 | 1.2 |
| 86. | Maintenance | $/mo. | 219. | 1007 | 981 | 158 | 1456 | 1008 | 87.5 | 47.5 |
| 87. | Memory Included | kbytes | 10 | 0 | 20 | 2.9 | 0 | 0 | 0 | 1.4 |
| 88. | Processor Alone—Price | $k | 122.4 | 450 | 506.2 | - | 500 | 817.5 | 138.1 | 62.68 |
| 89. | Rental | $k/mo | 2.35 | 9.7 | 11.3 | - | 10 | 19.275 | 3.0 | 1.181 |
| 90. | Maintenance | $/mo | 122 | 1007 | 854 | - | 1456 | 1008 | 87.5 | 42.1 |
| 91. | Maint. Per $100k | $/mo | 99.7 | 224 | 169 | 170 | 291 | 123.3 | 63.4 | 67.2 |
| 92. | Price: Rental Ratio | | 52.1 | 46.4 | 44.8 | 58.9 | 50.0 | 42.4 | 46.0 | 53.1 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 4.0 | 32.0 | 30.0 | 3.6 | 40.0 | 64.0 | 24.0 | 2.50 |
| 94. | Adams | $k/mo | - | - | - | - | - | 63.0 | 24.0 | 6.5 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone—Price | | 3.100 | 11.40 | 12.82 | 2.348 | 12.66 | 20.71 | 3.498 | 1.588 |
| 96. | Rental | | 2.848 | 11.76 | 13.70 | 1.909 | 12.12 | 23.36 | 3.636 | 1.432 |
| 97. | Maint. Per $100k | | .480 | 1.078 | .814 | .818 | 1.401 | .594 | .305 | .324 |
| 98. | System Rental—*EDP/IR* | | .454 | 3.636 | 3.409 | .409 | 4.545 | 7.272 | 2.727 | .284 |
| 98a. | Auerbach—Smallest | | - | 4.088 | - | - | 7.726 | 9.59 | 2.787 | .622 |
| 98b. | Auerbach—Largest | | - | 6.920 | - | - | 9.921 | 12.82 | 6.470 | 1.658 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | 4968 | 3150 | 8690 | 3755 | 3150 | 4450 | 2200 | 980 |
| 100. | Floor Space | ft.$^2$ | 25.8 | 18.5 | 206.5 | 20.9 | 18.5 | 23.3 | 11.3 | 6.24 |
| 101. | Volume | ft.$^3$ | 152.8 | 101.8 | 1123 | 127.1 | 101.8 | 134.2 | 64.8 | 30.2 |
| 102. | Electrical Load | kva | 16.8 | 40.3 | NA | 12.6 | 40.3 | 3.18 | 0.4 | - |
| 103. | Heat Dissipation | kBTU/hr. | 35.1 | 109.8 | 70.25 | 28.27 | 109.8 | 7.24 | 4.4 | 3.0 |
| 104. | Density—Weight | lb/ft.$^3$ | 32.5 | 31.0 | 7.74 | 29.5 | 31.0 | 33.2 | 34.0 | 32.5 |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | .230 | 1.08 | .062 | .222 | 1.08 | .054 | .068 | .099 |
| 106. | Price Per Pound | $/lb. | 31.7 | 142.9 | 58.2 | 24.7 | 158.7 | 184 | 62.8 | 64.0 |
| 107. | Memory Weight | lbs. | incl. | 4000 | incl | incl | 4000 | 2450 | 4300 | incl. |
| 108. | Floor Space | ft.$^2$ | - | 104.9 | - | - | 104.9 | 11.7 | 22.6 | |
| 109. | Volume | ft.$^3$ | - | 559.4 | - | - | 559.4 | 67.1 | 129.7 | |
| 110. | Electrical Load | kva | - | 23.4 | - | - | 23.4 | 8.03 | 1.80 | |
| 111. | Heat Dissipation | kBTU/hr. | - | 60.5 | - | - | 60.5 | 19.4 | 9.1 | |
| 112. | Density—Weight | lbs/ft.$^3$ | - | 7.15 | - | - | 7.15 | 36.5 | 33.1 | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | - | .108 | - | - | .108 | .289 | .070 | |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | - | 1.60 | - | - | 1.60 | 16.8 | 1.11 | |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | - | .300 | - | - | .300 | 2.93 | .193 | |
| 116. | Price Per Pound | $/lb. | - | 235 | - | - | 235 | 343 | 54.4 | |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>1620-1 | IBM<br>7030 | IBM<br>7080 | IBM<br>1410 | IBM<br>7074 | IBM<br>7072 | IBM<br>7094 | IBM<br>1440 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 9/60 | 5/61 | 8/61 | 11/61 | 12/61 | 6/62 | 9/62 | 4/63 |
| 2. | **Processor Performance** | | dec. | dec. | dec. | dec. | dec. | dec. | bin. | dec. |
| 3. | Word Length | bits | 4D | 64 | 6D | 6D | 50 | 50 | 36 | 6D |
| 4. | Memory Cycle Time | μsec. | 20 | 0.5 | 2.18 | 4.5 | 4 | 6 | 2.0 | 11.1 |
| 5. | Raw Speed–Add | μsec. | 960 | 3.5 | 13.1 | 88 | 10 | 12 | | 200 |
| 6. | Multiply | μsec. | 17700 | 40.0 | 140 | - | 56 | 40.2 | | |
| 7. | Add (Gille) | μsec. | 960 | - | 12.8 | - | 1 | - | 4.0 | - |
| 8. | Multiply (Gille) | μsec. | 17700 | - | 140 | - | 43 | - | 10.0 | - |
| 9. | Five Dec. Dig.–c=a+b | μsec. | 920 | - | 32 | 226 | 24 | 36 | 10 | 422 |
| 10. | c=ab | μsec. | 5320 | - | 134 | 1206 | 72 | 84 | 16 | 20500 |
| 11. | Addition Rate | Kops | 1.09 | 285.7 | 31.3 | 4.4 | 41.7 | 27.8 | 100 | 2.4 |
| 12. | Weighted Opns/sec. | Kops | .88 | 187.8 | 27.0 | 3.6 | 37.9 | 26.1 | 97.1 | .7 |
| 13. | Knight Index–Scientific | Kops | .095 | 371.7 | 27.1 | 1.67 | 41.99 | 22.71 | 175.9 | 1.41 |
| 14. | Commercial | Kops | .047 | 631.2 | 30.9 | 4.64 | 31.65 | 8.69 | 95.9 | 5.56 |
| 15. | Time Per Dollar | Sec/$ | 331.7 | 2.078 | 11.34 | 62.35 | 19.49 | 34.64 | 8.782 | 183.4 |
| 16. | Ops./$–Scientific | Kop/$ | 31.51 | 772.4 | 307.3 | 104.1 | 818.4 | 786.7 | 1544.8 | 258.6 |
| 17. | Commercial | Kop/$ | 15.59 | 1311.6 | 350.4 | 289.3 | 616.9 | 301.0 | 842.2 | 1019.7 |
| 18. | Memory Bit Rate | bit/μsec | 0.4 | 128.0 | 2.75 | 1.33 | 12.5 | 8.33 | 18.0 | .54 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.–Type | | IX | | VIIB | II | VIIB | VIIB | VIIB | II |
| 20. | Rental | $k/mo | 2.46 | | 51.75 | 8.42 | 40.47 | 32.92 | 72.40 | 4.05 |
| 21. | Performance–F1 | min | - | | .42 | 2.7 | .45 | 1.2 | .47 | 3.8 |
| 22. | F3 | min | - | | 2.0 | 20 | 2.2 | 5.7 | 1.9 | 73 |
| 23. | Random Access | min | - | | - | - | | - | - | - |
| 24. | Sorting | min | - | | 1.2 | 30 | 1.5 | 8.3 | 3.2 | 40 |
| 25. | Matrix Inv.–10 | min | 1.2 | | | .17 | .003 | .0037 | .0004 | |
| 26. | Matrix Inv.–40 | min | 55 | | | 9.0 | .17 | .24 | .029 | |
| 27. | P1 | ms | 3.7K | | | | 11 | 25 | 7.7 | |
| 28. | P3 | ms | 20K | | | | 350 | 400 | 140 | |
| 29. | Largest Config.–Type | | X | | VIIIB | VIIB | VIIIB | VIIIB | VIIIB | III |
| 30. | Rental | $k/mo | 3.58 | | 79.33 | 23.56 | 72.84 | 49.89 | 95.07 | 5.92 |
| 31. | Performance–F1 | min | - | | .18 | .85 | .18 | 1.2 | .21 | 2.9 |
| 32. | F3 | min | - | | 1.4 | 3.3 | 1.7 | 5.7 | .96 | 48 |
| 33. | Random Access | min | - | | - | | - | - | - | - |
| 34. | Sorting | min | - | | .42 | 7.0 | 1.2 | 8.3 | 1.5 | 19 |
| 35. | Matrix Inv.–10 | min | .35 | | | .17 | .003 | .0037 | .0004 | |
| 36. | Matrix Inv.–40 | min | 18 | | | 9.0 | .17 | .24 | .029 | |
| 37. | P1 | ms | 1K | | | | 11 | 25 | 7.7 | |
| 38. | P3 | ms | 12K | | | | 350 | 400 | 140 | |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 1.04 | | 2.98 | 2.33 | 7.35 | | 18.01 | 5.48 |
| 40. | Datamation (CresM63) | Kops | - | - | 21.31 | 3.79 | 35.03 | 100.0 | 79.74 | - |
| 41. | Adams Addition Rate | Kops | 1.78 | 666.7 | 90.9 | 11.4 | 100.0 | 83.3 | 250.0 | 5.0 |
| 41a. | Processor Ops./$ | kop/$ | 46.9 | - | 1205 | 949.3 | 2323 | - | 6898 | 6087 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed–Add | | .031 | 8.571 | 2.29 | - | 3.0 | 2.5 | - | .15 |
| 43. | Multiply | | .013 | 5.875 | 1.68 | - | 4.2 | 5.84 | - | |
| 44. | Weighted Opns/sec. | | .0976 | 20.84 | 3.0 | .40 | 4.2 | 2.9 | 10.77 | .078 |
| 45. | Knight Index–Scientific | | .012 | 46.80 | 3.4 | .210 | 5.29 | 2.86 | 22.15 | .178 |
| 46. | Commercial | | .003 | 36.90 | 1.81 | .271 | 1.85 | .508 | 5.61 | .325 |
| 47. | Time Per Dollar | | .220 | 35.07 | 6.43 | 1.17 | 3.74 | 2.10 | 8.30 | .397 |
| 48. | Scientific Opns/$ | | .0544 | 1.335 | .531 | .180 | 1.41 | 1.36 | 2.67 | .443 |
| 49. | Commericial Opns/$ | | .0125 | 1.052 | .281 | .232 | .495 | .242 | .676 | .818 |
| 50. | Memory Bit Rate | | .0750 | 24.00 | .516 | .098 | 2.34 | 1.56 | 3.38 | .101 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.–F1 | | - | - | 3.57 | .556 | 3.33 | 1.25 | 3.19 | .395 |
| 52. | F3 | | - | - | 10.0 | 1.0 | 9.09 | 3.51 | 10.53 | .274 |
| 53. | Random Access | | - | - | - | - | - | - | - | - |
| 54. | Sorting | | - | - | 7.67 | .307 | 6.13 | 1.11 | 2.88 | .230 |
| 55. | Matrix Inv.–10 | | .0208 | - | - | .147 | 8.33 | 6.76 | 62.5 | |
| 56. | Matrix Inv.–40 | | .0218 | - | - | .133 | 7.06 | 5.0 | 41.38 | |
| 57. | P1 | | .0270 | - | - | - | 9.09 | 4.0 | 13.0 | |
| 58. | P3 | | .212 | - | - | - | 12.09 | 10.58 | 30.21 | |
| 59. | Large Config.–F1 | | - | - | 8.33 | 1.76 | 8.33 | 1.25 | 7.14 | .517 |
| 60. | F3 | | - | - | 14.29 | 6.06 | 11.76 | 3.51 | 20.83 | .417 |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●

| Line | Item | Units | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturers: | | IBM | IBM | IBM | IBM | IBM | IBM | IBM | IBM |
| | Model Numbers: | | 1620-1 | 7030 | 7080 | 1410 | 7074 | 7072 | 7094 | 1440 |
| 61. | Random Access | | - | - | - | - | - | - | - | - |
| 62. | Sorting | | - | - | 21.90 | 1.31 | 7.67 | 1.11 | 6.13 | .484 |
| 63. | Matrix Inv.–10 | | .0714 | - | - | .147 | 8.33 | 6.76 | 62.5 | |
| 64. | Matrix Inv.–40 | | .0667 | | - | .133 | 7.06 | 5.0 | 41.38 | |
| 65. | P1 | | .100 | | - | - | 9.09 | 4.0 | 12.99 | |
| 66. | P3 | | .352 | | - | - | 12.09 | 10.58 | 30.21 | |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | .041 | | .118 | .092 | .291 | | .713 | .217 |
| 68. | Adams Addition Rate | | .0712 | 26.67 | 3.64 | .456 | 4.0 | 3.33 | 10.0 | .20 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | | | | | | |
| 70. | Bits Per Access | | 8 | 64 | 6 | 6 | 50 | 50 | 36 | 6 |
| 71. | Cycle Time | μsec. | 20 | 0.5 | 2.18 | 4.5 | 4.0 | 6.0 | 2.0 | 11.1 |
| 72. | Minimum Size | kwords | 20 | | 40 | 10 | 5 | 5 | 32K | 2 |
| 73. | Bytes | kbytes | 10 | | 40 | 10 | 25 | 25 | 196.6 | 2 |
| 74. | Maximum Size | kwords | 60 | | 160 | 80 | 30 | 30 | 32K | 16 |
| 75. | Bytes | kbytes | 30 | | 160 | 80 | 150 | 150 | 196.6 | 16 |
| 76. | Increment Size | kbytes | 10 | | 80 | 10 | 50 | | 196.6 | 2 |
| 77. | Price | $k | 37.1 | | 480 | 33.6 | 373.0 | | 840.0 | 3.25 |
| 78. | Rental | $k/mo | .750 | | 10.0 | .75 | 8.0 | | 17.5 | .20 |
| 79. | Maintenance | $/mo | 27.3 | | 380 | 4.3 | 51.5 | | 515 | 1 |
| 80. | Price Per Byte | $/by | 3.71 | - | 6.0 | 3.36 | 7.46 | - | 4.29 | 1.63 |
| 81. | Maint. Cost Per $100k | $/mo | 73.6 | | 79.2 | 12.8 | 13.8 | - | 61.3 | 30.8 |
| 82. | Price: Rental Ratio | | 49.5 | | 48.0 | 44.8 | 46.6 | | 48.0 | 16.3 |
| | **Processor–Sys. Price** | | | | | | | | | |
| 84. | Processor–Price | $k | 64.0 | | 760 | 189.4 | 362.4 | | 368.0 | 53.1 |
| 85. | Rental | $k/mo | 1.375 | | 16.0 | 3.8 | 8.5 | | 8.675 | .77 |
| 86. | Maintenance | $/mo. | 76.8 | | 767 | 66.5 | 224.3 | | 424 | 37.5 |
| 87. | Memory Included | kbytes | 10 | | 0 | 10 | 0 | | 0 | 2 |
| 88. | Processor Alone–Price | $k | 26.9 | | 760 | 155.8 | 362.4 | | 368.0 | 49.85 |
| 89. | Rental | $k/mo | .625 | | 16.0 | 3.05 | 8.5 | | 8.675 | .57 |
| 90. | Maintenance | $/mo | 49.5 | | 767 | 62.2 | 224.3 | | 424 | 36.5 |
| 91. | Maint. Per $100k | $/mo | 184.0 | | 109.6 | 39.9 | 61.9 | | 115.2 | 73.2 |
| 92. | Price: Rental Ratio | | 43.0 | | 47.5 | 51.1 | 42.6 | | 42.4 | 87.5 |
| 93. | System Rentals–*EDP/IR* | $k/mo | 2.00 | 300.0 | 60.0 | 17.0 | 27.0 | 27.0 | 75.5 | 4.3 |
| 94. | Adams | $k/mo | 2.825 | 160.0 | 55.0 | 13.5 | 29.3 | 15.8 | 70.0 | 3.0 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone–Price | | .681 | | 19.25 | 3.95 | 9.18 | - | 9.32 | 1.26 |
| 96. | Rental | | .758 | | 19.39 | 3.70 | 10.30 | | 10.51 | .69 |
| 97. | Maint. Per $100k | | .886 | | .528 | .192 | .298 | | .555 | .352 |
| 98. | System Rental–*EDP/IR* | | .227 | 34.09 | 6.82 | 1.93 | 3.07 | 3.07 | 8.58 | .489 |
| 98a. | Auerbach–Smallest | | .353 | | 7.44 | 1.21 | 5.81 | 4.73 | 10.40 | .582 |
| 98b. | Auerbach–Largest | | .514 | | 11.40 | 3.39 | 10.47 | 7.17 | 13.66 | .851 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor–Weight | lb. | 1210 | | 2600 | 2600 | 2500 | | 2225 | |
| 100. | Floor Space | ft.$^2$ | 19.3 | | 18.9 | 32.4 | 14.2 | | 11.7 | |
| 101. | Volume | ft.$^3$ | 70.6 | | 108.6 | 189.3 | 81.5 | | 67.1 | |
| 102. | Electrical Load | kva | - | | 0.86 | 6.1 | 17.8 | | 1.59 | |
| 103. | Heat Dissipation | kBTU/hr. | 10.0 | | 7.35 | 16.7 | 12.0 | | | |
| 104. | Density–Weight | lb/ft.$^3$ | 17.1 | | 23.9 | 13.7 | 30.7 | | 33.2 | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | .142 | | .068 | .088 | .147 | | | |
| 106. | Price Per Pound | $/lb. | 22.2 | | 292.3 | 72.8 | 145.0 | | 165.4 | |
| 107. | Memory Weight | lbs. | 830 | | 1500 | incl | 1500 | | | |
| 108. | Floor Space | ft.$^2$ | 11.4 | | 20.0 | - | 14.2 | | | |
| 109. | Volume | ft.$^3$ | 41.9 | | 116.7 | - | 81.5 | | | |
| 110. | Electrical Load | kva | | | 5.83 | - | 1.4 | | | |
| 111. | Heat Dissipation | kBTU/hr. | 2.0 | | 15.42 | - | 6.6 | | | |
| 112. | Density–Weight | lbs/ft.$^3$ | 19.8 | | 12.86 | | 18.4 | | | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | .048 | | .132 | | .081 | | | |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | .88 | | 4.0 | | 3.52 | | | |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | .239 | | .686 | | .613 | | | |
| 116. | Price Per Pound | $/lb. | 44.7 | | 320 | | 249 | | | |

### TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>7044 | IBM<br>7010 | IBM<br>1460 | IBM<br>7094II | IBM<br>360/40 | IBM<br>360/30 | IBM<br>360/50 | IBM<br>360/65 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 6/63 | 10/63 | 10/63 | 4/64 | 4/65 | 5/65 | 8/65 | 11/65 |
| 2. | **Processor Performance** | | bin. | dec. | dec. | bin. | | | | |
| 3. | Word Length | bits | 36 | 6D | 6D | 36 | 16D | 8D | 32D | 64D |
| 4. | Memory Cycle Time | μsec. | 2.0 | 2.4 | 6 | 1.0 | 2.5 | 1.5 | 2.0 | 0.75 |
| 5. | Raw Speed—Add | μsec. | 5 | 22 | 300 | 2.8 | 11.88 | 30 | 4.0 | 1.40 |
| 6. | Multiply | μsec. | 30 | N.A. | 1960 | 5.6 | 86.4 | 235 | 28.75 | 4.80 |
| 7. | Add (Gille) | μsec. | 5 | | | | - | - | - | - |
| 8. | Multiply (Gille) | μsec. | 22.5 | | | | - | - | - | - |
| 9. | Five Dec. Dig.—c=a+b | μsec. | 12 | 56 | 228 | 7.0 | 64 | 96 | 35 | 9.0 |
| 10. | c=ab | μsec. | 32 | 431 | 11000 | 9.8 | 178 | 395 | 86 | 32 |
| 11. | Addition Rate | Kops | 83.3 | 17.9 | 4.4 | 142.9 | 15.6 | 10.42 | 28.6 | 111.1 |
| 12. | Weighted Opns/sec. | Kops | 76.9 | 13.4 | 1.3 | 140.1 | 14.3 | 9.013 | 26.7 | 98.5 |
| 13. | Knight Index—Scientific | Kops | 67.7 | 5.73 | 1.61 | 217.1 | 33.4 | 7.94 | 187 | 1390 |
| 14. | Commercial | Kops | 23.4 | 11.54 | 7.20 | 95.2 | 50.1 | 17.1 | 149 | 810 |
| 15. | Time Per Dollar | Sec/$ | 23.98 | 31.18 | 69.28 | 8.20 | 54.08 | 72.88 | 27.47 | 13.86 |
| 16. | Ops./$—Scientific | Kop/$ | 1623.4 | 178.7 | 111.5 | 1780.2 | 1806.3 | 578.67 | 5136.9 | 19,265.4 |
| 17. | Commercial | Kop/$ | 561.1 | 359.8 | 498.8 | 780.6 | 2709.4 | 1246.2 | 4093.0 | 11,226.6 |
| 18. | Memory Bit Rate | bit/μsec | 18.0 | 5.0 | 1.0 | 36.0 | 6.4 | 5.33 | 16 | 85.33 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.—Type | | VIIA | III | III | | II | I | III | VIIB |
| 20. | Rental | $k/mo | 36.69 | 19.18 | 11.74 | | 7.22 | 4.10 | 15.4 | 35.18 |
| 21. | Performance—F1 | min | - | 1.4 | 1.4 | | 1.5 | - | 1.5 | .4 |
| 22. | F3 | min | - | 20 | 26 | | 20 | 67 | 20 | 2.0 |
| 23. | Random Access | min | - | - | - | | - | - | - | - |
| 24. | Sorting | min | 2.7 | 8.5 | 9.1 | | 10.4 | - | 9.7 | 2.0 |
| 25. | Matrix Inv.—10 | min | .001 | .06 | | | .0071 | .025 | .0017 | .00022 |
| 26. | Matrix Inv.—40 | min | .068 | 3.5 | | | .39 | 1.2 | .07 | .012 |
| 27. | P1 | ms | 13 | | | | 100 | 100 | 100 | 9.7 |
| 28. | P3 | ms | 450 | | | | 2000 | 4230 | 400 | 64 |
| 29. | Largest Config.—Type | | VIIIB | VIIB | | | VI | IVR | VIIB | VIIIB |
| 30. | Rental | $k/mo | 56.65 | 28.36 | | | 11.60 | 11.66 | 21.84 | 51.94 |
| 31. | Performance—F1 | min | .39 | .64 | | | 1.5 | - | .38 | .22 |
| 32. | F3 | min | 1.9 | 3.2 | | | 20 | - | 2.0 | 1.1 |
| 33. | Random Access | min | - | - | | | - | 18 | - | 20 |
| 34. | Sorting | min | 1.9 | 4.8 | | | 3.0 | 3.0 | 2.7 | 1.8 |
| 35. | Matrix Inv.—10 | min | .001 | .06 | | | .0071 | - | .0017 | .00022 |
| 36. | Matrix Inv.—40 | min | .068 | 3.4 | | | .39 | - | .07 | .012 |
| 37. | P1 | ms | 7.7 | | | | 100 | - | 9.7 | 6.5 |
| 38. | P3 | ms | 400 | | | | 2000 | - | 280 | 64 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 7.81 | 3.23 | | | 25.05 | 25.25 | 24.22 | 24.66 |
| 40. | Datamation (CresM63) | Kops | 53.13 | 6.77 | | | | | | |
| 41. | Adams Addition Rate | Kops | 200.0 | 30.3 | 9.26 | 714.3 | 84.2 | 25.0 | 250.0 | 769.2 |
| 41a. | Processor Ops./$ | kop/$ | 912.6 | 818.3 | - | - | 14887 | 12934 | 14415 | 27925 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed—Add | | 6.0 | 1.36 | .10 | 10.71 | 2.53 | 1.0 | 7.5 | 21.4 |
| 43. | Multiply | | 7.83 | N.A. | .120 | 42.0 | 2.72 | 1.0 | 8.17 | 49.0 |
| 44. | Weighted Opns/sec. | | 8.53 | 1.49 | .144 | 15.54 | 1.59 | 1.0 | 2.96 | 10.9 |
| 45. | Knight Index—Scientific | | 8.53 | .722 | .203 | 27.3 | 4.205 | 1.0 | 23.54 | 175.0 |
| 46. | Commercial | | 1.37 | .065 | .421 | 5.67 | 2.929 | 1.0 | 8.71 | 47.36 |
| 47. | Time Per Dollar | | 3.04 | 2.34 | 1.05 | 8.89 | 1.348 | 1.0 | 2.653 | 5.258 |
| 48. | Scientific Opns/$ | | 2.81 | .309 | .193 | 3.08 | 1.39 | 1.0 | 8.88 | 33.3 |
| 49. | Commericial Opns/$ | | .450 | .289 | .40 | .626 | 2.17 | 1.0 | 3.28 | 9.0 |
| 50. | Memory Bit Rate | | 3.38 | .938 | .188 | 6.65 | 1.20 | 1.0 | 3.00 | 16.0 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.—F1 | | - | 1.07 | 1.07 | - | 1.0 | - | 1.0 | 3.75 |
| 52. | F3 | | - | 1.0 | .769 | - | 1.0 | .299 | 1.0 | 10.0 |
| 53. | Random Access | | - | - | - | - | - | - | - | - |
| 54. | Sorting | | 3.41 | 1.08 | 1.01 | | .885 | - | .948 | 4.6 |
| 55. | Matrix Inv.—10 | | 25.0 | .417 | | | 3.52 | 1.0 | 14.7 | 113.6 |
| 56. | Matrix Inv.—40 | | 17.6 | .343 | | | 3.08 | 1.0 | 17.1 | 100.0 |
| 57. | P1 | | 7.69 | | | | 1.0 | 1.0 | 1.0 | 10.3 |
| 58. | P3 | | 9.40 | | | | 2.12 | 1.0 | 10.6 | 66.1 |
| 59. | Large Config.—F1 | | 3.85 | 2.34 | | | 1.0 | - | 3.95 | 6.82 |
| 60. | F3 | | 10.5 | 6.25 | | | 1.0 | - | 1.0 | 18.2 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>7044 | IBM<br>7010 | IBM<br>1460 | IBM<br>7094II | IBM<br>360/40 | IBM<br>360/30 | IBM<br>360/50 | IBM<br>360/65 |
|---|---|---|---|---|---|---|---|---|---|---|
| 61. | Random Access | | - | - | | | - | 1.39 | - | 1.25 |
| 62. | Sorting | | 4.84 | 1.92 | | | 3.07 | 3.07 | 3.41 | 5.11 |
| 63. | Matrix Inv.–10 | | 25.0 | .417 | | | 3.52 | - | 14.7 | 113.6 |
| 64. | Matrix Inv.–40 | | 17.6 | .353 | | | 3.08 | - | 17.1 | 100.0 |
| 65. | P1 | | 13.0 | | | | 1.0 | - | 10.3 | 15.4 |
| 66. | P3 | | 10.6 | | | | 2.12 | - | 15.1 | 66.1 |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | .309 | .128 | - | - | .992 | 1.00 | .959 | .977 |
| 68. | Adams Addition Rate | | 8.0 | 1.21 | .370 | 26.6 | 3.37 | 1.0 | 10.0 | 30.8 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | | | | | | |
| 70. | Bits Per Access | | 36 | 12 | 6 | 36 | 16 | 8 | 32 | 64 |
| 71. | Cycle Time | μsec. | 2.0 | 2.4 | 6.0 | | 2.5 | 1.5 | 2.0 | 0.75 |
| 72. | Minimum Size | kwords | 8K | 40 | 8 | | - | - | - | - |
| 73. | Bytes | kbytes | 48K | 40 | 8 | | 16K | 8K | 64K | 128k |
| 74. | Maximum Size | kwords | 32K | 100 | 16 | | - | - | - | - |
| 75. | Bytes | kbytes | 196K | 100 | 16 | | 256K | 64K | 512K | 2048k |
| 76. | Increment Size | kbytes | 48K | 20 | | | 32K | 16K | 128K | 256k |
| 77. | Price | $k | 50.0 | 51.0 | | | 54.45 | 41.32 | 178.5 | 399.6 |
| 78. | Rental | $k/mo | 1.5 | 1.0 | | | 1.20 | .900 | 3.80 | 9.3 |
| 79. | Maintenance | $/mo | 10 | 6 | | | 20 | 15 | 100 | 575 |
| 80. | Price Per Byte | $/by | 1.02 | 2.55 | | | 1.66 | 2.52 | 1.36 | 1.52 |
| 81. | Maint. Cost Per $100k | $/mo | 20.0 | 11.8 | | | 36.7 | 36.3 | 56.0 | 143.9 |
| 82. | Price: Rental Ratio | | 33.3 | 51.0 | | | 45.4 | 45.9 | 47.0 | 43.0 |
| | **Processor–Sys. Price** | | | | | | | | | |
| 84. | Processor–Price | $k | 890.0 | 540.0 | | | 135.4 | 60.14 | 409.1 | 960.3 |
| 85. | Rental | $k/mo | 17.5 | 10.8 | | | 2.70 | 1.275 | 8.35 | 22.75 |
| 86. | Maintenance | $/mo. | 210 | 157 | | | 105 | 90 | 260 | 985 |
| 87. | Memory Included | kbytes | 48K | 40 | | | 16K | 8K | 64K | 128K |
| 88. | Processor Alone–Price | $k | 840.0 | 438.0 | | | 108.2 | 39.48 | 319.9 | 760.5 |
| 89. | Rental | $k/mo | 16.0 | 8.8 | | | 2.10 | .825 | 6.45 | 18.1 |
| 90. | Maintenance | $/mo | 200 | 28 | | | 95 | 82 | 210 | 698 |
| 91. | Maint. Per $100k | $/mo | 23.8 | 6.4 | | | 87.8 | 207.7 | 65.6 | 91.8 |
| 92. | Price: Rental Ratio | | 52.5 | 49.8 | | | 51.5 | 47.9 | 49.6 | 42.0 |
| 93. | System Rentals–*EDP/IR* | $k/mo | 36.5 | 26.0 | 10.93 | 82.5 | 16.8 | 8.8 | 32.0 | 60.0 |
| 94. | Adams | $k/mo | 26.0 | 18.5 | 8.1 | 76.0 | 14.0 | 7.5 | 32.0 | 50.0 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone–Price | | 21.28 | 11.09 | | | 2.74 | 1.00 | 8.10 | 19.26 |
| 96. | Rental | | 19.39 | 10.67 | | | 2.55 | 1.00 | 7.82 | 21.94 |
| 97. | Maint. Per $100k | | .115 | .031 | | | .423 | 1.00 | .316 | .443 |
| 98. | System Rental–*EDP/IR* | | 4.15 | 2.95 | 1.24 | 9.38 | 1.91 | 1.00 | 3.64 | 6.82 |
| 98a. | Auerbach–Smallest | | 5.27 | 2.76 | 1.69 | | 1.04 | .589 | 2.21 | 5.05 |
| 98b. | Auerbach–Largest | | 8.14 | 4.07 | - | | 1.67 | 1.68 | 3.14 | 7.46 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor–Weight | lb. | 4200 | 3350 | | | 1700 | 1700 | 4700 | 4290 |
| 100. | Floor Space | $ft.^2$ | 44.8 | 40.4 | | | 12.9 | 15.1 | 33.3 | 22.8 |
| 101. | Volume | $ft.^3$ | 261.2 | 235.9 | | | 64.6 | 75.5 | 200.0 | 137.1 |
| 102. | Electrical Load | kva | 16.4 | 8.0 | | | 2.5 | 3.8 | 6.5 | 5.4 |
| 103. | Heat Dissipation | kBTU/hr. | | 20.5 | | | 7.0 | 10.0 | 20.4 | 15.8 |
| 104. | Density–Weight | $lb/ft.^3$ | 16.1 | 14.2 | | | 26.3 | 22.5 | 23.5 | 31.3 |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | .087 | | | .108 | .132 | .102 | .115 |
| 106. | Price Per Pound | $/lb. | 212 | 161 | | | 79.6 | 35.4 | 87.0 | 177 |
| 107. | Memory Weight | lbs. | incl. | incl. | | | incl. | incl. | incl. | 2070 |
| 108. | Floor Space | $ft.^2$ | | | | | | | | 17.2 |
| 109. | Volume | $ft.^3$ | | | | | | | | 103.2 |
| 110. | Electrical Load | kva | | | | | | | | 7.4 |
| 111. | Heat Dissipation | kBTU/hr. | | | | | | | | 25.3 |
| 112. | Density–Weight | $lbs/ft.^3$ | - | | | | | | | 20.1 |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | | | | | | | .245 |
| 114. | Capy. Per Floor Sp. | $kBy./ft^2$ | - | | | | | | | 15.2 |
| 115. | Capy. Per Vol. | $kBy./ft^3$ | - | | | | | | | 2.48 |
| 116. | Price Per Pound | $/lb. | | | | | | | | 164.1 |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>360/20 | IBM<br>1130 | IBM<br>360/44 | IBM<br>S3/10 | IBM<br>S3/6 | IBM<br>370/155 | IBM<br>370/165 | IBM<br>370/145 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 12/65 | 2/66 | 7/66 | 1/70 | 12/70 | 2/71 | 6/71 | 7/71 |
| 2. | **Processor Performance** | | | | bin. | | | | | |
| 3. | Word Length | bits | 8D | 16 | 32 | 8D | 8D | 16D | 32D | 64D |
| 4. | Memory Cycle Time | μsec. | 3.6 | 3.6 | 1.0 | 1.52 | 1.52 | .115 | .080 | .608 |
| 5. | Raw Speed—Add | μsec. | 448 | 8.0 | 2 | 26 | 26 | .993 | .16 | 2.14 |
| 6. | Multiply | μsec. | 4915 | 26.0 | | 3200 | 3200 | 9.62 | .7[illegible] | 20.08 |
| 7. | Add (Gille) | μsec. | | - | | | | | | |
| 8. | Multiply (Gille) | μsec. | | - | | | | | | |
| 9. | Five Dec. Dig.—c=a+b | μsec. | 1207 | 23.2 | 10 | 54 | 54 | 8.89 | 1.4 | 25.4 |
| 10. | c=ab | μsec. | 7530 | 44.5 | 23 | - | - | 40.76 | 2.7 | 126.5 |
| 11. | Addition Rate | Kops | .83 | 43.1 | 100 | 18.5 | 18.5 | 112.5 | 714.3 | 39.4 |
| 12. | Weighted Opns/sec. | Kops | .658 | 41.2 | 93.9 | 5.41 | 5.41 | 95.4 | 682.6 | 32.9 |
| 13. | Knight Index—Scientific | Kops | 1.93 | .016 | 1026 | | | | - | - |
| 14. | Commercial | Kops | 4.50 | .057 | 858 | 8.35 | 2.82 | 1203 | 3515 | 445.8 |
| 15. | Time Per Dollar | Sec/$ | 239.8 | 692.8 | 62.35 | 283.6 | 407.8 | 12.1 | 6.95 | 25.3 |
| 16. | Ops./$—Scientific | Kop/$ | 462.8 | 11.1 | 63971 | | | | | |
| 17. | Commercial | Kop/$ | 1079.1 | 39.5 | 53496.3 | 2368 | 1150 | 10890 | 24425 | 11262 |
| 18. | Memory Bit Rate | bit/μsec | 1.111 | 4.44 | 32.0 | 5.3 | 5.3 | 61.8 | 32.0 | 105.2 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.—Type | | I | IX | V | I | I | VIIA | VIIIR | VI |
| 20. | Rental | $k/mo | 2.78 | .925 | 11.72 | 2.117 | 1.245 | 31.06 | 63.59 | 16.83 |
| 21. | Performance—F1 | min | - | | 1.5 | | | | | 1.5 |
| 22. | F3 | min | 67 | | 20 | | | | | 20 |
| 23. | Random Access | min | - | | - | | | | 1.8 | 18 |
| 24. | Sorting | min | - | | 55 | | | | | 10 |
| 25. | Matrix Inv.—10 | min | - | .045 | .0017 | | | | | .0012 |
| 26. | Matrix Inv.—40 | min | - | 2.6 | .10 | | | | | .05 |
| 27. | P1 | ms | - | 2800 | 100 | | | | | 120 |
| 28. | P3 | ms | - | 8900 | 280 | | | | | 300 |
| 29. | Largest Config.—Type | | II | I | VIIA | IVR | IIIR | VIIIA | VIIIA | VIIIA |
| 30. | Rental | $k/mo | 3.56 | 1.275 | 14.53 | 4.427 | 1.585 | 40.33 | 67.75 | 28.901 |
| 31. | Performance—F1 | min | 6.0 | | .38 | | | | .21 | .38 |
| 32. | F3 | min | 21 | | 20 | | | | .28 | .16 |
| 33. | Random Access | min | 32 | | | | | | | 1.4 |
| 34. | Sorting | min | 10 | | 28 | | | | 1.5 | 1.8 |
| 35. | Matrix Inv.—10 | min | - | .045 | .0017 | | | | .00008 | .0012 |
| 36. | Matrix Inv.—40 | min | - | 2.6 | .10 | | | | .0043 | .05 |
| 37. | P1 | ms | - | 640 | 100 | | | | 9 | 60 |
| 38. | P3 | ms | - | 6700 | 280 | | | | 20 | 300 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 5.58 | 197.8 | 117.0 | 238.0 | 66.8 | 31.5 | 109.9 | 27.81 |
| 40. | Datamation (CresM63) | Kops | | - | - | - | - | - | - | - |
| 41. | Adams Addition Rate | Kops | 17.2 | 125.0 | 571.4 | 38.5 | 38.5 | 8696 | 12500 | 476.2 |
| 41a. | Processor Ops./$ | kop/$ | 11232 | 90.1 | 200521 | 9267 | 4888 | 28106 | 61733 | 26493 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed—Add | | .067 | 3.75 | | 1.15 | 1.15 | 30.2 | 187.5 | 14.0 |
| 43. | Multiply | | .048 | 9.04 | | | | 24.4 | 301.3 | 11.7 |
| 44. | Weighted Opns/sec. | | .073 | 4.57 | 10.4 | | | 10.6 | 75.7 | 3.65 |
| 45. | Knight Index—Scientific | | .243 | .002 | 129.2 | | | | | |
| 46. | Commercial | | .263 | .003 | 50.2 | | | | | |
| 47. | Time Per Dollar | | .304 | .105 | 1.17 | | | | | |
| 48. | Scientific Opns/$ | | .810 | .019 | 110.6 | | | | | |
| 49. | Commericial Opns/$ | | .866 | .032 | 42.9 | | | | | |
| 50. | Memory Bit Rate | | .208 | .833 | 6.0 | 1.0 | 1.0 | 11.6 | 6.0 | 21.8 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.—F1 | | - | | 1.0 | | | | | 1.0 |
| 52. | F3 | | .299 | | 1.0 | | | | | 1.0 |
| 53. | Random Access | | - | | - | | | | 13.9 | 1.39 |
| 54. | Sorting | | - | | .167 | | | | | .92 |
| 55. | Matrix Inv.—10 | | - | .556 | 14.7 | | | | | 20.8 |
| 56. | Matrix Inv.—40 | | - | .462 | 12.0 | | | | | 24.0 |
| 57. | P1 | | - | .036 | 1.0 | | | | | .833 |
| 58. | P3 | | - | .475 | 15.1 | | | | | 14.1 |
| 59. | Large Config.—F1 | | .25 | | 3.95 | | | | 7.14 | 3.95 |
| 60. | F3 | | .952 | | 1.0 | | | | 71.4 | 1.25 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>360/20 | IBM<br>1130 | IBM<br>360/44 | IBM<br>S3/10 | IBM<br>S3/6 | IBM<br>370/155 | IBM<br>370/165 | IBM<br>370/145 |
|---|---|---|---|---|---|---|---|---|---|---|
| 61. | Random Access | | .781 | | | | | | | 17.9 |
| 62. | Sorting | | .920 | | .329 | | | | 6.13 | 5.11 |
| 63. | Matrix Inv.–10 | | - | .556 | 14.7 | | | | 312.5 | 20.8 |
| 64. | Matrix Inv.–40 | | - | .462 | 12.0 | | | | 279.1 | 24.0 |
| 65. | P1 | | - | .156 | 1.0 | | | | 11.1 | 1.67 |
| 66. | P3 | | - | .631 | 15.1 | | | | 211.5 | 14.1 |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | .221 | 7.83 | 4.63 | 9.43 | 2.65 | 1.25 | 4.35 | 1.10 |
| 68. | Adams Addition Rate | | .688 | 5.0 | 22.9 | 1.54 | 1.54 | 347.8 | 500.0 | 19.0 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | | | | | | IC |
| 70. | Bits Per Access | | 4 | 16 | 32 | 8 | 8 | 128 | 64 | 64 |
| 71. | Cycle Time | μsec. | 3.6 | 3.6 | 1.0 | 1.52 | 1.52 | 2.07 | 2.0 | .608 |
| 72. | Minimum Size | kwords | - | 4K | 8K | 8K | 8K | 256K | | |
| 73. | Bytes | kbytes | 4K | 8K | 32K | 8K | 8K | 256K | 512K | 160K |
| 74. | Maximum Size | kwords | - | 32K | 64K | 48K | 16K | 2048K | | |
| 75. | Bytes | kbytes | 16K | 64K | 256K | 48K | 16K | 2048K | 3072K | 1024K |
| 76. | Increment Size | kbytes | 4K | 8K | 64K | 8K | 8K | 256K | 512K | 256K |
| 77. | Price | $k | 11.64 | 8.15 | 75.7 | 5.93 | 6.5 | 132 | 269.1 | 127.2 |
| 78. | Rental | $k/mo | .25 | .205 | 1.60 | .227 | .23 | 3.0 | 6.11 | 2.65 |
| 79. | Maintenance | $/mo | 6 | 5 | 30 | 4 | 5 | 290 | 590 | 170 |
| 80. | Price Per Byte | $/by | 2.84 | 0.99 | 1.16 | 0.72 | 0.79 | 0.50 | .51 | .49 |
| 81. | Maint. Cost Per $100k | $/mo | 51.5 | 61.3 | 39.6 | 67.5 | 76.9 | 219.6 | 219.2 | 133.6 |
| 82. | Price: Rental Ratio | | 46.6 | 39.8 | 47.3 | 26.1 | 28.3 | 44.0 | 44.0 | 48.0 |
| | **Processor–Sys. Price** | | | | | | | | | |
| 84. | Processor–Price | $k | 23.57 | 25.88 | 119.9 | 16.11 | 28.75 | 1091.0 | 1974.7 | 583.4 |
| 85. | Rental | $k/mo | .500 | .600 | 3.47 | .328 | .590 | 22.98 | 41.64 | 12.16 |
| 86. | Maintenance | $/mo. | 37 | 70 | 200 | 38 | 125 | 2020 | 3550 | 1070 |
| 87. | Memory Included | kbytes | 4K | 8K | 32K | 8K | 8K | 256K | 512K | 160K |
| 88. | Processor Alone–Price | $k | 11.93 | 17.73 | 82.05 | 10.18 | 22.25 | 959 | 1705.6 | 503.9 |
| 89. | Rental | $k/mo | .25 | .395 | 2.67 | .101 | .360 | 19.98 | 35.53 | 10.50 |
| 90. | Maintenance | $/mo | 31 | 65 | 185 | 34 | 120 | 1730 | 2960 | 964 |
| 91. | Maint. Per $100k | $/mo | 259.8 | 366.6 | 225.4 | 334.0 | 529.3 | 180.4 | 173.5 | 191.3 |
| 92. | Price: Rental Ratio | | 47.7 | 44.9 | 30.7 | 100.8 | 61.8 | 48.0 | 48.0 | 48.0 |
| 93. | System Rentals–*EDP/IR* | $k/mo | 2.8 | 1.55 | 11.0 | 2.2 | 1.53 | 51.7 | 89.8 | 24.7 |
| 94. | Adams | $k/mo | 1.7 | 0.9 | 10.0 | 1.7 | 1.8 | 51.5 | 96.5 | 21.6 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone–Price | | .302 | .449 | 2.08 | .258 | .564 | 24.29 | 43.20 | 12.76 |
| 96. | Rental | | .303 | .479 | 3.24 | .122 | .436 | 2422 | 43.07 | 12.73 |
| 97. | Maint. Per $100k | | 1.25 | 1.77 | 1.09 | 1.61 | 2.60 | .869 | .835 | .860 |
| 98. | System Rental–*EDP/IR* | | .318 | .176 | 1.25 | .193 | .174 | 5.85 | 10.20 | 2.81 |
| 98a. | Auerbach–Smallest | | .399 | .133 | 1.68 | .304 | .179 | 4.46 | 9.14 | 2.42 |
| 98b. | Auerbach–Largest | | .511 | .183 | 2.00 | .636 | .228 | 5.79 | 9.73 | 4.15 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor–Weight | lb. | | 500 | 2900 | 1000 | 1300 | 4710 | 4860 | 3240 |
| 100. | Floor Space | $ft.^2$ | | 11.7 | 20.7 | 7.3 | 7.8 | 25.0 | 32.7 | 28.9 |
| 101. | Volume | $ft.^3$ | | 31.1 | 124.0 | 27.5 | 39.2 | 125.0 | 212.5 | 144.7 |
| 102. | Electrical Load | kva | | 1.4 | 5.3 | 2.6 | 2.5 | 15.0 | | 17.2 |
| 103. | Heat Dissipation | kBTU/hr. | | 3.8 | 15.0 | 7.3 | 8.3 | 44.2 | 163.54 | 49.8 |
| 104. | Density–Weight | $lb/ft.^3$ | | 16.1 | 23.4 | 36.4 | 33.2 | 37.7 | 22.9 | 22.4 |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | .122 | .121 | .265 | .212 | .354 | .769 | .344 |
| 106. | Price Per Pound | $/lb. | | 51.8 | 41.3 | 16.1 | 22.1 | 203.6 | 350.9 | 180.0 |
| 107. | Memory Weight | lbs. | | incl. | incl. | incl. | incl. | 1800 | 4000 | incl. |
| 108. | Floor Space | $ft.^2$ | | | | | | 13.8 | 27.6 | |
| 109. | Volume | $ft.^3$ | | | | | | 68.9 | 160.7 | |
| 110. | Electrical Load | kva | | | | | | 4.5 | 9.2 | |
| 111. | Heat Dissipation | kBTU/hr. | | | | | | 13.5 | 27.3 | |
| 112. | Density–Weight | $lbs/ft.^3$ | - | | | | | 26.1 | 24.9 | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | | | | | .196 | .170 | |
| 114. | Capy. Per Floor Sp. | $kBy./ft^2$ | - | | | | | 18996 | 19.0 | |
| 115. | Capy. Per Vol. | $kBy./ft^3$ | - | | | | | 3.72 | 3.19 | |
| 116. | Price Per Pound | $/lb. | | | | | | 73.3 | 67.3 | |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>370/135 | IBM<br>370/125 | IBM<br>S3/15 | IBM<br>370/115 | BGH<br>205 | BGH<br>220 | BGH<br>200 | BGH<br>5500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 5/72 | 6/73 | 3/74 | 4/74 | 1/54 | 10/58 | 11/61 | 11/64 |
| 2. | **Processor Performance** | | | | | | dec. | dec. | dec. | |
| 3. | Word Length | bits | 32D | 16D | 8D | 16D | 44 | 44 | 6D | 48 |
| 4. | Memory Cycle Time | μsec. | .935 | .48 | 1.52 | .48 | 8500 | 10 | 6 | 4 |
| 5. | Raw Speed—Add | μsec. | 4.21 | 9.65 | 26 | 14.5 | 1100 | 200 | 414 | 1 |
| 6. | Multiply | μsec. | 25.52 | 134.2 | 3200 | 226.1 | 9300 | 2070 | 3348 | 32 |
| 7. | Add (Gille) | μsec. | | | | | 1920 | 185 | - | - |
| 8. | Multiply (Gille) | μsec. | | | | | 8820 | 1500 | - | - |
| 9. | Five Dec. Dig.—c=a+b | μsec. | 86.8 | | - | - | - | - | 414 | 17 |
| 10. | c=ab | μsec. | 410 | | | | - | - | 3762 | 44 |
| 11. | Addition Rate | Kops | 11.5 | | 38.5 | 69.0 | .52 | 5.40 | 2.4 | 58.8 |
| 12. | Weighted Opns/sec. | Kops | 9.7 | | 5.4 | 39.9 | .44 | 3.98 | 1.7 | 54.5 |
| 13. | Knight Index—Scientific | Kops | - | - | | | .081 | .810 | .163 | 376.3 |
| 14. | Commercial | Kops | 172.2 | 70.4 | 15.24 | 38.93 | .187 | 1.62 | .615 | 544.2 |
| 15. | Time Per Dollar | Sec/$ | 46.2 | 63.7 | 134.2 | 83.76 | 77.94 | 79.94 | 95.93 | 20.78 |
| 16. | Ops./$—Scientific | Kop/$ | - | - | | | 6.3 | 64.8 | 15.6 | 7813.3 |
| 17. | Commercial | Kop/$ | 7959 | 4483 | 2045 | 3261 | 14.6 | 129.5 | 59.0 | 11,308.5 |
| 18. | Memory Bit Rate | bit/μsec | 32.8 | 33.3 | 5.3 | 33.3 | .005 | 4.4 | 1.0 | 12 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.—Type | | III | | | | | | I | III |
| 20. | Rental | $k/mo | 11.6 | | | | | | 4.40 | 23.34 |
| 21. | Performance—F1 | min | 1.7 | | | | | | - | 1.2 |
| 22. | F3 | min | 20 | | | | | | 67 | 19 |
| 23. | Random Access | min | 27 | | | | | | | - |
| 24. | Sorting | min | 10 | | | | | | | - |
| 25. | Matrix Inv.—10 | min | .002 | | | | | | | .0025 |
| 26. | Matrix Inv.—40 | min | .14 | | | | | | | .14 |
| 27. | P1 | ms | 130 | | | | | | | 74 |
| 28. | P3 | ms | 600 | | | | | | | 330 |
| 29. | Largest Config.—Type | | IV | | | | | | III | VIIB |
| 30. | Rental | $k/mo | 14.6 | | | | | | 8.99 | 28.71 |
| 31. | Performance—F1 | min | .38 | | | | | | 1.5 | .55 |
| 32. | F3 | min | 16 | | | | | | 21 | 1.8 |
| 33. | Random Access | min | 18 | | | | | | - | - |
| 34. | Sorting | min | 2.2 | | | | | | 18 | 2.8 |
| 35. | Matrix Inv.—10 | min | .002 | | | | | | | .0025 |
| 36. | Matrix Inv.—40 | min | .14 | | | | | | | .14 |
| 37. | P1 | ms | 50 | | | | | | | 9.5 |
| 38. | P3 | ms | 600 | | | | | | | 330 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 38.36 | | 18.97 | 15.45 | 4.11 | | 84.46 | |
| 40. | Datamation (CresM63) | Kops | - | - | | | .140 | 1.37 | .631 | - |
| 41. | Adams Addition Rate | Kops | 238.1 | | | 62.5 | | | | 500.0 |
| 41a. | Processor Ops./$ | kop/$ | 27766 | - | 7518 | 8723 | 29.9 | 133.0 | - | 45889 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed—Add | | 7.13 | | 1.15 | 2.07 | .027 | .150 | .072 | 30 |
| 43. | Multiply | | 9.21 | | 0.073 | 1.04 | .025 | .114 | .070 | 7.34 |
| 44. | Weighted Opns/sec. | | 1.08 | | .599 | 4.43 | .049 | .442 | .189 | 6.05 |
| 45. | Knight Index—Scientific | | | | | | .010 | .102 | .021 | 47.4 |
| 46. | Commercial | | | | .891 | 2.28 | .011 | .095 | .036 | 31.8 |
| 47. | Time Per Dollar | | | | .543 | .870 | .935 | .912 | .760 | 3.51 |
| 48. | Scientific Opns/$ | | | | | | .011 | .112 | .027 | 13.5 |
| 49. | Commericial Opns/$ | | | | 1.64 | 2.62 | .012 | .104 | .047 | 9.07 |
| 50. | Memory Bit Rate | | 7.8 | 6.25 | 1.00 | 6.25 | .0009 | .825 | .188 | 2.25 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.—F1 | | .882 | | | | | | | 1.25 |
| 52. | F3 | | 1.0 | | | | | | .299 | 1.05 |
| 53. | Random Access | | .926 | | | | | | | - |
| 54. | Sorting | | 2.5 | | | | | | | - |
| 55. | Matrix Inv.—10 | | 12.5 | | | | | | | 10.0 |
| 56. | Matrix Inv.—40 | | 8.57 | | | | | | | 8.57 |
| 57. | P1 | | .769 | | | | | | | 1.35 |
| 58. | P3 | | 7.05 | | | | | | | 12.8 |
| 59. | Large Config.—F1 | | 3.95 | | | | | | 1.0 | 2.73 |
| 60. | F3 | | 1.25 | | | | | | .952 | 11.1 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | IBM<br>370/135 | IBM<br>370/125 | IBM<br>S3/15 | IBM<br>370/115 | BGH<br>205 | BGH<br>220 | BGH<br>200 | BGH<br>5500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 61. | Random Access | | 1.39 | | | | | | | - |
| 62. | Sorting | | 4.0 | | | | | | .511 | 3.29 |
| 63. | Matrix Inv.—10 | | 12.5 | | | | | | | 10.0 |
| 64. | Matrix Inv.—40 | | 8.57 | | | | | | | 8.57 |
| 65. | P1 | | 2.0 | | | | | | | 10.5 |
| 66. | P3 | | 7.05 | | | | | | | 12.8 |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | 1.52 | | | | | .016 | | 3.34 |
| 68. | Adams Addition Rate | | 9.52 | | | | | | | 20.0 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | IC | IC | IC | IC | drum | | | |
| 70. | Bits Per Access | | 32 | 16 | 8 | 16 | 44 | 44 | 6 | 48 |
| 71. | Cycle Time | µsec. | .935 | 0.48 | 1.52 | 0.48 | 8500 | 10 | 6 | 4 |
| 72. | Minimum Size | kwords | | | 48K | | 4.08 | 2 | 4.8 | 4K |
| 73. | Bytes | kbytes | 96K | 96K | 48K | 64K | 20.4 | 10 | 4.8 | 32K |
| 74. | Maximum Size | kwords | | | 256K | | 4.08 | 10 | 19.2 | 32K |
| 75. | Bytes | kbytes | 512K | 256K | 256K | 256K | 20.4 | 50 | 19.2 | 256K |
| 76. | Increment Size | kbytes | 96K | 32K | 16K | 32K | - | 25 | | 32K |
| 77. | Price | $k | 88.05 | 9.7 | 4.16 | 8.35 | - | 18.0 | | 60.2 |
| 78. | Rental | $k/mo | 1.80 | .20 | .115 | .225 | - | 0.5 | | 1.45 |
| 79. | Maintenance | $/mo | 60 | 5 | 5 | 5 | | - | | 60 |
| 80. | Price Per Byte | $/by | .90 | .30 | 0.254 | 0.254 | - | 0.72 | - | 1.84 |
| 81. | Maint. Cost Per $100k | $/mo | 68.1 | 51.5 | 120.2 | 59.88 | - | - | - | 99.7 |
| 82. | Price: Rental Ratio | | 48.9 | 48.5 | 36.2 | 37.1 | - | 36.0 | - | 41.5 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 281.23 | 231.6 | 65.51 | 122.15 | 135 | 320 | | 487.6 |
| 85. | Rental | $k/mo | 5.67 | 4.775 | 1.61 | 3.235 | 3.9 | 7.8 | | 11.75 |
| 86. | Maintenance | $/mo. | 460 | 290 | 227 | 294 | - | - | | 445 |
| 87. | Memory Included | kbytes | 96K | 96K | 48K | 64K | 20.4 | 10 | | 96K |
| 88. | Processor Alone—Price | $k | 193.18 | 202.5 | 53.03 | 105.45 | - | 312.8 | | 307.0 |
| 89. | Rental | $k/mo | 3.87 | 4.175 | 1.265 | 2.785 | - | 7.6 | | 7.4 |
| 90. | Maintenance | $/mo | 400 | 275 | 212 | 284 | - | - | | 265 |
| 91. | Maint. Per $100k | $/mo | 207.1 | 135.8 | 399.8 | 269.3 | | - | | 86.3 |
| 92. | Price: Rental Ratio | | 50.0 | 48.5 | 41.9 | 37.9 | | 41.1 | | 41.5 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 13.5 | 9.8 | 4.65 | 7.45 | 4.6 | 14.0 | 5.4 | 22.0 |
| 94. | Adams | $k/mo | 18.2 | - | 3.0 | 6.0 | - | - | - | 22.5 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone—Price | | 4.89 | 5.13 | 1.34 | 2.67 | | 7.92 | | 7.78 |
| 96. | Rental | | 4.69 | 5.06 | 1.53 | 3.38 | | 9.21 | | 8.97 |
| 97. | Maint. Per $100k | | .997 | .654 | 1.92 | 1.30 | | | | .416 |
| 98. | System Rental—*EDP/IR* | | 1.53 | 1.11 | .528 | .847 | .523 | 1.59 | .614 | 2.5 |
| 98a. | Auerbach—Smallest | | 1.67 | | | | | | .632 | 3.35 |
| 98b. | Auerbach—Largest | | 2.10 | | | | | | 1.29 | 4.13 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | 1440 | 1325 | | | 3175 | 2800 | | |
| 100. | Floor Space | ft.$^2$ | 14.9 | 13.6 | | | 28.0 | 31.8 | | |
| 101. | Volume | ft.$^3$ | 74.6 | 67.8 | | | 175.0 | 201.5 | | |
| 102. | Electrical Load | kva | 9.46 | 4.5 | | | 16.5 | 12.0 | | |
| 103. | Heat Dissipation | kBTU/hr. | 28.88 | 12.4 | | | 56.1 | 41.0 | | |
| 104. | Density—Weight | lb/ft.$^3$ | 19.3 | 19.5 | | | 18.1 | 13.9 | | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | .387 | .182 | | | .321 | .203 | | |
| 106. | Price Per Pound | $/lb. | 195.3 | 174.8 | | | 42.5 | 114.3 | | |
| 107. | Memory Weight | lbs. | incl. | incl. | | | incl. | incl. | | |
| 108. | Floor Space | ft.$^2$ | | | | | | | | |
| 109. | Volume | ft.$^3$ | | | | | | | | |
| 110. | Electrical Load | kva | | | | | | | | |
| 111. | Heat Dissipation | kBTU/hr. | | | | | | | | |
| 112. | Density—Weight | lbs/ft.$^3$ | - | | | | | | | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | | | | | | | |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | - | | | | | | | |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | - | | | | | | | |
| 116. | Price Per Pound | $/lb. | | | | | | | | |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item Manufacturers: Model Numbers: | Units | BGH 3500 | BGH 500 | CDC G-15 | CDC LGP-30 | CDC 160A | CDC 1604 | CDC 3600 | CDC 6600 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 5/67 | 11/68 | 7/55 | 9/56 | 7/61 | 1/60 | 6/63 | 8/64 |
| 2. | **Processor Performance** | | dec | dec | bin | bin | bin. | bin. | bin. | bin. |
| 3. | Word Length | bits | 16D | 6D | 29 | 32 | 12 | 48 | 48 | 60 |
| 4. | Memory Cycle Time | μsec. | 1.0 | 6 | 14500 | 7500 | 6.4 | 4.8 | 1.5 | 1.0 |
| 5. | Raw Speed—Add | μsec. | 32 | 414 | 15120 | 2000 | 16.0 | 7.2 | 2.1 | .333 |
| 6. | Multiply | μsec. | 200 | 3348 | 31280 | 17000 | 120 | 29.2 | 4.3 | 1.0 |
| 7. | Add (Gille) | μsec. | | | 1080 | 2260 | - | 14.2 | - | - |
| 8. | Multiply (Gille) | μsec. | | | 20790 | 17600 | - | 38.0 | - | - |
| 9. | Five Dec. Dig.—c=a+b | μsec. | 37.5 | 414 | - | - | 480 | 21.6 | 6.0 | 0.3 |
| 10. | c=ab | μsec. | 208.0 | 3762 | - | - | 7700 | 39.6 | 10.3 | 1.9 |
| 11. | Addition Rate | Kops | 26.7 | 2.42 | 0.66 | .44 | 2.1 | 46.3 | 166.7 | 3333.3 |
| 12. | Weighted Opns/sec. | Kops | 21.7 | 1.72 | .062 | .33 | 1.2 | 44.4 | 161.0 | 2631.6 |
| 13. | Knight Index—Scientific | Kops | 154.84 | | .057 | .042 | 1.015 | 58.3 | 315.9 | 7020 |
| 14. | Commercial | Kops | 130.25 | | .030 | .033 | 1.780 | 20.4 | 74.9 | 4090 |
| 15. | Time Per Dollar | Sec/$ | 69.31 | 164.2 | 419.9 | 479.6 | 138.6 | 18.34 | 11.34 | 8.31 |
| 16. | Ops./$—Scientific | Kop/$ | 10732 | | 23.9 | 20.1 | 140.7 | 1069.2 | 3582.3 | 58,336.2 |
| 17. | Commercial | Kop/$ | 9028 | | 12.6 | 15.8 | 246.7 | 374.1 | 849.4 | 33,988.0 |
| 18. | Memory Bit Rate | bit/μsec | 16 | 1 | .002 | .004 | 1.875 | 7.5 | 32 | 60 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.—Type | | IVR | II | - | IX | IX | VI | VIIB | VIIA |
| 20. | Rental | $k/mo | 11.06 | 3.96 | | 1.100 | 2.902 | 43.80 | 58.60 | 58.05 |
| 21. | Performance—F1 | min | | 2.2 | | | - | .95 | .19 | 0.38 |
| 22. | F3 | min | | 19 | | - | - | 40 | 1.2 | 2.00 |
| 23. | Random Access | min | 21 | - | | - - | - | - | - | |
| 24. | Sorting | min | - | 22 | - | - | - | 3.2 | 2.0 | 2.5 |
| 25. | Matrix Inv.—10 | min | - | - | - | 37 | .47 | .0013 | .0003 | .00003 |
| 26. | Matrix Inv.—40 | min | - | - | - | - | 19 | .075 | .017 | .0014 |
| 27. | P1 | ms | - | - | - | 58000 | 3000 | - | 6.0 | 13 |
| 28. | P3 | ms | - | - | - | - | 63000 | - | 61 | 13 |
| 29. | Largest Config.—Type | | VIIA | III | - | X | X | VIIB | VIIIB | VIIA |
| 30. | Rental | $k/mo | 16.00 | 5.95 | - | 1.365 | 4.212 | 46.13 | 73.91 | 71.20 |
| 31. | Performance—F1 | min | .37 | 1.4 | - | - | - | .45 | .19 | 0.12 |
| 32. | F3 | min | 18 | 19 | - | - | - | 2.3 | 1.0 | 1.00 |
| 33. | Random Access | min | - | - | - | - | - | - | - | - |
| 34. | Sorting | min | 2.5 | 9.5 | - | - | - | 3.2 | 1.4 | 1.3 |
| 35. | Matrix Inv.—10 | min | .013 | - | - | 37 | .07 | .0013 | .003 | .00003 |
| 36. | Matrix Inv.—40 | min | .75 | - | - | - | 3.7 | .075 | .017 | .0014 |
| 37. | P1 | ms | 78 | - | - | 50000 | 700 | 12 | 60 | 6.2 |
| 38. | P3 | ms | 3500 | - | - | - | 9200 | 270 | 61 | 6.2 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 11.17 | 1.85 | - | - | 44.64 | 4.34 | 22.89 | 52.87 |
| 40. | Datamation (CresM63) | Kops | - | - | - | - | 7.01 | 41.42 | 151.3 | - |
| 41. | Adams Addition Rate | Kops | 31.2 | 5.88 | - | - | 78.1 | - | 483.1 | 3333 |
| 41a. | Processor Ops./$ | kop/$ | 46550 | - | 12.2 | 18.7 | 1269 | 636.4 | 3595 | 71892 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed—Add | | .938 | .072 | .0020 | .015 | 1.875 | 4.17 | 14.29 | 90.1 |
| 43. | Multiply | | 1.18 | .070 | .0075 | .014 | 1.96 | 8.05 | 54.65 | |
| 44. | Weighted Opns/sec. | | 2.41 | .191 | .0069 | .037 | .133 | .488 | 17.86 | 554.8 |
| 45. | Knight Index—Scientific | | 19.50 | - | .007 | .005 | .128 | 7.34 | 39.79 | 884.1 |
| 46. | Commercial | | 7.62 | - | .002 | .002 | .104 | 1.19 | 4.38 | 239.2 |
| 47. | Time Per Dollar | | 1.05 | .444 | .174 | .152 | .526 | 3.97 | 6.43 | 8.77 |
| 48. | Scientific Opns/$ | | 18.55 | - | .041 | .035 | .243 | 1.85 | 6.19 | 100.8 |
| 49. | Commericial Opns/$ | | 7.24 | - | .010 | .013 | .198 | .300 | .682 | 27.3 |
| 50. | Memory Bit Rate | | 3.00 | 0.188 | .0004 | .0008 | .352 | 1.406 | 6.0 | 11.3 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.—F1 | | - | .68 | - | - | - | 1.58 | 7.89 | 3.95 |
| 52. | F3 | | - | 1.05 | - | - | - | .500 | 16.7 | 10.0 |
| 53. | Random Access | | 1.19 | - | - | - | - | - | - | - |
| 54. | Sorting | | - | .42 | - | - | - | 2.88 | 4.60 | 3.68 |
| 55. | Matrix Inv.—10 | | - | - | - | .001 | .053 | 19.2 | 83.3 | 833.3 |
| 56. | Matrix Inv.—40 | | - | - | - | - | .063 | 16.0 | 70.6 | 857.1 |
| 57. | P1 | | - | - | - | .002 | .033 | - | 16.7 | 7.69 |
| 58. | P3 | | - | - | - | - | .067 | - | 69.3 | 325.4 |
| 59. | Large Config.—F1 | | 4.05 | 1.07 | - | - | - | 3.33 | 7.89 | 7.80 |
| 60. | F3 | | 1.11 | 1.05 | - | - | - | 8.70 | 20.0 | 20.0 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item | Units | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturers: | | BGH | BGH | CDC | CDC | CDC | CDC | CDC | CDC |
| | Model Numbers: | | 3500 | 500 | G-15 | LGP-30 | 160A | 1604 | 3600 | 6600 |
| 61. | Random Access | | - | - | - | - | - | - | - | |
| 62. | Sorting | | 3.68 | .97 | - | - | - | 2.88 | 6.57 | 7.08 |
| 63. | Matrix Inv.—10 | | 1.92 | - | - | .001 | .357 | 19.2 | 8.33 | 833.3 |
| 64. | Matrix Inv.—40 | | 1.60 | - | - | - | .324 | 16.0 | 70.6 | 857.1 |
| 65. | P1 | | 1.28 | - | - | .002 | .143 | 8.33 | 16.7 | 16.13 |
| 66. | P3 | | 1.21 | - | - | - | .460 | 15.7 | 69.3 | 682.3 |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | - | - | - | - | 1.77 | .172 | .907 | 2.09 |
| 68. | Adams Addition Rate | | - | - | - | - | 3.12 | - | 19.3 | 133.3 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | drum | drum | | | | |
| 70. | Bits Per Access | | 16 | 6.0 | 29 | 32 | 12 | 48 | 48 | 60 |
| 71. | Cycle Time | μsec. | 1.0 | 6.0 | 14500 | 7500 | 6.4 | 6.4 | 1.5 | 1.0 |
| 72. | Minimum Size | kwords | 5.0 | 9.6 | 2.176 | 4K | 8K | 8K | 16K | 32K |
| 73. | Bytes | kbytes | 10.0 | 9.6 | 7.616 | 16K | 16K | 64K | 128K | 320K |
| 74. | Maximum Size | kwords | 250.0 | 19.2 | 2.176 | 4K | 32K | 32K | 256K | 128K |
| 75. | Bytes | kbytes | 500.0 | 19.2 | 7.616 | 16K | 64K | 256K | 2048K | 1280K |
| 76. | Increment Size | kbytes | 10.0 | 9.6K | - | - | 16K | 8K | 128K | 640K |
| 77. | Price | $k | 21.6 | 9.6 | - | - | 50.0 | 80 | 290 | 1660 |
| 78. | Rental | $k/mo | .45 | .20 | - | - | 1.25 | 2.5 | 7.455 | 18.0 |
| 79. | Maintenance | $/mo | 20 | 20 | - | - | 100 | - | 800 | 2050 |
| 80. | Price Per Byte | $/by | 2.16 | 0.98 | - | - | 3.05 | 9.77 | 2.21 | 2.53 |
| 81. | Maint. Cost Per $100k | $/mo | 92.6 | 208.3 | - | - | 200 | | 276 | 123.4 |
| 82. | Price: Rental Ratio | | 48.0 | 48.0 | - | - | 40.0 | 32.0 | 38.9 | 92.2 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 81.36 | 51.45 | 51.0 | 43.5 | 60.0 | 700 | 911.0 | 3450 |
| 85. | Rental | $k/mo | 1.746 | 1.015 | 1.53 | 1.10 | 1.5 | 22.5 | 13.0 | 53.5 |
| 86. | Maintenance | $/mo. | 140 | 120 | 500 | 146 | 200 | 1458 | 1855 | 7000 |
| 87. | Memory Included | kbytes | 0 | 9.6 | 7.616 | 16K | 8K | 8K | 0 | 640K |
| 88. | Processor Alone—Price | $k | 81.36 | 41.85 | - | - | 35.0 | 620.0 | 911.0 | 1790 |
| 89. | Rental | $k/mo | 1.746 | .815 | - | - | .875 | 20.0 | 13.0 | 35.5 |
| 90. | Maintenance | $/mo | 140 | 100 | - | - | 150 | - | 1855 | 4950 |
| 91. | Maint. Per $100k | $/mo | 172.1 | 238.9 | - | - | 429 | - | 204 | 277 |
| 92. | Price: Rental Ratio | | 46.6 | 51.3 | - | - | 40.0 | 31.0 | 70.1 | 50.4 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 14.7 | 3.8 | 1.0 | 1.3 | 3.4 | 45.0 | 58.0 | 110 |
| 94. | Adams | $k/mo | 16.2 | - | - | - | 5.65 | | 47.0 | 73.1 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone—Price | | 2.06 | 1.06 | - | - | .887 | 15.70 | 23.07 | 45.34 |
| 96. | Rental | | 2.12 | .988 | - | - | 1.06 | 24.24 | 15.76 | 43.03 |
| 97. | Maint. Per $100k | | .829 | 1.15 | | | 2.065 | | .982 | 1.32 |
| 98. | System Rental—*EDP/IR* | | 1.67 | .432 | .114 | .148 | .386 | 5.11 | 6.59 | 12.5 |
| 98a. | Auerbach—Smallest | | 1.59 | .57 | - | .156 | .417 | 6.29 | 8.42 | 8.34 |
| 98b. | Auerbach—Largest | | 2.30 | .85 | - | .196 | .605 | 6.63 | 10.62 | 10.23 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | | | 965 | 800 | 810 | 2200 | 4000 | |
| 100. | Floor Space | ft.$^2$ | | | 6.94 | 7.94 | 12.8 | 15.0 | 22.4 | |
| 101. | Volume | ft.$^3$ | | | 35.3 | 21.8 | 31.0 | 82.5 | 139.8 | |
| 102. | Electrical Load | kva | | | 4.4 | 1.5 | 2.86 | 5.0 | 4.7 | |
| 103. | Heat Dissipation | kBTU/hr. | | | 14.3 | 5.0 | - | 13.7 | 17 | |
| 104. | Density—Weight | lb/ft.$^3$ | | | 27.3 | 36.7 | 26.1 | 26.7 | 28.6 | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | | .405 | .229 | - | .166 | .122 | |
| 106. | Price Per Pound | $/lb. | | | 52.8 | 54.4 | 74.1 | 318.2 | 227.8 | |
| 107. | Memory Weight | lbs. | | | incl. | incl. | incl. | incl. | 1100 | |
| 108. | Floor Space | ft.$^2$ | | | | | - | - | 44.4 | |
| 109. | Volume | ft.$^3$ | | | | | - | - | 277.7 | |
| 110. | Electrical Load | kva | | | | | - | - | 2.3 | |
| 111. | Heat Dissipation | kBTU/hr. | | | | | - | - | 8.0 | |
| 112. | Density—Weight | lbs/ft.$^3$ | | | | | - | - | 3.96 | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | | | | - | - | .029 | |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | | | | | - | - | 2.95 | |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | | | | | - | | .461 | |
| 116. | Price Per Pound | $/lb. | | | | | - | | 72.5 | |

### TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | CDC<br>Cyb/76 | DEC<br>PDP-8 | DEC<br>PDP-11 | GE<br>225 | GE<br>115 | HIS<br>800 | HIS<br>200 | HIS<br>120 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 3/72 | 5/65 | 4/70 | 4/61 | 12/65 | 12/60 | 3/64 | 1/66 |
| 2. | **Processor Performance** | | bin. | bin. | bin. | dec. | | | | |
| 3. | Word Length | bits | 60 | 12 | 16 | 20 | 8 | 48 | 6D | 6D |
| 4. | Memory Cycle Time | μsec. | .275 | 1.5 | 1.2 | 18 | 6.5 | 6.0 | 2.0 | 3.0 |
| 5. | Raw Speed—Add | μsec. | .055 | 3.0 | 2.4 | 36 | 114 | 18 | 48 | 69 |
| 6. | Multiply | μsec. | .1375 | | | 288 | 21100 | 200 | 374 | 3100 |
| 7. | Add (Gille) | μsec. | | | | 36 | | 24 | - | - |
| 8. | Multiply (Gille) | μsec. | | | | 225 | | 162 | - | - |
| 9. | Five Dec. Dig.—c=a+b | μsec. | .55 | | | 108 | 110 | 24 | 84 | 123 |
| 10. | c=ab | μsec. | - | | | 474 | 4365 | 200 | 480 | 3100 |
| 11. | Addition Rate | Kops | 1818 | 333.3 | 416.6 | 9.25 | 9.09 | 41.7 | 11.9 | 8.1 |
| 12. | Weighted Opns/sec. | Kops | - | - | - | 8.10 | 3.10 | 30.5 | 9.6 | 3.7 |
| 13. | Knight Index—Scientific | Kops | | 1.77 | | 6.57 | | 28.8 | 1.15 | 2.11 |
| 14. | Commercial | Kops | 10,220 | .99 | | 7.13 | | 23.8 | 7.03 | 9.53 |
| 15. | Time Per Dollar | Sec/$ | 3.78 | 230.9 | | 77.94 | | 14.85 | 103.9 | 190.0 |
| 16. | Ops./$—Scientific | Kop/$ | | 408.7 | | 512.1 | | 427.7 | 119.5 | 400.9 |
| 17. | Commercial | Kop/$ | 38,632 | 228.6 | | 555.7 | | 353.4 | 730.4 | 1810.7 |
| 18. | Memory Bit Rate | bit/μsec | 218 | 8.0 | 13.3 | 1.11 | 1.23 | 8.0 | 3.0 | 2.0 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.—Type | | | | | I | | VI | II | II |
| 20. | Rental | $k/mo | | | | 5.12 | | 20.33 | 4.42 | 3.34 |
| 21. | Performance—F1 | min | | | | - | | 0.6 | 3.4 | 4 |
| 22. | F3 | min | | | | 67 | | 17 | 21 | 29 |
| 23. | Random Access | min | | | | - | | - | - | - |
| 24. | Sorting | min | | | | - | | 6.3 | 34 | 41 |
| 25. | Matrix Inv.—10 | min | | | | 0.31 | | .003 | | |
| 26. | Matrix Inv.—40 | min | | | | 15 | | 0.17 | - | - |
| 27. | P1 | ms | | | | - | | 90 | - | - |
| 28. | P3 | ms | | | | - | | 600 | - | - |
| 29. | Largest Config.—Type | | | | | IV | | VIIIA | IV | III |
| 30. | Rental | $k/mo | | | | 19.32 | | 54.0 | 14.19 | 5.89 |
| 31. | Performance—F1 | min | | | | 0.8 | | 0.2 | 0.39 | 2.1 |
| 32. | F3 | min | | | | 18 | | 17 | 17 | 29 |
| 33. | Random Access | min | | | | - | | - | - | - |
| 34. | Sorting | min | | | | 8.5 | | 1.5 | 2.8 | 10 |
| 35. | Matrix Inv.—10 | min | | | | 0.31 | | .003 | - | - |
| 36. | Matrix Inv.—40 | min | | - | | 15 | | 0.17 | - | - |
| 37. | P1 | ms | | | | | | 72 | - | - |
| 38. | P3 | ms | | | | | | .600 | - | - |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 280.8 | 757.6 | 10417 | 13.35 | | 4.98 | 14.95 | 11.84 |
| 40. | Datamation (CresM63) | Kops | | | | 5.54 | | 16.89 | - | - |
| 41. | Adams Addition Rate | Kops | 36,364 | 333.3 | 434.8 | 27.8 | 6.76 | 41.7 | 22.7 | 15.2 |
| 41a. | Processor Ops./$ | kop/$ | 157,853 | 2246 | - | 3422 | - | 2130 | 5036 | 7773 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed—Add | | 545.5 | 10.0 | 12.5 | .833 | .263 | 1.67 | .625 | .435 |
| 43. | Multiply | | 1709 | | | .816 | .011 | 1.18 | .628 | .076 |
| 44. | Weighted Opns/sec. | | | | | .899 | .344 | 3.38 | 1.07 | .411 |
| 45. | Knight Index—Scientific | | | .223 | | .827 | | 3.63 | .145 | .266 |
| 46. | Commercial | | 2530 | .058 | | .417 | | 1.39 | .411 | .557 |
| 47. | Time Per Dollar | | 19.28 | .316 | | .935 | | 4.91 | .701 | .384 |
| 48. | Scientific Opns/$ | | | .706 | | .885 | | .739 | .207 | .693 |
| 49. | Commericial Opns/$ | | 1314 | .183 | | .446 | | .284 | .586 | 1.45 |
| 50. | Memory Bit Rate | | 40.88 | 1.50 | 2.50 | .208 | .231 | 4.29 | .563 | .375 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.—F1 | | | | | | | 2.50 | .441 | .375 |
| 52. | F3 | | | | | .289 | | 1.18 | .952 | .690 |
| 53. | Random Access | | | - | - | - | - | - | - | - |
| 54. | Sorting | | | | | | | 1.46 | .271 | .224 |
| 55. | Matrix Inv.—10 | | | | | .081 | | 8.33 | - | - |
| 56. | Matrix Inv.—40 | | | | | .080 | | 70.6 | - | - |
| 57. | P1 | | | | | | | 1.11 | | |
| 58. | P3 | | | | | | | 7.05 | | |
| 59. | Large Config.—F1 | | | | | 1.875 | | 7.50 | 3.85 | .714 |
| 60. | F3 | | | | | 1.110 | | 1.18 | 1.18 | .690 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item Manufacturers: Model Numbers: | Units | CDC Cyb/76 | DEC PDP-8 | DEC PDP-11 | GE 225 | GE 115 | HIS 800 | HIS 200 | HIS 120 |
|---|---|---|---|---|---|---|---|---|---|---|
| 61. | Random Access | | | | | | | - | - | - |
| 62. | Sorting | | | | | 1.08 | | 6.13 | 3.29 | .920 |
| 63. | Matrix Inv.—10 | | | | | .081 | | 8.33 | | |
| 64. | Matrix Inv.—40 | | | | | .080 | | 70.6 | | |
| 65. | P1 | | | | | | | 1.39 | | |
| 66. | P3 | | | | | | | 7.05 | | |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | | 30.00 | 412.6 | .829 | | .197 | .592 | .469 |
| 68. | Adams Addition Rate | | | 13.33 | 17.39 | 1.11 | .270 | 1.67 | .908 | .608 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | | | | | | |
| 70. | Bits Per Access | | 60 | 12 | 16 | 20 | 8 | 48 | 6 | 6 |
| 71. | Cycle Time | µsec. | .275 | 1.5 | 1.2 | 18 | 6.5 | 6 | 2.0 | 3.0 |
| 72. | Minimum Size | kwords | 288 | 4K | 4K | 4K | 4K | 4K | 4K | 2K |
| 73. | Bytes | kbytes | 2880 | 8K | 8K | 12K | 4K | 32K | 4K | 2K |
| 74. | Maximum Size | kwords | 577 | 32K | 32K | 16K | 16K | 7K | 64K | 32K |
| 75. | Bytes | kbytes | 5770 | 64K | 64K | 48K | 16K | 56K | 64K | 32K |
| 76. | Increment Size | kbytes | 320K | 8K | 8K | 12K | | 32K | 4K | 2K |
| 77. | Price | $k | 640.0 | 10.0 | 3.0 | 30 | | 76.8 | 10.8 | 5.4 |
| 78. | Rental | $k/mo | 14.60 | - | | 0.6 | | 1.61 | .266 | .121 |
| 79. | Maintenance | $/mo | 1400 | - | 25 | - | | 97 | 15 | 9 |
| 80. | Price Per Byte | $/by | 1.95 | 1.22 | .367 | 2.44 | | 2.34 | 2.64 | 2.64 |
| 81. | Maint. Cost Per $100k | $/mo | 218.8 | | 833.3 | - | | 126 | 139 | 167 |
| 82. | Price: Rental Ratio | | 43.8 | | | 50.0 | | 47.7 | 40.6 | 44.6 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 4100 | 21 | 7.0 | 135 | | 410.4 | 46.44 | 37.155 |
| 85. | Rental | $k/mo | 82.0 | - | - | 1.9 | | 8.584 | 1.137 | .886 |
| 86. | Maintenance | $/mo. | 12720 | - | 65 | - | | 510 | 92 | 95 |
| 87. | Memory Included | kbytes | 2880 | 4K | 16K | 12K | | 32K | 4K | 2K |
| 88. | Processor Alone—Price | $k | 2180 | 11 | 1.0 | 105 | | 333.6 | 35.64 | 31.755 |
| 89. | Rental | $k/mo | 40.4 | .275 | .025 | 1.3 | | 6.974 | .871 | .765 |
| 90. | Maintenance | $/mo | 8440 | - | 15 | - | | 413 | 77 | 86 |
| 91. | Maint. Per $100k | $/mo | 387.2 | | 1500 | - | | 124 | 216 | 271 |
| 92. | Price: Rental Ratio | | 54.0 | | | 80.8 | | 47.8 | 40.9 | 41.5 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 165.0 | 0.525 | .375 | 8.0 | 1.375 | 22.0 | 5.7 | 2.6 |
| 94. | Adams | $k/mo | 103 | 0.5 | .75 | 7.0 | 2.50 | 22.0 | 6.0 | 2.5 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone—Price | | 55.22 | .28 | .025 | 2.66 | | 8.45 | .903 | .804 |
| 96. | Rental | | 48.97 | - | - | 1.58 | | 8.45 | 1.056 | .927 |
| 97. | Maint. Per $100k | | 1.86 | | 7.22 | - | | .597 | 1.040 | 1.305 |
| 98. | System Rental—*EDP/IR* | | 18.75 | .060 | .043 | .909 | .156 | 2.50 | .648 | .295 |
| 98a. | Auerbach—Smallest | | | | | .736 | | 2.92 | .635 | .480 |
| 98b. | Auerbach—Largest | | | | | 2.78 | | 7.76 | 2.04 | .846 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | | | | 2065 | | 8520 | | |
| 100. | Floor Space | ft.$^2$ | | | | 25.8 | | 70.2 | | |
| 101. | Volume | ft.$^3$ | | | | 163.3 | | 421.2 | | |
| 102. | Electrical Load | kva | | | | 5.9 | | 35.9 | | |
| 103. | Heat Dissipation | kBTU/hr. | | | | 11.8 | | 42.96 | | |
| 104. | Density—Weight | lb/ft.$^3$ | | | | 12.6 | | 20.2 | | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | | | .072 | | .182 | | |
| 106. | Price Per Pound | $/lb. | | | | 65.4 | | 39.2 | | |
| 107. | Memory Weight | lbs. | | | | incl. | | 200 | | |
| 108. | Floor Space | ft.$^2$ | | | | | | 4.2 | | |
| 109. | Volume | ft.$^3$ | | | | | | 25.0 | | |
| 110. | Electrical Load | kva | | | | | | 0.6 | | |
| 111. | Heat Dissipation | kBTU/hr. | | | | | | 32.5 | | |
| 112. | Density—Weight | lbs/ft.$^3$ | | | | | | 16.0 | | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | | | | | 1.30 | | |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | | | | | | 7.80 | | |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | | | | | | 1311 | | |
| 116. | Price Per Pound | $/lb. | | | | | | 384 | | |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●

| Line | Item | Units | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturers: | | NCR | NCR | NCR | NCR | NCR | RCA | RCA | RCA |
| | Model Numbers: | | 390 | 315 | 500 | 100 | 50 | Bizmac | 501 | 301 |
| 1. | **Date 1st Installed** | mo/yr | 5/61 | 5/62 | 10/65 | 9/68 | 2/71 | 11/55 | 6/59 | 2/61 |
| 2. | **Processor Performance** | | dec. | dec. | dec. | | | dec. | bin. | dec. |
| 3. | Word Length | bits | 48 | 12 | 48 | 4D | 8D | 6D | 6D | 6D |
| 4. | Memory Cycle Time | μsec. | 22 | 6 | 1080 | 0.8 | .8 | 20 | 15 | 7 |
| 5. | Raw Speed–Add | μsec. | 11000 | 46 | | 51 | 59 | 420 | 330 | |
| 6. | Multiply | μsec. | 250000 | 460 | | 3780 | 3780 | 5225 | 5700 | |
| 7. | Add (Gille) | μsec. | | 36 | | | | 320 | 420 | 210 |
| 8. | Multiply (Gille) | μsec. | | 900 | | | | 5225 | 6435 | 7800 |
| 9. | Five Dec. Dig.–c=a+b | μsec. | | 168 | 11,290 | 82.4 | 106.4 | - | - | 294 |
| 10. | c=ab | μsec. | | 466 | 32,300 | 3780 | 3827 | - | | 8400 |
| 11. | Addition Rate | Kops | .091 | 5.95 | .089 | 12.1 | 9.40 | 3.125 | 2.381 | 3.40 |
| 12. | Weighted Opns/sec. | Kops | .035 | 5.46 | .081 | 3.7 | 3.42 | 1.77 | 1.39 | 1.43 |
| 13. | Knight Index–Scientific | Kops | .002 | 3.41 | | | | .286 | .639 | .323 |
| 14. | Commercial | Kops | .010 | 11.46 | | | | .968 | 1.877 | 1.055 |
| 15. | Time Per Dollar | Sec/$ | 328.2 | 65.63 | | | 320.0 | 5.668 | 38.97 | 113.4 |
| 16. | Ops./$–Scientific | Kop/$ | .656 | 233.8 | | | | 1.62 | 24.9 | 36.6 |
| 17. | Commercial | Kop/$ | 3.3 | 752.1 | | | | 5.5 | 73.1 | 119.6 |
| 18. | Memory Bit Rate | bit/μsec | .045 | 2.0 | .044 | 10.0 | 10 | 0.3 | 1.6 | .857 |
| | Auerbach Performance | | | | | | | | | |
| 19. | Smallest Config.–Type | | - | II | - | III | - | - | - | II |
| 20. | Rental | $k/mo | | 5.925 | | 3.325 | | | | 5.08 |
| 21. | Performance–F1 | min | | 3.3 | | 1.3 | | | | 5.7 |
| 22. | F3 | min | | 29 | | 53 | | | | 49 |
| 23. | Random Access | min | | - | | 33 | | | | - |
| 24. | Sorting | min | | 26 | | 15 | | | | 60 |
| 25. | Matrix Inv.–10 | min | | .09 | | .18 | | | | 0.37 |
| 26. | Matrix Inv.–40 | min | | - | | 10 | | | | 20 |
| 27. | P1 | ms | | 32 | | 400 | | | | - |
| 28. | P3 | ms | | 2000 | | 27000 | | | | - |
| 29. | Largest Config.–Type | | | IV | | | | | | VI |
| 30. | Rental | $k/mo | | 19.29 | | | | | | 12.88 |
| 31. | Performance–F1 | min | | 0.4 | | | | | | 1.5 |
| 32. | F3 | min | | 18 | | | | | | 32 |
| 33. | Random Access | min | | - | | | | | | - |
| 34. | Sorting | min | | 2.6 | | | | | | 15 |
| 35. | Matrix Inv.–10 | min | | .09 | | | | | | .02 |
| 36. | Matrix Inv.–40 | min | | 5 | | | | | | 1.0 |
| 37. | P1 | ms | | 23 | | | | | | 300 |
| 38. | P3 | ms | | 2000 | | | | | | 3700 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | | 10.45 | | | 9.98 | | .279 | 2.59 |
| 40. | Datamation (CresM63) | Kops | | 4.93 | | | | | .929 | 1.49 |
| 41. | Adams Addition Rate | Kops | .088 | 20.8 | .097 | 15.4 | 16.95 | | 2.78 | 10.2 |
| 41a. | Processor Ops./$ | kop/$ | 4.5 | 5501 | - | - | - | - | 172.2 | 572.5 |
| | Perf. Ratios to 360/30 | | | | | | | | | |
| 42. | Raw Speed–Add | | .0027 | .652 | | .588 | .508 | .071 | .091 | .143 |
| 43. | Multiply | | .0009 | .511 | | .062 | .062 | .045 | .041 | .030 |
| 44. | Weighted Opns/sec. | | .0039 | .606 | .0090 | .411 | .379 | .196 | .264 | .159 |
| 45. | Knight Index–Scientific | | .0003 | .429 | | | | .036 | .080 | .041 |
| 46. | Commercial | | - | .009 | | | | .057 | .110 | .062 |
| 47. | Time Per Dollar | | .222 | 1.11 | | | .228 | 12.9 | 1.87 | .643 |
| 48. | Scientific Opns/$ | | .001 | .404 | | | | .003 | .043 | .063 |
| 49. | Commericial Opns/$ | | .003 | .604 | | | | .004 | .059 | .096 |
| 50. | Memory Bit Rate | | .008 | .375 | .008 | 1.88 | 1.88 | .056 | .300 | .161 |
| | Auerbach Performance | | | | | | | | | |
| 51. | Small Config.–F1 | | | .454 | | 1.15 | | | | .263 |
| 52. | F3 | | | .690 | | .377 | | | | .408 |
| 53. | Random Access | | | - | | .758 | | | | - |
| 54. | Sorting | | | .354 | | .613 | | | | .153 |
| 55. | Matrix Inv.–10 | | | .278 | | .139 | | | | .068 |
| 56. | Matrix Inv.–40 | | | - | | .120 | | | | .060 |
| 57. | P1 | | | 3.125 | | .250 | | | | - |
| 58. | P3 | | | 2.115 | | .157 | | | | - |
| 59. | Large Config.–F1 | | | 3.75 | | | | | | 1.00 |
| 60. | F3 | | | 1.11 | | | | | | .625 |

## TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●

| Line | Item Manufacturers: Model Numbers: | Units | NCR 390 | NCR 315 | NCR 500 | NCR 100 | NCR 50 | RCA Bizmac | RCA 501 | RCA 301 |
|---|---|---|---|---|---|---|---|---|---|---|
| 61. | Random Access | | | - | | | | | | - |
| 62. | Sorting | | | 3.54 | | | | | | .181 |
| 63. | Matrix Inv.—10 | | | .278 | | | | | | 1.25 |
| 64. | Matrix Inv.—40 | | | .240 | | | | | | 1.20 |
| 65. | P1 | | | 4.35 | | | | | | .333 |
| 66. | P3 | | | 2.115 | | | | | | 1.143 |
| | Other Perf. Measures | | | | | | | | | |
| 67. | Additions Per $ | | | .414 | | | | | .011 | .103 |
| 68. | Adams Addition Rate | | .0035 | .832 | .0039 | .616 | | | .111 | .408 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | | | rod | | | |
| 70. | Bits Per Access | | 1 | 12 | 48 | 8 | 8 | 6 | 24 | 6 |
| 71. | Cycle Time | µsec. | 22 | 6 | 1080 | .8 | 0.8 | 20 | 15 | 7 |
| 72. | Minimum Size | kwords | 0.2 | 2 | | | | 4 | 16K | 10 |
| 73. | Bytes | kbytes | 1.2 | 4 | | | 16 | 4 | 16K | 10 |
| 74. | Maximum Size | kwords | 0.2 | 40 | | | | 4 | 256K | 40 |
| 75. | Bytes | kbytes | 1.2 | 80 | | | 32 | 4 | 256K | 40 |
| 76. | Increment Size | kbytes | | 10 | | | 16K | | 16K | 10 |
| 77. | Price | $k | | 55.0 | | | 4.995 | | 57.0 | 23.5 |
| 78. | Rental | $k/mo | | 1.10 | | | .325 | | 1.0 | .600 |
| 79. | Maintenance | $/mo | | 20 | | | 12 | | - | - |
| 80. | Price Per Byte | $/by | | 5.50 | | | 0.305 | | 3.48 | 2.35 |
| 81. | Maint. Cost Per $100k | $/mo | | 36.4 | | | 240.2 | | - | - |
| 82. | Price: Rental Ratio | | | 50.0 | | | 15.37 | | 57.0 | 39.2 |
| | **Processor Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 56.3 | 82.5 | | | 47.0 | | 320.0 | 89.4 |
| 85. | Rental | $k/mo | 1.395 | 1.30 | | | 1.385 | | 6.8 | 1.75 |
| 86. | Maintenance | $/mo | - | 160 | | | 347 | | - | - |
| 87. | Memory Included | kbytes | 1.2 | - | | | 16K | | 0 | 10 |
| 88. | Processor Alone—Price | $k | | 82.5 | | | 42.0 | | 320.0 | 65.9 |
| 89. | Rental | $k/mo | | 1.30 | | | 1.060 | | 6.8 | 1.15 |
| 90. | Maintenance | $/mo | | 160 | | | 335 | | - | - |
| 91. | Maint. Per $100k | $/mo | | 194 | | | 797.6 | | - | - |
| 92. | Price: Rental Ratio | | | 63.5 | | | 39.6 | | 47.1 | 57.3 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 1.85 | 8.50 | 1.65 | 2.6 | 1.95 | 100.0 | 15.0 | 6.0 |
| 94. | Adams | $k/mo | 1.85 | 8.50 | 1.63 | 3.2 | 1.7 | - | 16.0 | 5.2 |
| | Ratios to 360/30 | | | | | | | | | |
| 95. | Processor Alone—Price | | | 2.09 | | | 1.06 | | 8.11 | 2.26 |
| 96. | Rental | | | 1.58 | | | 1.28 | | 8.24 | 1.39 |
| 97. | Maint. Per $100k | | | .934 | | | 3.84 | | - | - |
| 98. | System Rental—*EDP/IR* | | .210 | .966 | .188 | .295 | .222 | 11.36 | 1.70 | .682 |
| 98a. | Auerbach—Smallest | | | .851 | | .478 | | | | .730 |
| 98b. | Auerbach—Largest | | | 2.77 | | | | | | 1.85 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | 1000 | 1433 | | | | | 5000 | - |
| 100. | Floor Space | ft.$^2$ | 78 | 17.7 | | | | | 60.9 | |
| 101. | Volume | ft.$^3$ | | 76.6 | | | | | 281.5 | |
| 102. | Electrical Load | kva | 4.8 | 3.5 | | | | | 10.0 | |
| 103. | Heat Dissipation | kBTU/hr. | | 12.0 | | | | | 24.2 | |
| 104. | Density—Weight | lb/ft.$^3$ | | 18.7 | | | | | 17.8 | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | .157 | | | | | .086 | |
| 106. | Price Per Pound | $/lb. | | 57.6 | | | | | | |
| 107. | Memory Weight | lbs. | incl. | 715 | | | | | 1000 | |
| 108. | Floor Space | ft.$^2$ | | 7.17 | | | | | 20.8 | |
| 109. | Volume | ft.$^3$ | | 31.1 | | | | | 119.5 | |
| 110. | Electrical Load | kva | | 2.1 | | | | | 4.3 | |
| 111. | Heat Dissipation | kBTU/hr. | | 7.1 | | | | | 10.24 | |
| 112. | Density—Weight | lbs/ft.$^3$ | | 23.0 | | | | | 8.4 | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | .229 | | | | | .086 | |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | | 1.39 | | | | | .788 | |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | | .322 | | | | | 137.1 | |
| 116. | Price Per Pound | $/lb. | | 76.9 | | | | | 57.0 | |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●**

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | RCA<br>70/45 | Univac<br>UI | Univac<br>UII | Univac<br>SS80,90 | Univac<br>UIII | Univac<br>1004 | Univac<br>1108 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 11/65 | 3/51 | 11/57 | 8/58 | 8/62 | 2/63 | 9/65 |
| 2. | **Processor Performance** | | | dec. | dec. | dec. | dec. | dec. | |
| 3. | Word Length | bits | 16D | 48 | 72 | 40 | 25 | 6 | 36 |
| 4. | Memory Cycle Time | μsec. | 1.44 | 220 | 40 | 1700 | 4 | 8 | .75 |
| 5. | Raw Speed—Add | μsec. | 8.88 | 525 | 120 | 1360 | | 112 | .75 |
| 6. | Multiply | μsec. | 65.64 | 2150 | 1800 | 1275 | | 7260 | 2.375 |
| 7. | Add (Gille) | μsec. | | - | 440 | 153 | 8 | | |
| 8. | Multiply (Gille) | μsec. | | - | 1520 | 561 | 80 | | |
| 9. | Five Dec. Dig.—c=a+b | μsec. | 25 | - | - | | 24 | | 2.3 |
| 10. | c=ab | μsec. | 82 | - | - | | 116 | | 3.9 |
| 11. | Addition Rate | Kops | 40.0 | 1.90 | 2.27 | 6.53 | 41.67 | 8.93 | 434.8 |
| 12. | Weighted Opns/sec. | Kops | 35.9 | 1.65 | 2.02 | 5.76 | 34.97 | 2.13 | 420.2 |
| 13. | Knight Index—Scientific | Kops | 211.61 | .140 | 1.16 | .329 | 22.7 | .097 | 2075 |
| 14. | Commercial | Kops | 290.49 | .271 | 2.36 | .490 | 22.8 | 1.473 | 2088 |
| 15. | Time Per Dollar | Sec/$ | 41.57 | .4.94 | 22.27 | 124.7 | 27.11 | 415.7 | 10.39 |
| 16. | Ops./$—Scientific | Kop/$ | 8797 | 3.5 | 25.8 | 41.0 | 615.4 | 40.3 | 21,559.3 |
| 17. | Commercial | Kop/$ | 12076 | 6.8 | 52.6 | 61.1 | 618.1 | 612.3 | 21,694.3 |
| 18. | Memory Bit Rate | bit/μsec | 11.1 | .218 | 1.8 | .024 | 6.25 | 0.75 | 48 |
| | Auerbach Performance | | | | | | | | |
| 19. | Smallest Config.—Type | | III | | - | I | III | I | VIIA |
| 20. | Rental | $k/mo | 7.66 | | | 4.325 | 19.0 | 1.8 | 45.25 |
| 21. | Performance—F1 | min | 1.4 | | | | .19 | | 0.27 |
| 22. | F3 | min | 22 | | | 130 | 20 | 100 | 1.5 |
| 23. | Random Access | min | - | | | | - | | - |
| 24. | Sorting | min | 9.4 | | | | 1.2 | | 1.9 |
| 25. | Matrix Inv.—10 | min | .0053 | | | | .024 | | .00017 |
| 26. | Matrix Inv.—40 | min | .30 | | | | 1.4 | | .0089 |
| 27. | P1 | ms | 47 | | | | 25 | | 7 |
| 28. | P3 | ms | 1150 | | | | 2500 | | 21 |
| 29. | Largest Config.—Type | | VIIB | | - | III | VIIIB | II | VIIIA |
| 30. | Rental | $k/mo | 14.58 | | | 7.40 | 38.73 | 2.725 | 58.40 |
| 31. | Performance—F1 | min | .36 | | | 3.0 | .19 | 3.2 | .27 |
| 32. | F3 | min | 2.1 | | | 24 | 1.5 | 27 | 1.3 |
| 33. | Random Access | min | - | | | - | - | | - |
| 34. | Sorting | min | 2.4 | | | 19 | 1.2 | | 1.9 |
| 35. | Matrix Inv.—10 | min | .0053 | | | | .024 | | .00017 |
| 36. | Matrix Inv.—40 | min | .30 | | | | 1.4 | | .0089 |
| 37. | P1 | ms | 9.5 | | | | | | 7 |
| 38. | P3 | ms | 1150 | | | | | | 21 |
| | Other Perf. Measures | | | | | | | | |
| 39. | Additions Per $ | M | 17.79 | | | | 11.84 | - | 56.31 |
| 40. | Datamation (CresM63) | Kops | | | 1.90 | .192 | 30.48 | | |
| 41. | Adams Addition Rate | Kops | 104.2 | | - | 19.6 | 125.0 | 8.93 | 1333 |
| 41a. | Processor Ops./$ | kop/$ | 58567 | 12.6 | 79.4 | 176.2 | 2156 | 799.3 | 88035 |
| | Perf. Ratios to 360/30 | | | | | | | | |
| 42. | Raw Speed—Add | | 3.38 | .057 | .25 | .022 | | .268 | 40.0 |
| 43. | Multiply | | 3.58 | .109 | .131 | .184 | | .032 | 98.9 |
| 44. | Weighted Opns/sec. | | 3.98 | | .224 | .639 | 3.88 | .236 | 46.62 |
| 45. | Knight Index—Scientific | | 26.65 | .018 | .146 | .041 | 2.86 | .001 | 261.3 |
| 46. | Commercial | | 16.99 | .016 | .138 | .029 | 1.33 | .086 | 122.1 |
| 47. | Time Per Dollar | | 1.75 | 2.92 | 3.27 | .584 | 2.69 | .175 | 7.01 |
| 48. | Scientific Opns/$ | | 15.20 | .006 | .045 | .071 | 1.06 | .070 | 37.3 |
| 49. | Commericial Opns/$ | | 9.69 | .005 | .042 | .049 | .460 | .491 | 17.4 |
| 50. | Memory Bit Rate | | 2.08 | .041 | .338 | .0045 | 1.17 | .141 | 9.00 |
| | Auerbach Performance | | | | | | | | |
| 51. | Small Config.—F1 | | 1.07 | | | - | 7.89 | | 5.55 |
| 52. | F3 | | .91 | | | .154 | 1.0 | .200 | 13.33 |
| 53. | Random Access | | - | | | | - | - | - |
| 54. | Sorting | | .98 | | | | 7.67 | | 4.84 |
| 55. | Matrix Inv.—10 | | 4.72 | | | | 1.04 | | 147.1 |
| 56. | Matrix Inv.—40 | | 4.00 | | | | .857 | | 134.8 |
| 57. | P1 | | 2.13 | | | | 4.00 | | 14.3 |
| 58. | P3 | | 3.68 | | | | 1.69 | | 201.4 |
| 59. | Large Config.—F1 | | 4.17 | | | .500 | 7.89 | .469 | 5.56 |
| 60. | F3 | | 9.52 | | | .833 | 13.33 | .741 | 15.38 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | RCA<br>70/45 | Univac<br>UI | Univac<br>UII | Univac<br>SS80,90 | Univac<br>UIII | Univac<br>1004 | Univac<br>1108 |
|---|---|---|---|---|---|---|---|---|---|
| 61. | Random Access | | | | | - | - | - | - |
| 62. | Sorting | | 3.83 | | | .484 | 7.67 | | 4.84 |
| 63. | Matrix Inv.—10 | | 4.72 | | | | 1.04 | | 147.1 |
| 64. | Matrix Inv.—40 | | 4.00 | | | | .857 | | 134.8 |
| 65. | P1 | | 10.53 | | | | | | 14.3 |
| 66. | P3 | | 3.68 | | | | | | 201.4 |
| | Other Perf. Measures | | | | | | | | |
| 67. | Additions Per $ | | | | | | .469 | | 2.23 |
| 68. | Adams Addition Rate | | | | | .784 | 5.0 | .357 | 53.33 |
| | **Memory** | | | | | | | | |
| 69. | Type (if not core) | | | Hg Line | | drum | | | |
| 70. | Bits Per Access | | | 48 | 72 | 40 | 25 | 6 | 36 |
| 71. | Cycle Time | µsec. | | 220 | 40 | 1700 | 4 | 8 | .75 |
| 72. | Minimum Size | kwords | 8K | 1 | 2 | 2.4 | 8K | .96 | 64K |
| 73. | Bytes | kbytes | 16K | 8 | 24 | 12.0 | 32K | .96 | 384K |
| 74. | Maximum Size | kwords | 128K | 1 | 2 | 9.2 | 32K | 1.96 | 256K |
| 75. | Bytes | kbytes | 256K | 8 | 24 | 46.0 | 128K | 1.96 | 1536K |
| 76. | Increment Size | kbytes | 16K | - | - | 2.0 | 32K | | 384K |
| 77. | Price | $k | 29.1 | | | 12.5 | 67.5 | | 448.5 |
| 78. | Rental | $k/mo | .615 | | | 0.40 | 1.4 | | 10.24 |
| 79. | Maintenance | $/mo | 37 | | | 25 | 90 | | 735 |
| 80. | Price Per Byte | $/by | 1.78 | | | 6.25 | 2.06 | | 1.14 |
| 81. | Maint. Cost Per $100k | $/mo | 127.1 | | | 200 | 133.3 | | 163.9 |
| 82. | Price: Rental Ratio | | 47.3 | | | 31.3 | 48.2 | | 43.8 |
| | **Processor—Sys. Price** | | | | | | | | |
| 84. | Processor—Price | $k | 174.6 | 750.0 | 970.0 | 110.0 | 390.0 | 45.08 | 646.8 |
| 85. | Rental | $k/mo | 3.71 | 13.39 | 18.54 | 1.735 | 8.0 | 1.15 | 14.8 |
| 86. | Maintenance | $/mo | 222.5 | - | 3.06 | 350 | 500 | 205 | 2425 |
| 87. | Memory Included | kbytes | 16K | 8 | 24 | 13 | 32K | .96 | 0 |
| 88. | Processor Alone—Price | $k | 145.5 | | | | 322.5 | | 646.8 |
| 89. | Rental | $k/mo | 3.095 | | | | 6.6 | | 14.8 |
| 90. | Maintenance | $/mo | 185.5 | | | | 410 | | 2425 |
| 91. | Maint. Per $100k | $/mo | 127.5 | | | | 127.1 | | 374.9 |
| 92. | Price: Rental Ratio | | 47.0 | | | | 48.9 | | 43.7 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 24.0 | 25.0 | 25.0 | 8.0 | 20.0 | 1.90 | 65.0 |
| 94. | Adams | $k/mo | 12.5 | - | - | 8.0 | 22.5 | 1.50 | 60.0 |
| | Ratios to 360/30 | | | | | | | | |
| 95. | Processor Alone—Price | | 3.69 | | | | | | |
| 96. | Rental | | 3:75 | | | | | | |
| 97. | Maint. Per $100k | | .614 | | | | | | |
| 98. | System Rental—*EDP/IR* | | 2.73 | 2.84 | 2.84 | .909 | 2.27 | .216 | 7.39 |
| 98a. | Auerbach—Smallest | | 1.10 | | | .621 | 2.73 | .259 | 6.50 |
| 98b. | Auerbach—Largest | | 2.09 | | | 1.063 | 5.56 | .392 | 8.39 |
| | **Physical Char.** | | | | | | | | |
| 99. | Processor—Weight | lb. | | 16686 | 15000 | 3532 | 6200 | 2021 | |
| 100. | Floor Space | ft.² | | 112.2 | 112.3 | 24.0 | 30.5 | 31.1 | |
| 101. | Volume | ft.³ | | 953.5 | 963.7 | 138.3 | 180.3 | 142.4 | |
| 102. | Electrical Load | kva | | 90.0 | 85.0 | 16.9 | 9.1 | 3.0 | |
| 103. | Heat Dissipation | kBTU/hr. | | | 289.0 | 27.66 | 24.6 | 8.5 | |
| 104. | Density—Weight | lb/ft.³ | | 17.5 | 15.6 | 25.5 | 34.4 | 14.2 | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | | .300 | .200 | .136 | .060 | |
| 106. | Price Per Pound | $/lb. | | | 64.7 | 31.1 | 62.9 | 22.3 | |
| 107. | Memory Weight | lbs. | | | incl. | incl. | incl. | incl. | |
| 108. | Floor Space | ft.² | | | | | | | |
| 109. | Volume | ft.³ | | | | | | | |
| 110. | Electrical Load | kva | | | | | | | |
| 111. | Heat Dissipation | kBTU/hr. | | | | | | | |
| 112. | Density—Weight | lbs/ft.³ | | | | | | | |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | | | | | | | |
| 114. | Capy. Per Floor Sp. | kBy./ft² | | | | | | | |
| 115. | Capy. Per Vol. | kBy./ft³ | | | | | | | |
| 116. | Price Per Pound | $/lb. | | | | | | | |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS ●**

| Line | Item<br>Manufacturers:<br>Model Numbers: | Units | Univac<br>9200 | Univac<br>9300 | Univac<br>9400 |
|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 6/67 | 9/67 | 5/69 |
| 2. | **Processor Performance** | | | | |
| 3. | Word Length | bits | 8D | 8 | 16D |
| 4. | Memory Cycle Time | μsec. | 1.2 | 0.6 | 0.6 |
| 5. | Raw Speed—Add | μsec. | 95 | 47 | 21.0 |
| 6. | Multiply | μsec. | | | |
| 7. | Add (Gille) | μsec. | | | |
| 8. | Multiply (Gille) | μsec. | | | |
| 9. | Five Dec. Dig.—c=a+b | μsec. | 187.2 | 93.6 | 54 |
| 10. | c=ab | μsec. | 2980 | 1490 | 347 |
| 11. | Addition Rate | Kops | 5.34 | 10.7 | 18.5 |
| 12. | Weighted Opns/sec. | Kops | 3.06 | 6.13 | 14.6 |
| 13. | Knight Index—Scientific | Kops | 1.59 | 4.35 | |
| 14. | Commercial | Kops | 7.46 | 18.42 | |
| 15. | Time Per Dollar | Sec/$ | 415.7 | 138.6 | 62.4 |
| 16. | Ops./$—Scientific | Kop/$ | 661.0 | 602.9 | |
| 17. | Commercial | Kop/$ | 3,101.1 | 2553.0 | |
| 18. | Memory Bit Rate | bit/μsec | 6.67 | 13.33 | 26.7 |
| | Auerbach Performance | | | | |
| 19. | Smallest Config.—Type | | I | I | III |
| 20. | Rental | $k/mo | 1.29 | 1.74 | 4.55 |
| 21. | Performance—F1 | min | | | 1.2 |
| 22. | F3 | min | 206 | 206 | 15 |
| 23. | Random Access | min | | | |
| 24. | Sorting | min | | | |
| 25. | Matrix Inv.—10 | min | | | |
| 26. | Matrix Inv.—40 | min | | | |
| 27. | P1 | ms | | | |
| 28. | P3 | ms | | | |
| 29. | Largest Config.—Type | | | IV | IV |
| 30. | Rental | $k/mo | | 7.81 | 11.55 |
| 31. | Performance—F1 | min | | | .36 |
| 32. | F3 | min | | 21.2 | 15 |
| 33. | Random Access | min | | - | |
| 34. | Sorting | min | | 4.7 | |
| 35. | Matrix Inv.—10 | min | | | |
| 36. | Matrix Inv.—40 | min | | | |
| 37. | P1 | ms | | | |
| 38. | P3 | ms | | | |
| | Other Perf. Measures | | | | |
| 39. | Additions Per $ | M | 23.50 | 21.98 | 38.84 |
| 40. | Datamation (CresM63) | Kops | | | |
| 41. | Adams Addition Rate | Kops | 9.62 | 19.2 | 166.6 |
| 41a. | Processor Ops./$ | kop/$ | 16625 | 18998 | |
| | Perf. Ratios to 360/30 | | | | |
| 42. | Raw Speed—Add | | .316 | .638 | 1.43 |
| 43. | Multiply | | | | |
| 44. | Weighted Opns/sec. | | .340 | .680 | 1.62 |
| 45. | Knight Index—Scientific | | .200 | .548 | |
| 46. | Commercial | | .436 | 1.10 | |
| 47. | Time Per Dollar | | .175 | .526 | 1.17 |
| 48. | Scientific Opns/$ | | 1.14 | 1.04 | |
| 49. | Commericial Opns/$ | | 2.49 | 2.05 | |
| 50. | Memory Bit Rate | | 1.25 | 2.50 | 5.01 |
| | Auerbach Performance | | | | |
| 51. | Small Config.—F1 | | | | 1.25 |
| 52. | F3 | | .097 | .097 | 1.33 |
| 53. | Random Access | | - | - | |
| 54. | Sorting | | | | |
| 55. | Matrix Inv.—10 | | | | |
| 56. | Matrix Inv.—40 | | | | |
| 57. | P1 | | | | |
| 58. | P3 | | | | |
| 59. | Large Config.—F1 | | | | 4.17 |
| 60. | F3 | | | .943 | 1.33 |

**TABLE II.2.11.1 SYSTEM CHARACTERISTICS (continued) ●**

| Line | Item | Units | | | |
|---|---|---|---|---|---|
| | **Manufacturers:** | | **Univac** | **Univac** | **Univac** |
| | **Model Numbers:** | | **9200** | **9300** | **9400** |
| 61. | Random Access | | - | - | |
| 62. | Sorting | | | 1.96 | |
| 63. | Matrix Inv.—10 | | | | |
| 64. | Matrix Inv.—40 | | | | |
| 65. | P1 | | | | |
| 66. | P3 | | | | |
| | Other Perf. Measures | | | | |
| 67. | Additions Per $ | | .931 | .870 | |
| 68. | Adams Addition Rate | | .385 | .768 | |
| | **Memory** | | | | |
| 69. | Type (if not core) | | | | wire |
| 70. | Bits Per Access | | 8 | 8 | |
| 71. | Cycle Time | μsec. | 1.2 | 0.6 | |
| 72. | Minimum Size | kwords | 8K | 8K | |
| 73. | Bytes | kbytes | 8K | 8K | 24K |
| 74. | Maximum Size | kwords | 16K | 32K | |
| 75. | Bytes | kbytes | 16K | 32K | 256K |
| 76. | Increment Size | kbytes | 8K | 8K | 24K |
| 77. | Price | $k | 15.87 | 23.23 | 55.465 |
| 78. | Rental | $k/mo | .365 | .53 | 1.275 |
| 79. | Maintenance | $/mo | 30 | 45 | 225 |
| 80. | Price Per Byte | $/by | 1.94 | 2.84 | 2.26 |
| 81. | Maint. Cost Per $100k | $/mo | 189.0 | 193.7 | 405.7 |
| 82. | Price: Rental Ratio | | 43.5 | 43.8 | 43.5 |
| | **Processor—Sys. Price** | | | | |
| 84. | Processor—Price | $k | 12.2 | 26.5 | 33.28 |
| 85. | Rental | $k/mo | .28 | .605 | .765 |
| 86. | Maintenance | $/mo. | 65 | 150 | 135 |
| 87. | Memory Included | kbytes | 0 | 0 | 0 |
| 88. | Processor Alone—Price | $k | 12.2 | 26.5 | 33.28 |
| 89. | Rental | $k/mo | .28 | .605 | .765 |
| 90. | Maintenance | $/mo | 65 | 150 | 135 |
| 91. | Maint. Per $100k | $/mo | 532.8 | 566.0 | 405.6 |
| 92. | Price: Rental Ratio | | 43.6 | 43.8 | 43.5 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 1.60 | 3.60 | 10.0 |
| 94. | Adams | $k/mo | 1.85 | 5.5 | 13.7 |
| | Ratios to 360/30 | | | | |
| 95. | Processor Alone—Price | | | | .843 |
| 96. | Rental | | | | .927 |
| 97. | Maint. Per $100k | | | | 1.95 |
| 98. | System Rental—*EDP/IR* | | .182 | .409 | 1.14 |
| 98a. | Auerbach—Smallest | | .185 | .250 | .65 |
| 98b. | Auerbach—Largest | | | 1.122 | 1.66 |
| | **Physical Char.** | | | | |
| 99. | Processor—Weight | lb. | | | 900 |
| 100. | Floor Space | ft.$^2$ | | | 54.36 |
| 101. | Volume | ft.$^3$ | | | 289.9 |
| 102. | Electrical Load | kva | | | 1.7 |
| 103. | Heat Dissipation | kBTU/hr. | | | 5.511 |
| 104. | Density—Weight | lb/ft.$^3$ | | | 3.10 |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | | 0.019 |
| 106. | Price Per Pound | $/lb. | | | 36.98 |
| 107. | Memory Weight | lbs. | 650 | 650 | 1250 |
| 108. | Floor Space | ft.$^2$ | 7.09 | 7.09 | 9.20 |
| 109. | Volume | ft.$^3$ | 24.2 | 24.2 | 49.1 |
| 110. | Electrical Load | kva | 1.0 | 1.0 | 3.2 |
| 111. | Heat Dissipation | kBTU/hr. | 3.413 | 3.413 | 5.300 |
| 112. | Density—Weight | lbs/ft.$^3$ | 26.9 | 26.9 | 25.5 |
| 113. | Heat Per Cu. Ft. | kBTU/hr. | .141 | .141 | 0.108 |
| 114. | Capy. Per Floor Sp. | kBy./ft$^2$ | 1.13 | 1.13 | 2.67 |
| 115. | Capy. Per Vol. | kBy./ft$^3$ | .331 | .331 | 0.501 |
| 116. | Price Per Pound | $/lb. | 24.4 | 35.7 | 44.4 |

## FIGURE II.2.11 THE KNIGHT PERFORMANCE INDEX—NOTES

In a Ph.D. thesis published at Carnegie Institute in 1963, K.E. Knight proposed a set of system performance measures and applied them to all the computers produced up to that time. The results were published in 1966 and updated in 1968 (KnigK66,68). Two of the measures provided a way of computing a performance index, one for commercial, the other for scientific applications. The formulae are shown in Figure II.2.11.

The index starts with a measure of processor speed, found by dividing one million by the time, in seconds, required by the processor to perform a million operations. That speed is then multiplied by a (arbitrary) memory factor to produce the performance index. The memory factor gives extra weight to long words, big memories, and variable-word-length machines. And it ascribes more importance to memory in scientific than in commercial applications. It was developed as a sort of concensus of the opinions of 43 senior computer engineers and programmers regarding the importance of memory to performance.

The time required to perform a million operations has two parts: a processor portion, based on the time required for elementary operations and the expected frequency of those operations; and an input-output portion, based on the time, not overlapped with processor time, required to input and output the data associated with the million computer operations. The various weighting and other factors proposed by Knight and shown in the figure are based on measurements Knight made on a number of computer systems and programs. Comments:

1. The parameters used in the formulae are not altogether well-defined. What is "addition time" for a variable-word-length machine where addition is a function of the length of the operands? How does one determine the "useful I/O time required for non-overlapped rewind time", necessary to determine R? Does one use maximum or average memory capacity in calculating the memory factor? What values should one use for W (input and output words per million computer operations) when a moving-head-file is the primary I/O device—should it be treated like a magnetic tape, or like unit record devices? These and other ambiguities make it difficult to check Knight's calculations. The sample calculations at the bottom of the figure show a set of assumptions made to compute Knight's commercial index for four generations of IBM computers: the 650, 1401, 360/30, 370/135, and S3/10. The computed results, shown on the next-to-last line in the table, differ from Knight's result, and there appears to be no way of determining the reason for the differences—Knight's thesis does not include his values for the various parameters.

2. There is some confusion regarding the weighting factor for addition. In his *Datamation* paper (KnigK66), Knight specified the weight should be .10/.25 (scientific/commercial) for "computers without index registers or indirect addressing", and .25/.45 for "computers with index registers or indirect addressing". Aside from the ambiguity (what should we use for a machine with index registers but no indirect addressing?), the weights seem illogical—why should an index register machine be penalized? In his thesis, however, Knight writes that 25%/20% of the instructions are indexed (in scientific/commercial problems), so that "a computing system that did not contain index registers or indirect addressing would have to perform the equivalent of one extra addition for each indexed operation". He thus concluded that, for machines which must perform indexing in their arithmetic registers, the weighting factor should be .35/.45—the parameters we show here in Figure II.2.11.

3. Implicit in Knight's formula is an estimate of average workload, in the sense to be discussed in Section 2.21. The estimates are contained in Knight's values for W—the number of input and output words required per million internal computer operations. Since input and output words are the same, he clearly estimates there would be one output character generated for each input character read. Other sources (see Figure 2.21.3, Table 2.21.3) indicate the average is much higher. His values for W range from 2000 to 100,000 words per million computer operations, corresponding to a range of 10 to 500 computer operations per word. Most of the machines Knight measured in arriving at these figures had word lengths of 4 to 6 characters—the IBM 704, 650, 7070, 7090, and the Bendix G-15. Two, the IBM 705 and 1401, were variable word-length machines whose "words" were presumably one character long. The workload measured in computer operations required per *character* (surely a more fundamental measure than characters per *word*), thus could have averaged from as little as 1.7 operations per character to a maximum of 500. Other sources (see Figure 2.21.7, Table 2.21.3) show ratios in the few hundreds to thousands—none lower than about fifteen.

4. It appears there is one serious logical flaw in Knight's index, having to do with the overlap between I/O and compute time. Observe that he computes I/O time based on the number of I/O characters and the I/O device rate, and then applies an overlap factor to allow for the fact that, in a buffered system, input and output can occur while the processor is operating. In his thesis, Knight stated that the IBM 7090 has a compute time of 4.56 seconds per million computer operations and an I/O time, after overlap, of 17.6 seconds. Since the 7090 permitted simultaneous read, write, and compute, Knight's OL factor must have been 0.7 or less. Thus the I/O time *before* applying the overlap factor must have been 17.6/0.7 = 25.1, and the presumed overlap is 25.1 - 17.6 = 7.5 seconds. But clearly it is impossible for the overlap of I/O and compute to exceed the compute time of 4.56 seconds. Consistent application of the formula will thus tend to overestimate the performance of bufferred systems with input-output times longer than compute times.

$$\text{Performance Index} = \frac{10^6 \times (\text{Memory Factor})}{\text{Processor Time per Million Operations}}$$

$$\text{Memory Factor} = \left[\frac{(L-7)}{(36-7)} \frac{T}{(32{,}000)} (WF)\right]^i$$

- $L$ = Word Length, in Bits
- $T$ = Total Number of Words in Memory
- $WF$ = The Word Factor
  - = 1 for Fixed-Word-Length Systems
  - = 2 for Variable-Word-Length Systems
- $i$ = Exponential Memory Weighting Factor
  - = 0.5 for Scientific Computation
  - = 0.333 for Commercial Computation

Processor Time = $t_c + t_{i/o}$ (in seconds)

- $t_c$ = CPU Time per Million Operations
  - = $(C_1 A_{Fi} + C_2 A_{Fl} + C_3 M + C_4 D + C_5 L)$
  - $A_{Fi}$ = Fixed-Point Addition Time (microseconds)
  - $A_{Fl}$ = Floating Point Addition Time (microseconds)
  - $M$ = Multiplication Time (microseconds)
  - $D$ = Division Time (microseconds)
  - $L$ = Logic Operation Time (microseconds)
  - $C_i$ = Weighting Factors Representing the Percentages of Various Operations

| | Scientific Computation | Commercial Computation |
|---|---|---|
| $C_1$ | 0.10 | 0.25 |
| $C_2$ | 0.10 | 0 |
| $C_3$ | 0.06 | 0.01 |
| $C_4$ | 0.02 | 0 |
| $C_5$ | 0.72 | 0.74 |
| Total | 1.00 | 1.00 |
| Add to $C_1$ if CPU has no index registers or indirect addressing | 0.25 | 0.20 |

- $t_{i/o}$ = Non-Overlapped I/O Time per Million Operations
  - = $P_c$(Primary I/O System Time) + $(1 - P_c)$ (Secondary I/O System Time)
- $P_c$ = Fraction of the I/O Characters Handled by the Primary I/O System

I/O System Time -- Primary or Secondary

$$= (OL)(R)\left[\frac{W_i B}{K_i} + \frac{W_o B}{K_o} + N(S + H)\right]$$

Where (OL), R, $W_i$, $W_o$, $K_o$, N, S, and H are selected, as appropriate, depending on whether the primary or secondary I/O time is being calculated.

- OL = Overlap Factor -- the fraction of I/O time not overlapped with the computer
  - = 1.0 for systems with no overlap -- no buffer
  - = 0.85 if system permits read or write with compute
  - = 0.70 if system permits read, write, and compute
  - = 0.60 if system permits multiple read, write, and compute
  - = 0.55 if system permits multiple read, write, and compute with program interrupt
- R = 1 + the fraction the useful I/O time that is required for non-overlapped rewind time
- $W_i$ = the number of input words per million internal operations entering on the primary (or secondary) I/O system (see values below)
- $W_o$ = the number of output words per million internal operations leaving on the primary (or secondary) I/O system (see values below)
- B = the number of I/O characters per word
- $K_i$ = the input transfer rate (char./sec.)
- $K_o$ = The output transfer rate (char./sec.)
- N = the number of times separate records are read or written per million operations (see values below)
- S = the I/O system start time not overlapped with computation
- H = the I/O system stop time not overlapped with computation

| | | Scientific Computation | Commercial Computation |
|---|---|---|---|
| $W_i = W_o$ | | | |
| | Magnetic Tape | 20,000 | 100,000 |
| | Other I/O | 2,000 | 10,000 |
| N | | 4 | 20 |

Sample Calculations -- Commercial Performance Index

| | | IBM 650 | IBM 1401 | IBM 360/30 | IBM 370/135 | IBM S3/10 |
|---|---|---|---|---|---|---|
| **Memory Factor:** | | | | | | |
| Word Length | L | 50 | 8 | 8 | 8 | 8 |
| Number of words* | T | 3000 | 8910 | 36,864 | 311,296 | 28,670 |
| Word Factor | WF | 1 | 2 | 2 | 2 | 2 |
| Exponential Factor | i | 0.333 | 0.333 | 0.333 | 0.333 | 0.333 |
| Memory Factor | | 0.519 | 0.268 | 0.430 | 0.875 | 0.395 |
| **CPU Time:** | | | | | | |
| Weighting Factors | $C_1$ | 0.45 | 0.25 | 0.25 | 0.25 | 0.25 |
| | $C_2$ | 0 | 0 | 0 | 0 | 0 |
| | $C_3$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | $C_4$ | 0 | 0 | 0 | 0 | 0 |
| | $C_5$ | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 |
| Operation Times** | $A_{Fi}$ | 5200 | 230 | 30 | 4.2 | 26 |
| | M | 11,600 | 2085 | 235 | 25.5 | 3200 |
| | L | 2400 | 80 | 16 | 2.3 | 7 |
| CPU Time | $t_c$ | 4232 | 137.6 | 21.7 | 3.00 | 43.7 |
| **I/O Time:** | | | | | | |
| Primary I/O System | | Mag.Tape | Mag.Tape | Mag.Tape | Mag.Tape | MHF |
| Overlap Factor | OL | 1.0 | 0.85 | 0.55 | 0.55 | 0.55 |
| Rewind Factor | R | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 |
| Input Words | $W_i$ | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 |
| Output Words | $W_o$ | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 |
| Characters-Word | B | 5 | 1 | 1 | 1 | 1 |
| Input Rate | $K_i$ | 15,000 | 41,670 | 60,000 | 80,000 | 199,000 |
| Output Rate | $K_o$ | 15,000 | 41,670 | 60,000 | 80,000 | 199,000 |
| Input Time | $\frac{W_o B}{K_i}$ | 33 | 2.4 | 1.67 | 1.25 | 0.50 |
| Output Time | $\frac{W_o B}{K_o}$ | 33 | 2.4 | 1.67 | 1.25 | 0.50 |
| Number of Records | N | 20 | 20 | 20 | 20 | - |
| Start Time | S | 0.1 | .009 | .0090 | .006 | - |
| Stop Time | H | 0.1 | .004 | .0036 | .009 | - |
| Primary I/O Time | | 74 | 4.7 | 2.17 | 1.69 | 0.55 |
| Secondary I/O System | | Unit Record | Unit Record | Unit Record | Unit Record | Unit Record |
| Overlap Factor | OL | 1.0 | 0.85 | 0.55 | 0.55 | 0.55 |
| Rewind Factor | R | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Input Words | $W_i$ | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 |
| Output Words | $W_o$ | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 |
| Characters/Word | B | 5 | 1 | 1 | 1 | 1 |
| Input Rate | $K_i$ | 267 | 1067 | 1333 | 1600 | 400 |
| Output Rate | $K_o$ | 133 | 333 | 1000 | 2640 | 320 |
| Input Time | $\frac{W_i B}{K_i}$ | 187 | 9.4 | 7.50 | 6.25 | 25.0 |
| Output Time | $\frac{W_o B}{K_o}$ | 375 | 30.0 | 10.00 | 3.79 | 31.3 |
| Secondary I/O Time | | 562 | 33.5 | 9.63 | 5.52 | 30.94 |
| Primary System Factor | $P_c$ | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| Non-Overlapped I/O Time | $t_{i/o}$ | 123 | 7.6 | 2.92 | 2.08 | 3.59 |
| Processor Time | $t_c + t_{i/o}$ | 4355 | 145.2 | 24.62 | 5.08 | 47.29 |
| Performance Index | | 119 | 1845 | 17,469 | 172,244 | 8353 |
| Knight's Index as Published | | 291 | 1626 | 17,100 | - | - |

Notes:
* Average of Minimum and Maximum number of words
** For variable-word-length machines, arithmetic times are for five-digit operands

FIGURE II.2.11 THE KNIGHT PERFORMANCE INDEX

## TABLE II.2.11.2 SYSTEM MEMORY CAPACITY AND PRICE—NOTES

The data for this table basically comes from two sources: General Service Administration (GSA) Price Lists; and Auerbach Reports (AuerCTR). The IBM, CDC, and Univac data comes from the GSA Price Catalogues published by those companies, for the year specified after the computer name—generally within one or two years of the introduction of each indicated computer. The data for the Burroughs 5500 system comes from Auerbach—no Burroughs catalogue was available.

Where appropriate, I have included power supplies with systems—in early systems, processors and power supplies were priced separately. Specifically, the IBM 650 systems includes the 655; and the 705 includes the 745.

### TABLE II.2.11.2 SYSTEM MEMORY CAPACITY AND PRICE ●

| | Units | Memory Capacity and Price | | | | |
|---|---|---|---|---|---|---|
| IBM 650 ('60) | | | | | | |
| Memory Capy. | kby | 10 | 20 | | | |
| Price | $k | 157.4 | 192.4 | | | |
| Rental | k$/mo | 3.2 | 4.05 | | | |
| Maintenance | $/mo | 219.2 | 316.2 | | | |
| Incremental Cost | $/by | | 3.50 | | | |
| Maint. Cost/$100k | $/mo | 139.3 | 164.3 | | | |
| IBM 705 (705III) | | | | | | |
| Memory Capy. | kby | 20 | 40 | (40) | (80) | |
| Price | $k | 562.4 | 652.4 | 888.0 | 1228 | |
| Rental | k$/mo | 12.85 | 15.35 | 16.5 | 22.5 | |
| Maintenance | $/mo | 981 | 1185 | 889 | 1121 | |
| Incremental Cost | $/by | | 4.50 | | 8.50 | |
| Maint. Cost/$100k | $/mo | 174.4 | 181.6 | 100.1 | 91.3 | |
| IBM 1401 ('60) | | | | | | |
| Memory Capy. | kby | 1.4 | 2.0 | 4.0 | 8.0 | 16.0 |
| Price | $k | 70.5 | 71.3 | 72.35 | 94.7 | 130.45 |
| Rental | k$/mo | 1.20 | 1.30 | 1.43 | 2.06 | 3.08 |
| Maintenance | $/mo | 47.5 | 47.5 | 49.0 | 64.5 | 73.0 |
| Incremental Cost | $/by | | 1.33 | .525 | 5.59 | 4.47 |
| Maint. Cost/$100k | $/mo | 67.4 | 66.6 | 67.7 | 68.1 | 56.0 |
| CDC 6600 ('65) | | | | | | |
| Memory Capy. | kby | 320 | 640 | 1280 | | |
| Price | $k | 2600 | 3450 | 5110 | | |
| Rental | k$/mo | 41.9 | 53.5 | 71.5 | | |
| Maintenance | $/mo | 5700 | 6400 | 7210 | | |
| Incremental Cost | $/by | | 2.59 | 2.53 | | |
| Maint. Cost/$100k | $/mo | 219.2 | 185.5 | 141.1 | | |
| BGH 5500 ('65) | | | | | | |
| Memory Capy. | kby | 96 | 128 | 256 | | |
| Price | $k | 487.6 | 547.8 | 788.5 | | |
| Rental | k$/mo | 11.75 | 13.2 | 19.0 | | |
| Maintenance | $/mo | 445 | 505 | 745 | | |
| Incremental Cost | $/by | | 1.84 | 1.79 | | |
| Maint. Cost/$100k | $/mo | 91.3 | 92.2 | 94.5 | | |
| Univac 1108 ('65) | | | | | | |
| Memory Capy. | kby | 384 | 768 | 1152 | 1536 | |
| Price | $k | 1071.0 | 1491.0 | 1911.0 | 2331.0 | |
| Rental | k$/mo | 25.5 | 35.5 | 45.5 | 55.5 | |
| Maintenance | $/mo | 2782.0 | 3332 | 3832 | 4332 | |
| Incremental Cost | $/by | | 1.07 | 1.07 | 1.07 | |
| Maint. Cost/$100k | $/mo | 259.8 | 223.5 | 200.5 | 185.8 | |
| IBM 360/20 ('67) | | | | | | |
| Memory Capy. | kby | 4 | 8 | 12 | 16 | |
| Price | $k | 23.57 | 32.59 | 44.23 | 55.10 | |
| Rental | k$/mo | .500 | .700 | .95 | 1.20 | |
| Maintenance | $/mo | 37 | 42 | 48 | 52 | |
| Incremental Cost | $/by | | 2.20 | 2.84 | 2.66 | |
| Maint. Cost/$100k | $/mo | 157.0 | 128.9 | 108.5 | 94.4 | |
| IBM 360/30 ('67) | | | | | | |
| Memory Capy. | kby | 8 | 16 | 32 | 64 | |
| Price | $k | 60.14 | 82.65 | 123.97 | 178.39 | |
| Rental | k$/mo | 1.275 | 1.775 | 2.675 | 3.875 | |
| Maintenance | $/mo | 90 | 100 | 115 | 135 | |
| Incremental Cost | $/by | | 2.75 | 2.52 | 1.66 | |
| Maint. Cost/$100k | $/mo | 150.0 | 121.0 | 92.8 | 75.7 | |
| IBM 360/40('67) | | | | | | |
| Memory Capy. | kby | 16 | 32 | 64 | 128 | 256 |
| Price | $k | 135.4 | 176.7 | 231.15 | 306.8 | 485.3 |

**TABLE II.2.11.2 SYSTEM MEMORY CAPACITY AND PRICE (continued) ●**

| | Units | Memory Capacity and Price | | | | |
|---|---|---|---|---|---|---|
| Rental | k$/mo | 2.70 | 3.60 | 4.80 | 6.4 | 10.2 |
| Maintenance | $/mo | 105 | 120 | 140 | 170 | 270 |
| Incremental Cost | $/by | | 2.52 | 1.66 | 1.15 | 1.36 |
| Maint. Cost/$100k | $/mo | 77.5 | 67.9 | 60.6 | 55.4 | 55.5 |
| IBM 360/44('67) | | | | | | |
| Memory Capy. | kby | 32 | 64 | 128 | 256 | |
| Price | $k | 119.9 | 174.3 | 250.0 | 428.5 | |
| Rental | k$/mo | 3.47 | 4.67 | 6.27 | 10.07 | |
| Maintenance | $/mo | 200 | 220 | 250 | 350 | |
| Incremental Cost | $/by | | 1.66 | 1.15 | 1.36 | |
| Maint. Cost./$100k | $/mo | 166.8 | 126.2 | 100.0 | 81.7 | |
| IBM 360/50('67) | | | | | | |
| Memory Capy. | kby | 64 | 128 | 256 | 512 | |
| Price | $k | 409.1 | 484.7 | 663.2 | 950.1 | |
| Rental | k$/mo | 8.35 | 9.95 | 13.75 | 19.95 | |
| Maintenance | $/mo | 260 | 290 | 390 | 570 | |
| Incremental Cost | $/by | | 1.15 | 1.36 | 1.09 | |
| Maint. Cost/$100k | $/mo | 63.6 | 59.8 | 58.8 | 60.0 | |
| IBM 360/65('67) | | | | | | |
| Memory Capy. | kby | 128 | 256 | 512 | 1024 | |
| Price | $k | 960.3 | 1358 | 1757.6 | 2174.7 | |
| Rental | k$/mo | 22.75 | 32.0 | 41.3 | 51.1 | |
| Maintenance | $/mo | 985 | 1560 | 2135 | 2730 | |
| Incremental Cost | $/by | | 3.03 | 1.52 | .796 | |
| Maint. Cost/$100k | $/mo | 102.6 | 114.9 | 121.5 | 125.5 | |
| IBM S3/6('71) | | | | | | |
| Memory Capy. | kby | 8 | 12 | 16 | | |
| Price | $k | 28.75 | 34.55 | 35.25 | | |
| Rental | k$/mo | .590 | .705 | .820 | | |
| Maintenance | $/mo | 125 | 130 | 130 | | |
| Incremental Cost | $/by | | 1.27 | .181 | | |
| Maint. Cost/$100k | $/mo | 434.8 | 376.3 | 368.8 | | |
| IBM S3/10('71) | | | | | | |
| Memory Capy. | kby | 8 | 12 | 16 | 32 | 48 |
| Price | $k | 16.11 | 21.3 | 22.04 | 39.96 | 57.87 |
| Rental | k$/mo | .328 | .434 | .555 | 1.04 | 1.36 |
| Maintenance | $/mo | 38 | 42 | 42 | 56 | 78 |
| Incremental Cost | $/by | | 1.27 | .181 | 1.09 | 1.09 |
| Maint. Cost/$100k | $/mo | 235.9 | 197.2 | 190.6 | 140.1 | 134.8 |
| IBM S3/15 ('75) | | | | | | |
| Memory Capy. | kby | 48 | 64 | 96 | 128 | |
| Price | k$ | 63.0 | 67.0 | 78.0 | 86.0 | |
| Rental | k$/mo | 1.63 | 1.74 | 2.01 | 2.225 | |
| Maintenance | $/mo | 227 | 232 | 238 | 248 | |
| Incremental Cost | $/by | | .244 | .336 | .244 | |
| Maint. Cost/$100k | $/mo | 360.3 | 346.3 | 305.1 | 283.7 | |
| IBM 1130 ('71) | | | | | | |
| Memory Capy. | kby | 4 | 8 | 16 | 32 | |
| Price | $k | 33.57 | 41.48 | 63.00 | 104.7 | |
| Rental | k$/mo | .78 | .98 | 1.465 | 2.435 | |
| Maintenance | $/mo | 95 | 100 | 150 | 165 | |
| Incremental Cost | $/by | | 1.93 | 2.63 | 2.55 | |
| Maint. Cost/$100k | $/mo | 283.0 | 241.1 | 238.1 | 157.6 | |
| IBM 370/125 ('73) | | | | | | |
| Memory Capy. | kby | 96 | 128 | 160 | 192 | 256 |
| Price | $k | 231.6 | 241.3 | 251.0 | 260.7 | 280.1 |
| Rental | k$/mo | 4.775 | 4.975 | 5.175 | 5.375 | 5.775 |
| Maintenance | $/mo | 290 | 295 | 300 | 305 | 315 |
| Incremental Cost | $/by | | .296 | .296 | .296 | .296 |
| Maint. Cost/$100k | $/mo | 125.2 | 122.3 | 119.5 | 117.0 | 112.5 |
| IBM 370/135 ('73) | | | | | | |
| Memory Capy. | kby | 96 | 192 | 256 | 384 | 512 |
| Price | $k | 281.23 | 369.28 | 415.0 | 475.0 | 535.0 |
| Rental | k$/mo | 5.67 | 7.47 | 8.67 | 9.92 | 11.17 |
| Maintenance | $/mo | 460 | 520 | 610 | 710 | 810 |
| Incremental Cost | $/by | | .896 | .697 | .458 | .458 |
| Maint. Cost/$100k | $/mo | 163.6 | 140.8 | 147.0 | 149.5 | 151.4 |
| IBM 370/145 ('73) | | | | | | |
| Memory Capy. | kby | 160 | 256 | 512 | 1024 | |

TABLE II.2.11.2 SYSTEM MEMORY CAPACITY AND PRICE (continued) ●

| | Units | Memory Capacity and Price | | | |
|---|---|---|---|---|---|
| Price | $k | 583.4 | 669.8 | 797.0 | 1037.0 |
| Rental | k$/mo | 12.16 | 13.96 | 16.61 | 21.61 |
| Maintenance | $/mo | 1070 | 1130 | 1300 | 1695 |
| Incremental Price | $/by | | .879 | .485 | .458 |
| Maint. Cost/$100k | $/mo | 183.4 | 168.7 | 163.1 | 163.5 |
| IBM 370/155 ('73) | | | | | |
| Memory Capy. | kby | 256 | 512 | 1024 | 2048 |
| Price | $k | 1091.0 | 1225.4 | 1515.4 | 1888.3 |
| Rental | k$/mo | 22.98 | 26.03 | 32.57 | 40.84 |
| Maintenance | $/mo | 2020 | 2310 | 2900 | 3540 |
| Incremental Price | $/by | | .513 | .553 | .355 |
| Maint. Cost/$100k | $/mo | 185.2 | 188.5 | 191.4 | 187.5 |
| IBM 370/165 ('73) | | | | | |
| Memory Capy. | kby | 512 | 1024 | 2048 | 3072 |
| Price | $k | 1974.7 | 2243.8 | 2808.0 | 3387.8 |
| Rental | k$/mo | 41.64 | 47.75 | 60.5 | 73.58 |
| Maintenance | $/mo | 3550 | 4140 | 5380 | 6640 |
| Incremental Price | $/by | | .513 | .538 | .553 |
| Maint. Cost/$100k | $/mo | 179.8 | 184.5 | 191.6 | 196.0 |

## TABLE II.2.11.3 IBM PRICE TRENDS I —NOTES

This table reports the result of an analysis of samples of purchase prices, rentals, and maintenance prices, for IBM equipment. For the years 1960, 1963, 1967, and 1969, the sources were the "authorized federal supply schedule price lists" for each of the (fiscal) years. For 1973, the source was an IBM publication, "Notice to IBM Customers" dated November 26, 1973 and providing a new set of prices effective that date.

My procedure in creating the table was as follows: I began by selecting, for each year, a sample set of model numbers in each of the indicated categories. I tried to choose model numbers for the more important and widely used units. And in each year I included some new units, together with all previously-selected units which still appeared in the catalogue. For each of these model numbers in each year, I compiled a list showing the basic monthly rental, the purchase price (excluding excise tax) and the monthly maintenance charge. Next, for each device in each year, I computed the ratio of price to monthly rental and of maintenance price to purchase price (in the latter case, I used purchase price expressed in units of $100,000). Finally, I averaged these two ratios over the units included in each category of machine (processors, processor storage, controllers, etc.), and averaged all ratios to get the figures labelled "Total—All Units".

There are basically six sections to the table: three sets of rows, and two column groupings. The first nine rows show the number of model numbers included in each sample; the second block of nine rows shows the price/rental ratio for that group of model numbers; and the last block shows the maintenance price per $100k sales price.

The first five columns, under the general heading "all units" provides a cumulative record of the average ratios for all units in the sample. Each year thus contains data on units first released some years before. The six columns labelled "new units only" represent a sub-sample of the columns labelled "all units" for 1960, the two samples are the same. For 1963, I omitted, in the "new units" sample, any model numbers which had been included in the 1960 sample. For 1967 and 1969, I omitted all model numbers which had appeared in either the 1960 or 1963 sample. And for 1973, I omitted all model numbers appearing in the 1960, 1963, and 1967 samples. The result should be that, for the "new units only" columns, the 1963 data should include only units introduced between 1960 and 1963; the 1967 column includes only units introduced between 1963 and 1967; the 1969 data includes only units introduced between 1963 and 1969; and the 1973 data includes only units introduced between 1967 and 1973.

The column labelled "1967 Sharpe" shows the result of a similar but more limited study published earlier (SharW69,pp. 270-277).

## TABLE II.2.11.4 IBM PRODUCT PRICE TRENDS II—NOTES

This table shows how IBM's prices for various products have changed between 1960 and 1973. The data for the years 1971 and later comes from the *IBM Consultants Manual.* The data for all other years comes from IBM's GSA Catalogues of prices to the federal government. In 1964 there was a mid-year price change for some products; I therefore provide two columns for that year. If, for a particular unit, none of its prices changed, I made no entry in the second column.

The data on each product appears in six consecutive lines. The first line shows the unit's model number, and its purchase price in thousands of dollars. The second line shows monthly rental in thousands of dollars per month; and the third line maintenance cost in dollars per month. In IBM terminology, these are generally known as "purchase price excluding taxes", "basic monthly rental", and "maintenance monthly charge".

The second group of three lines appearing for each model number shows the trends in unit price compared to the original price I have recorded. They are computed by taking the ratio of the appropriate price to the first price in the corresponding row. For example, looking at the ratios for the 650-2 processor in the year 1968: The purchase ratio of .250 is the ratio of $28.8k to $115k; the rental ratio of 1.0 is the ratio of $2.4k to $2.4k; and the maintenance ratio of 1.92 is the ratio of $355 to $185.

### TABLE II.2.11.3 IBM PRODUCT PRICE TRENDS I ●

| | All Units 1960 | All Units 1963 | All Units 1967 | All Units 1969 | All Units 1973 | New Units Only 1960 | New Units Only 1963 | New Units Only 1967 | New Units Only 1967 Sharpe | New Units Only 1969 | New Units Only 1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number in Sample** | | | | | | | | | | | |
| Processors | 18 | 67 | 99 | 103 | 158 | 18 | 53 | 36 | 52 | 58 | 56 |
| Processor Storage | 9 | 19 | 20 | 20 | 32 | 9 | 10 | 3 | 5 | 10 | 12 |
| Controllers | 20 | 28 | 32 | 24 | 43 | 20 | 10 | 14 | 14 | 15 | 10 |
| Magnetic Tape Units | 3 | 10 | 22 | 22 | 18 | 3 | 8 | 13 | 27 | 15 | 5 |
| Moving-Head Files | 12 | 21 | 19 | 28 | 42 | 12 | 9 | 7 | 5 | 17 | 18 |
| Head-Per-Track Files | 1 | 3 | 3 | 2 | 4 | 1 | 2 | 2 | 2 | 2 | 2 |
| Card Equipment | 12 | 19 | 28 | 24 | 33 | 12 | 7 | 12 | 11 | 14 | 5 |
| Line Printers | 8 | 10 | 20 | 23 | 27 | 8 | 4 | 10 | 2 | 14 | 7 |
| Total | 83 | 177 | 243 | 246 | 357 | 83 | 103 | 97 | 118 | 145 | 115 |
| **Price/Rental Ratio** | | | | | | | | | | | |
| Processors | 51.1 | 53.6 | 45.9 | 47.1 | 46.7 | 51.1 | 54.3 | 42.6 | 42.8 | 44.5 | 45.5 |
| Processor Storage | 42.5 | 45.4 | 45.4 | 47.2 | 43.7 | 42.5 | 48.6 | 44.9 | 46.2 | 46.8 | 41.5 |
| Controllers | 47.4 | 48.0 | 43.3 | 47.5 | 41.1 | 47.4 | 49.6 | 48.0 | 49.2 | 46.5 | 37.3 |
| Magnetic Tape Units | 42.1 | 49.6 | 44.9 | 46.9 | 39.5 | 42.1 | 49.9 | 46.6 | 48.7 | 43.2 | 42.0 |
| Moving-Head Files | 50.8 | 48.3 | 47.3 | 43.7 | 55.5 | 50.8 | 45.0 | 47.6 | 41.2 | 43.1 | 39.4 |
| Head-Per-Track Files | 39.1 | 43.6 | 46.0 | 42.1 | 37.8 | 39.1 | 45.9 | 42.1 | 43.3 | 42.1 | 39.9 |
| Card Equipment | 46.6 | 49.0 | 50.2 | 50.2 | 47.3 | 46.6 | 54.8 | 53.1 | 53.5 | 49.9 | 42.7 |
| Line Printers | 47.0 | 48.6 | 48.9 | 47.8 | 43.5 | 47.0 | 52.6 | 50.1 | 45.1 | 47.8 | 41.5 |
| Total—All Units | 47.7 | 50.8 | 46.7 | 47.1 | 44.4 | 47.7 | 51.8 | 46.4 | 46.1 | 44.2 | 42.8 |
| **Maintenance Price Per $100k Sales Price ($/mo.)** | | | | | | | | | | | |
| Processors | 80 | 84 | 91 | 119 | 148 | 80 | 78 | 106 | 104 | 131 | 218 |
| Processor Storage | 29 | 47 | 67 | 86 | 124 | 29 | 50 | 135 | 127 | 125 | 142 |
| Controllers | 71 | 109 | 112 | 88 | 154 | 71 | 108 | 93 | 74 | 96 | 298 |
| Magnetic Tape Units | 470 | 318 | 395 | 314 | 419 | 470 | 311 | 323 | 262 | 331 | 418 |
| Moving-Head Files | 439 | 325 | 269 | 289 | 366 | 439 | 172 | 243 | 227 | 291 | 402 |
| Head-Per-Track Files | 160 | 221 | 304 | 408 | 352 | 160 | 132 | 414 | 408 | 408 | 278 |
| Card Equipment | 207 | 199 | 401 | 439 | 437 | 207 | 190 | 340 | 312 | 519 | 514 |
| Line Printers | 394 | 281 | 373 | 398 | 434 | 394 | 238 | 339 | 264 | 381 | 589 |
| Total—All Units | 188 | 152 | 195 | 210 | 237 | 188 | 119 | 203 | 170 | 232 | 291 |
| Deflated (1958 dollars) | 182 | 142 | 166 | 164 | 154 | 182 | 111 | 173 | 145 | 181 | 189 |

### TABLE II.2.11.4 IBM PRODUCT PRICE TRENDS II

| | Units | 1960 | 1963 | 1964-1 | 1964-2 | 1967 | 1968 | 1969 | 1971 | 1973 | 1975 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Processors** | | | | | | | | | | | |
| 650-2—Purchase | $k | 115.0 | 115.0 | 115.0 | | 28.8 | 28.8 | | | | |
| Rental | $/mo | 2400 | 2400 | 2400 | | 2400 | 2400 | | | | |
| Maintenance | $/mo | 185 | 185 | 173 | | 355 | 355 | | | | |
| Ratios-Purchase | | 1.0 | 1.0 | 1.0 | 1.0 | .250 | .250 | | | | |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | |
| Maint. | | 1.0 | 1.0 | .935 | .935 | 1.92 | 1.92 | | | | |
| 1401-C6—Purchase | $k | | 133.7 | 133.7 | | 133.7 | 133.7 | 129.6 | | 132.0 | 137.3 |
| Rental | $/mo | | 2755 | 2755 | | 2755 | 2755 | 2670 | | 2720 | 2825 |
| Maintenance | $/mo | | 85 | 79 | | 95 | 95 | 86 | | 87 | 102 |
| Ratios-Purchase | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .969 | | .987 | 1.03 |
| Rental | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .969 | | .987 | 1.03 |
| Maint. | | | 1.0 | .929 | .929 | 1.12 | 1.12 | 1.01 | | 1.02 | 1.20 |
| 2030-D—Purchase | $k | | | 85.2 | | 82.7 | 82.7 | 80.2 | 80.2 | 81.7 | 85.0 |
| Rental | $/mo | | | 1775 | | 1775 | 1830 | 1775 | 1850 | 1880 | 1950 |
| Maintenance | $/mo | | | 100 | | 100 | 100 | 100 | 108 | 110 | 129 |
| Ratios-Purchase | | | | 1.0 | 1.0 | .971 | .971 | .941 | .941 | .959 | .998 |
| Rental | | | | 1.0 | 1.0 | 1.0 | 1.03 | 1.0 | 1.04 | 1.06 | 1.10 |
| Maint. | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.08 | 1.10 | 1.29 |
| 5410-A6—Purchase | $k | | | | | | | 48.3 | 39.7 | 40.7 | 34.6 |
| Rental | $/mo | | | | | | | 985 | 1040 | 1060 | 1185 |
| Maintenance | $/mo | | | | | | | 30 | 56 | 57 | 62 |
| Ratios-Purchase | | | | | | | | 1.0 | .822 | .843 | .716 |
| Rental | | | | | | | | 1.0 | 1.06 | 1.08 | 1.20 |
| Maint. | | | | | | | | 1.0 | 1.87 | 1.90 | 2.07 |
| 3135-GF—Purchase | | | | | | | | | 369.3 | 348.5 | 415.0 |
| Rental | $/mo | | | | | | | | 7470 | 7050 | 8385 |

**TABLE II.2.11.4 IBM PRODUCT PRICE TRENDS II (continued)**

| | Units | 1960 | 1963 | 1964-1 | 1964-2 | 1967 | 1968 | 1969 | 1971 | 1973 | 1975 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maintenance | $/mo | | | | | | | | 650 | 650 | 622 |
| Ratios-Purchase | | | | | | | | | 1.0 | .944 | 1.12 |
| Rental | | | | | | | | | 1.0 | .944 | 1.12 |
| Maint. | | | | | | | | | 1.0 | 1.0 | .957 |
| **Core Memories** | | | | | | | | | | | |
| 1406-1—Purchase | $k | 20.1 | 24.5 | 24.5 | | 24.5 | 24.5 | 23.8 | 23.8 | 24.2 | NA |
| Rental | $/mo | 575 | 575 | 575 | | 575 | 575 | 560 | 560 | 571 | |
| Maintenance | $/mo | 14 | 14 | 13 | | 15 | 15 | 15 | 15 | 15 | |
| Ratios-Purchase | | 1.0 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.18 | 1.18 | 1.20 | |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .974 | .974 | .993 | |
| Maint. | | 1.0 | 1.0 | .929 | .929 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | |
| 2365-1—Purchase | $k | | | | | 276.5 | 276.5 | 268.8 | | 273.0 | NA |
| Rental | $/mo | | | | | 6200 | 6385 | 6195 | | 6310 | |
| Maintenance | $/mo | | | | | 375 | 375 | 300 | | 275 | |
| Ratios-Purchase | | | | | | 1.0 | 1.0 | .972 | | .987 | |
| Rental | | | | | | 1.0 | 1.03 | .999 | | 1.02 | |
| Maint. | | | | | | 1.0 | 1.0 | .80 | | .733 | |
| **Magnetic Tape Units** | | | | | | | | | | | |
| 729-2—Purchase | $k | 27.5 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 | 34.9 | 29.7 | 30.2 | NA |
| Rental | $/mo | 700 | 700 | 700 | 700 | 700 | 700 | 680 | 680 | 693 | |
| Maintenance | $/mo | 135 | 116 | 108 | 103 | 103 | 103 | 99 | 99 | 100 | |
| Ratios-Purchase | | 1.0 | 1.31 | 1.31 | 1.31 | 1.31 | 1.31 | 1.27 | 1.08 | 1.10 | |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .97 | .97 | .99 | |
| Maint. | | 1.0 | .859 | .80 | .763 | .763 | .763 | .733 | .733 | .741 | |
| 7330-1—Purchase | $k | | 22.0 | 22.0 | | 22.0 | 22.0 | 21.3 | | 21.7 | NA |
| Rental | $/mo | | 450 | 450 | | 450 | 450 | 435 | | 443 | |
| Maintenance | $/mo | | 52 | 49 | | 59 | 59 | 59 | | 59 | |
| Ratios-Purchase | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .968 | | .986 | |
| Rental | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .967 | | .984 | |
| Maint. | | | 1.0 | .942 | .942 | 1.13 | 1.13 | 1.13 | | 1.13 | |
| 2401-4—Purchase | $k | | | | | 18.0 | 18.0 | 17.4 | 14.8 | 15.0 | 16.5 |
| Rental | $/mo | | | | | 385 | 395 | 385 | 385 | 392 | 432 |
| Maintenance | $/mo | | | | | 74 | 74 | 74 | 74 | 80 | 94 |
| Ratios-Purchase | | | | | | 1.0 | 1.0 | .967 | .822 | .833 | .917 |
| Rental | | | | | | 1.0 | 1.03 | 1.0 | 1.0 | 1.02 | 1.12 |
| Maint. | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.08 | 1.27 |
| 2420-7—Purchase | $k | | | | | | 54.6 | 53.0 | 45.0 | 45.9 | 50.6 |
| Rental | $/mo | | | | | | 1050 | 1020 | 1020 | 1039 | 1140 |
| Maintenance | $/mo | | | | | | 120 | 120 | 120 | 122 | 143 |
| Ratios-Purchase | | | | | | | | .971 | .824 | .841 | .927 |
| Rental | | | | | | | | .971 | .971 | .990 | 1.09 |
| Maint. | | | | | | | | 1.00 | 1.00 | 1.02 | 1.19 |
| **Moving-Head Files** | | | | | | | | | | | |
| 350-3 or 355-2—Purchase | $k | 57.0 | 57.0 | 57.0 | | NA | | | | | |
| Rental | $/mo | 1075 | 1075 | 1075 | | | | | | | |
| Maintenance | $/mo | 225 | 225 | 209 | | | | | | | |
| Ratios-Purchase | | 1.0 | 1.0 | 1.0 | 1.0 | | | | | | |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | | | | | | |
| Maint. | | 1.0 | 1.0 | .929 | .929 | | | | | | |
| 1311-2—Purchase | $k | | 17.0 | 28.8 | 28.8 | 28.8 | 28.8 | 16.0 | 16.0 | 16.3 | NA |
| Rental | $/mo | | 375 | 650 | 650 | 650 | 650 | 350 | 350 | 357 | |
| Maintenance | $/mo | | 29 | 52 | 50 | 63 | 63 | 46 | 46 | 46 | |
| Ratios-Purchase | | | 1.0 | 1.69 | 1.69 | 1.69 | 1.69 | .941 | .941 | .959 | |
| Rental | | | 1.0 | 1.73 | 1.73 | 1.73 | 1.73 | .933 | .933 | .952 | |
| Maint. | | | 1.0 | 1.79 | 1.72 | 2.17 | 2.17 | 1.59 | 1.59 | 1.59 | |
| 2311-1—Purchase | $k | | | 26.3 | | 25.5 | 25.5 | 24.7 | 21.0 | 21.4 | 23.6 |
| Rental | $/mo | | | 575 | | 590 | 590 | 570 | 570 | 580 | 639 |
| Maintenance | $/mo | | | 51 | | 55 | 55 | 55 | 55 | 56 | 66 |
| Ratios-Purchase | | | | 1.0 | 1.0 | .970 | .970 | .939 | .798 | .814 | .897 |
| Rental | | | | 1.0 | 1.0 | 1.03 | 1.03 | .991 | .991 | 1.01 | 1.11 |
| Maint. | | | | 1.0 | 1.0 | 1.08 | 1.08 | 1.08 | 1.08 | 1.10 | 1.29 |
| 2314-1—Purchase | $k | | | | | 244.4 | 244.4 | 237.1 | 177.8 | 181.0 | NA |
| Rental | $/mo | | | | | 5250 | 5410 | 5250 | 5250 | 5350 | |
| Maintenance | $/mo | | | | | 615 | 615 | 615 | 615 | 627 | |
| Ratios-Purchase | | | | | | 1.0 | 1.0 | .970 | .727 | .741 | |
| Rental | | | | | | 1.0 | 1.03 | 1.0 | 1.0 | 1.02 | |
| Maint. | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.02 | |
| 3330-1—Purchase | $k | | | | | | | | 51.9 | 52.9 | 47.6 |

**TABLE II.2.11.4 IBM PRODUCT PRICE TRENDS II (continued)**

| | Units | 1960 | 1963 | 1964-1 | 1964-2 | 1967 | 1968 | 1969 | 1971 | 1973 | 1975 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rental | $/mo | | | | | | | | 1300 | 1320 | 1450 |
| Maintenance | $/mo | | | | | | | | 170 | 173 | 187 |
| Ratios-Purchase | | | | | | | | | 1.0 | 1.02 | .917 |
| Rental | | | | | | | | | 1.0 | 1.02 | 1.12 |
| Maint. | | | | | | | | | 1.0 | 1.02 | 1.10 |
| **Punched-Card Units** | | | | | | | | | | | |
| 533-1—Purchase | $k | 25.0 | 25.0 | 25.0 | | 6.3 | 6.3 | NA | | | |
| Rental | $/mo | 550 | 550 | 550 | | 550 | 550 | | | | |
| Maintenance | $/mo | 53 | 53 | 49 | | 134 | 134 | | | | |
| Ratios-Purchase | | 1.0 | 1.0 | 1.0 | 1.0 | .252 | .252 | | | | |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | |
| Maint. | | 1.0 | 1.0 | .925 | .925 | 2.53 | 2.53 | | | | |
| 1402-1—Purchase | $k | | 30.0 | 30.0 | | 30.0 | 30.0 | 29.1 | NA | | |
| Rental | $/mo | | 550 | 550 | | 550 | 550 | 535 | | | |
| Maintenance | $/mo | | 45 | 42 | | 120 | 120 | 120 | | | |
| Ratios-Purchase | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .970 | | | |
| Rental | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .973 | | | |
| Maint. | | | 1.0 | .933 | .933 | 2.67 | 2.67 | 2.67 | | | |
| 2540-1—Purchase | $k | | | | | 34.0 | | 32.9 | 32.9 | 33.5 | 36.9 |
| Rental | $/mo | | | | | 660 | | 660 | 710 | 724 | 797 |
| Maintenance | $/mo | | | | | 115 | | 115 | 124 | 126 | 136 |
| Ratios-Purchase | | | | | | 1.0 | | .968 | .968 | .985 | 1.09 |
| Rental | | | | | | 1.0 | | 1.0 | 1.08 | 1.10 | 1.21 |
| Maint. | | | | | | 1.0 | | 1.0 | 1.08 | 1.10 | 1.18 |
| **Line Printers** | | | | | | | | | | | |
| 716-1—Purchase | $k | 54.2 | 54.2 | 54.2 | 54.2 | 54.2 | 54.2 | NA | | | |
| Rental | $/mo | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | | | | |
| Maintenance | $/mo | 116 | 116 | 108 | 103 | 135 | 135 | | | | |
| Ratios-Purchase | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | |
| Maint. | | 1.0 | 1.0 | .931 | .888 | 1.16 | 1.16 | | | | |
| 1403-1—Purchase | $k | 30.3 | 32.9 | 32.9 | | 32.9 | 32.9 | 31.9 | | 27.6 | 30.4 |
| Rental | $/mo | 725 | 725 | 725 | | 725 | 725 | 705 | | 718 | 790 |
| Maintenance | $/mo | 172 | 130 | 122 | | 166 | 166 | 138 | | 151 | 177 |
| Ratios-Purchase | | 1.0 | 1.09 | 1.09 | 1.09 | 1.09 | 1.09 | 1.05 | | .911 | 1.00 |
| Rental | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | .972 | | .990 | 1.09 |
| Maint. | | 1.0 | .756 | .709 | .709 | .965 | .965 | .802 | | .878 | 1.03 |
| 1403-N1—Purchase | $k | | | 41.2 | | 41.2 | 41.2 | 40.0 | 34.0 | 34.6 | 38.1 |
| Rental | $/mo | | | 900 | | 900 | 900 | 875 | 875 | 892 | 983 |
| Maintenance | $/mo | | | 138 | | 183 | 183 | 183 | 183 | 200 | 235 |
| Ratios-Purchase | | | | 1.0 | 1.0 | 1.0 | 1.0 | .971 | .825 | .840 | .925 |
| Rental | | | | 1.0 | 1.0 | 1.0 | 1.0 | .972 | .972 | .991 | 1.09 |
| Maint. | | | | 1.0 | 1.0 | 1.33 | 1.33 | 1.33 | 1.33 | 1.45 | 1.70 |
| **Head-Per-Track Files** | | | | | | | | | | | |
| 2301-1—Purchase | $k | | | 211.3 | | 96.0 | 96.0 | 93.1 | 79.2 | 80.7 | NA |
| Rental | $/mo | | | 4400 | | 2250 | 2250 | 2180 | 2180 | 2220 | |
| Maintenance | $/mo | | | 225 | | 435 | 435 | 400 | 360 | 367 | |
| Ratios-Purchase | | | | 1.0 | 1.0 | .454 | .454 | .441 | .375 | .429 | |
| Rental | | | | 1.0 | 1.0 | .511 | .511 | .495 | .495 | .505 | |
| Maint. | | | | 1.0 | 1.0 | 1.93 | 1.93 | 1.78 | 1.60 | 1.63 | |

## TABLE II.2.120.1 FLIP-FLOPS IN COMMERCIALLY AVAILABLE MODULES—NOTES

The data in this table comes from a series of dated sales brochures advertising modules and giving specifications and prices. Three separate categories of modules are shown, corresponding to three different frequency ranges as indicated in the first column. For each category, modules are listed in chronological order as shown in the second column. The manufacturers represented are the Computer Control Company (CCC—now a division of Honeywell), the Electronic Engineering Company of California (EECO), and the Digital Equipment Corporation (DEC). Access time, in microseconds, was computed as the reciprocal of operating frequency for each module. Price per flip-flop was computed by dividing module price (generally in purchase quantities of one hundred) by the number of flip-flops mounted on a module. Flip-flop volume was computed by dividing the volume of a module mount, computed by multiplying together its outside dimensions, by the maximum number of modules such a mount would hold. Power per flip-flop was computed by dividing module power by the number of flip-flops mounted on the module.

## TABLE II.2.120.2 SUMMARY OF REPRESENTATIVE MEMORY TECHNOLOGIES—NOTES

Except for the last entries, all data in this table comes from previous tables. The flip-flop summary is abstracted from Table II.2.120.1; the core and IC memory data from Table II.2.11.1; the head-per-track file information from Table II.2.12.2; the moving-head-file data from Table II.2.12.1; the magnetic tape unit data from Table II.2.12.3.

The specifications on data cells comes from the IBM Consultants Manual. The 1965 and 1970 prices come from IBM's GSA Pricing Catalogues for the years 1964 and 1971, respectively.

## TABLE II.2.120.3 MISCELLANEOUS INPUT-OUTPUT TECHNOLOGIES—NOTES

With the slight exception noted in the next paragraph, the data for this table comes from three articles: the CRT terminal information from McLaR73; the computer output microfilm information from HarmG69; and the optical character reader data from ReagF71-2.

The price data on the IBM terminals in the first portion of the table comes from the IBM 1974 Consultants Manual. For the IBM 2260, the two-unit price was computed by adding the price of a 2260-1 with keyboard to one-half the price of a 2848-3 controller including a 3357. The price for a 24-unit display was similarly calculated by adding the price of a 2260-2 with keyboard to 1/24th of the price of an appropriate controller (consisting of a 2848-1, twelve 3355's, and four 4859's). The price of a 2265 with keyboard includes the price of a 2845 controller. The 3275 display does not require a controller, though of course the price does include a keyboard.

### TABLE II.2.120.1 FLIP-FLOPS IN COMMERCIALLY AVAILABLE MODULES

| Operating Frequency (MHZ) | Year | Manufacturer | Access Time (microseconds) | Per Flip-Flop Values Price ($) | Volume (cu. in.) | Power (mw) | Technology |
|---|---|---|---|---|---|---|---|
| 0.1 to 1.0 | 1957 | C.C.C. | 10 | 49. | 9.1 | 190 | Transistor |
| | 1959 | E.E.Co. | 10 | 8.1 | 47.4 | 2590 | Vacuum Tube |
| | 1959 | E.E.Co. | 5 | 27.2 | 3.2 | 60 | Transistor |
| | 1960 | D.E.C. | 2 | 40. | 15.2 | 910 | Ge Transistor |
| | 1961 | C.C.C | 1 | 99. | 12.6 | 216 | Transistor |
| | 1962 | C.C.C. | 5 | 9.1 | 8.5 | 150 | Transistor |
| | 1962 | C.C.C. | 1 | 18.1 | 8.5 | 325 | Transistor |
| | 1962 | D.E.C. | 2 | 41. | 15.2 | 910 | Transistor |
| | 1963 | C.C.C. | 1 | 19.5 | 8.5 | 325 | Si Transistor |
| | 1964 | D.E.C. | 2 | 41. | 15.2 | 910 | Transistor |
| 1.01-5.0 | 1960 | D.E.C. | 0.2 | 84. | 15.2 | 820 | Transistor |
| | 1962 | D.E.C. | 0.2 | 85. | 15.2 | 820 | Transistor |
| | 1962 | C.C.C. | 0.2 | 27.4 | 8.5 | 450 | Ge Transistor |
| | 1964 | D.E.C. | 0.2 | 59. | 15.2 | 820 | Transistor |
| | 1965 | D.E.C. | 0.5 | 8.2 | 2.6 | 130 | I.C. |
| | 1966 | E.E.Co. | 0.2 | 6.8 | 2.0 | 20 | I.C. |
| Over 5.01 | 1960 | D.E.C. | 0.1 | 160. | 30.4 | 1710 | Transistor |
| | 1961 | C.C.C. | 0.06 | 156. | 10.4 | 1080 | Transistor |
| | 1962 | D.E.C. | 0.1 | 115. | 15.2 | 1300 | Transistor |
| | 1964 | D.E.C. | 0.1 | 70. | 15.2 | 1300 | Transistor |
| | 1965 | D.E.C. | 0.1 | 10. | 2.6 | 350 | I.C. |
| | 1972 | D.E.C. | 0.17 | 3.3 | 0.8 | 34 | I.C. |

### TABLE II.2.120.2 SUMMARY OF REPRESENTATIVE MEMORY TECHNOLOGIES ●

| | | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| **Flip-Flops** | | | | | | |
| Representative Unit | | CCC Module | DEC Module | DEC Module | DEC Module | |
| Price—Per Flip-Flop | $ | 50 | 40 | 8 | 5 | |
| Per Byte | $ | 400 | 320 | 64 | 40 | |

**TABLE II.2.120.2 SUMMARY OF REPRESENTATIVE MEMORY TECHNOLOGIES (Continued) ●**

| | | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| Access Time | Microsec. | 10 | 2 | 0.5 | 0.2 | |
| Capacity Per Module | Bytes | .125 | .125 | 0.5 | 1.0 | |
| **Core Memory** | | | | | | |
| Processor | | | IBM 1401 | IBM 360/30 | IBM 370/135 | IBM 370/135 |
| Incre. Price Per Byte | $ | | 5 | 2.52 | 0.70 | 0.79 |
| Access Time | Microsec. | | 11.5 | 2 | 0.77 | 0.77 |
| Maximum Capacity | kBytes | | 16 | 64 | 256 | 512 |
| **Integrated Circuit** | | | | | | |
| Processor | | | | | | IBM 370/125 |
| Incre. Price per Byte | $ | | | | | 0.30 |
| Access Time | Microsec. | | | | | 0.8 |
| Maximum Capacity | kBytes | | | | | 256 |
| **Head-Per-Track Files** | | | | | | |
| Representative Unit | | IBM 734 | Uni 8112 | IBM 2303 | IBM 2305-2 | IBM 2305-2 |
| Price Per Byte | cents | 183 | 23.4 | 2.73 | 1.4 | 1.3 |
| Access Time | ms | 12.5 | 17.3 | 8.75 | 5.0 | 5.0 |
| Maximum Capacity | MBytes | .06 | 3.932 | 3.91 | 11.259 | 11.259 |
| **Moving-Head Files** | | | | | | |
| Representative Unit | | IBM 350-3 | IBM 1301-1 | IBM 2314-1 | IBM 3330-1 | IBM 3330-11 |
| Price Per Byte | cents | 1.14 | .413 | .105 | .026 | .0185 |
| Access Time | ms | 500 | 132 | 87.5 | 38.3 | 38.3 |
| Maximum Capacity | MBytes | 5 | 28 | 29.176 | 100 | 200 |
| **Magnetic Tape Units** | | | | | | |
| Representative Unit | | IBM 727 | IBM 729-2 | IBM 2401-6 | IBM 3410-3 | IBM 3420-8 |
| Price Per Byte | cents | .36 | .24 | .166 | .054 | .050 |
| Rewind Time | sec. | 72 | 72 | 60 | 120 | 45 |
| Maximum Capacity | MBytes | 5.0 | 11.3 | 23.51 | 23.51 | 62.61 |
| **Data Cells** | | | | | | |
| Representative Unit | | | | IBM 2321 | IBM 2321 | |
| Purchase Price | $k | | | 136.5 | 109.17 | |
| Maximum Capacity | MBytes | | | 400 | 400 | |
| Price Per Byte | cents | | | .034 | .027 | |
| Access Time | ms | | | 390 | 390 | |

**TABLE II.2.120.3 MISCELLANEOUS INPUT-OUTPUT TECHNOLOGIES**

| | Maximum Data Transfer Rate (kby/sec.) | Purchase Price ($k) | Notes |
|---|---|---|---|
| **Terminals** | | | |
| BGH TD 700 | 0.48 | 3.85 | |
| BGH TD 800 | 0.48 | 5.49 | |
| IBM 2260 | 0.24 | 12.74 | 2 Units, 960-byte display |
| IBM 2260 | 0.24 | 3.58 | 24 Units, 240-byte display |
| IBM 2265 | 0.24 | 14.625 | 960-byte display |
| IBM 3275 | 0.24 | 6.1 | 480-byte display |
| Uni 100 | 0.96 | 5.95 | |
| CC-30 | 0.96 | 3.5 | |
| CDC 713-10 | 0.03 | 1.995 | |
| **COM** | | | |
| BGH 9260 | 50.0 | 85.0 | |
| BGH 9262 | 96.0 | 125.0 | |
| Memorex 1603 | 22.0 | 44.25 | |
| 3M F-EBR | 44.0 | 86.6 | Graphics Capability |
| SC 4440 | 49.5 | 102.5 | |
| **OCR** | | | |
| BGH 9134-1 | 2.70 | 90.0 | Check Reader |
| CDC 915 | .37 | 120.0 | Page Reader |
| CDC 921 | 2.21 | 60.0 | Forms Reader |
| CDC 936 | .75 | 156.0 | 12 Fonts |
| HIS 200 | 2.40 | 50.0 | Bar Code |
| HIS 243 | .70 | 163.0 | Forms Reader |
| IBM 1287-1 | 2.00 | 122.2 | Numeric Forms Reader |
| IBM 1287-3 | 2.00 | 183.5 | Alphanumeric Forms Reader |
| IBM 1288 | 1.00 | 223.4 | Alphanumeric Page Reader |
| NCR 420-2 | 1.66 | 86.0 | Journal Tape Reader |
| Univac 2703 | 1.50 | 42.0 | Forms Reader |

## TABLES II.2.12.1-5 PERIPHERAL PRODUCTS—NOTES

The next few tables provide data on the most widely-used forms of peripheral products. Each table is accompanied by a set of explanatory notes, as usual; but I begin by making a few remarks applicable to all these tables.

The choice of products to be included in the tables was largely arbitrary. I attempted to choose peripherals which were used with the "important" systems, as defined in Table II.2.10. I therefore concentrated principally on the IBM peripherals, and added some from Burroughs (as used with the 205 and 5500), CDC (as used with the 6600), and Univac (as used with the Univac I, the 1004, and the 1108). I had no way of knowing which peripherals were most widely used (except for the IBM peripherals—see Table II.1.22), and so chose the peripheral model numbers which, in various reference works (see next paragraph) seemed to be offered with the "principal" computers.

My principal sources were as follows. For date of first installation: AuerCTR (where date of first installation was explicitly given in detailed peripheral products sheets); and, most often, by guessing a date related to the date of first shipment of the associated computer. For unit characteristics: manufacturer's literature, where available; WeikM; GillF61; AuerCTR; and CresM. For price data, I used the manufacturer's GSA price catalogs where available. Explicitly, I used the IBM catalogs for 1960, 1963, 1964, 1967, 1968, and 1969; the Univac catalogs for 1963, 1965, and 1967; and the CDC catalog for 1964 (in each case, the date given is the year beginning the period covered by the catalog. For example, a 1964 GSA catalog covers the period from July 1, 1964 through June 30, 1965). I have also used price lists associated with the IBM Consultant's Manual for the years 1971 to 1975. For other prices, I used WeikM, GillF61, and various issues of AuerCTR. For data on physical characteristics: for data on early systems, I used WeikM and GillF61. For more recent equipment the data comes from AuerCTR, and from two IBM manuals both entitled "Installation Manual—Physical Planning", one for System/360 and the other for System/370 (GC22-6820-11, dated April 1972, and GC22-7004-1, dated February 1972).

## TABLE II.2.12.1 MOVING-HEAD-FILES—NOTES

**Unit Characteristics.** 3. Moving-head-files have been constructed in two different configurations; as a stack of disks rotating on a common axis with read/write heads which move radially along the disks to access particular tracks; and as drums (cylinders) having heads which move along the axis of the drum. For disk files, the number of surfaces is the number of disk sides on which data is recorded. For drums, the number of "surfaces" is the number of cylinder segments, each of which is accessed by one axially-moving head.

4. Where the data is recorded on a removable medium, the model number of the medium is given on this line.

5. This line gives the outside diameter of the recording medium, in inches.

6-8a. Line 6 records the number of tracks on each of the surfaces of line 3. Lines 7 and 8 give the number of tracks per inch, and the number of bits per inch recorded on a track, both figures referring, of course, to the surface of the recording medium. Line 8a is the product of lines 7 and 8, and records the number of bits per square inch of recording area.

9-10a. The density on line 8 represents the maximum number of bits which can be stored in an inch of track—that is, in an inch along the direction of relative motion of the disk or drum and the read-write head. In practice, it is not possible to record at that density over the whole track, because when data is written by a magnetic head the writing action may alter data previously recorded just before the area currently being written. Therefore, data must be written in blocks or records, having spaces between them to allow for this effect. The total storage capacity of a device is very much dependent upon the number of bits written in each block—if blocks are short, much of the potential capacity of a track must be used for these inter-block gaps. Where variable-length records may be written on a device, the device manufacturer generally quotes a maximum capacity based on longest records and therefore the smallest number of gaps.

Line 9 shows the minimum number of records on each of the tracks of line 6. Line 10 shows the maximum number of bytes in each of these records. And line 10a provides a measure of the effect of the gap by showing how many bytes per record are lost for each additional record added per track. (For many devices, I could not determine this loss factor. And for those for which I could find a figure, the number given is an average.)

11-15. The time required for a moving-head-file to gain access to a particular block of data is a function of two attributes of the mechanism: the time required for the head, or assemblage of heads, to move from its current location to a location over the track containing the desired record; and the time required for the device to rotate from its position at the time the head reaches the desired track until the required record is under the head.

The second component of time is a function only of the speed at which the device rotates. That speed is given, in revolutions per minute, on line 11; and the average time required to wait for data, generally called the latency, is shown in line 12 in milliseconds. Average latency is generally one half of the time required for the disk to make a complete revolution. The average time required for the head assembly to move from one random location to another is shown on line 13. And the maximum and minimum head-motion times are shown on lines 14 and 15.

**Performance.** 17-17a. The maximum rate at which data can be transferred to or from the file is defined as the maximum number of bytes in a track multiplied by the disk speed. Line 17, then, is the product of lines 9, 10, and 11, divided by 60,000 to convert the result into thousands of characters per second. The "effective" transfer rate on line 17a is from AuerCTR, and estimates the maximum effective transfer rate of blocks of data to or from the file, assuming it is optimally located and taking into account the computer commands necessary to effect transfers.

18. Maximum capacity is the product of the number of surfaces (line 3), the number of tracks per surface (line 6), the number of records per track (line 9), and the number of bytes or characters per record (line 10). The units are millions of bytes.

19. Average access time is the sum of the average latency on line 12 and the average seek time on line 13. Generally speaking, the minimum access time will be the number on

## TABLE II.2.12.1 MOVING HEAD FILES ●

| | Manufacturers: Model Number: | | IBM 350-3 | IBM 355-2 | IBM 1405-1 | IBM 1405-2 | IBM 1301-1 | IBM 1301-2 | IBM 1311-2 | IBM 2311-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date Ist Installed** | mo/yr | /56 | /56? | /60 | /60? | /61 | /61 | /63 | 7/65 |
| 2. | **Unit Characteristics** | | | | | | | | | |
| 3. | Medium—No. Surfaces | | 100 | 100 | 50 | 100 | 40 | 80 | 10 | 10 |
| 4. | Disk Pack Model No. | | None | None | None | None | None | None | 1316 | 1316 |
| 5. | Diameter | in. | 24 | 24 | 24 | 24 | 24 | 24 | 14 | 14 |
| 6. | Recording—No. of Tracks | | 100 | 200 | 200 | 200 | 250 | 250 | 100 | 200 |
| 7. | Track Density | tr/in | 20 | 40 | 40 | 40 | 50 | 50 | 50 | 100 |
| 8. | Recording Density | b/in | 100 | - | 200 | 200 | 500 | 500 | 1000 | 1000 |
| 8a. | Area Density | bpsi | 2000 | - | 8000 | 8000 | 25000 | 25000 | 50000 | 100,000 |
| 9. | Records Per Track | | 10 | 1 | 5 | 5 | 1 | 1 | 20 | 1 |
| 10. | Bytes Per Record | | 50 | 600 | 200 | 200 | 2800 | 2800 | 100 | 3625 |
| 10a | By. Lost/Addl. Record | | - | - | - | - | 38 | 38 | - | 60 |
| 11. | Mechanism—Speed | rpm | 1200 | 1200 | 1200 | 1200 | 1790 | 1790 | 1500 | 2400 |
| 12. | Av. Latency | ms | 25 | 25 | 25 | 25 | 17 | 17 | 20 | 12.5 |
| 13. | Seek Time—Av. | ms | 475 | 575 | 600 | 600 | 115 | 115 | 250 | 85 |
| 14. | Maximum | ms | 800 | | 815 | 815 | 180 | 180 | 400 | 145 |
| 15. | Minimum | ms | 150 | | 0 | 0 | 0 | 0 | 0 | 0 |
| 16. | Performance | | | | | | | | | |
| 17. | Transfer Rate—Max. | kbps | 10.0 | 12.0 | 20.0 | 20.0 | 83.53 | 83.53 | 50.0 | 145.0 |
| 17a | Effective | kbps | | | 8.4 | 8.4 | 82.3 | 82.3 | 38.2 | 104.0 |
| 18. | Max. Unit Capacity | Mby | 5 | 12 | 10 | 20 | 28 | 56 | 2 | 7.25 |
| 19. | Av. Access Time | ms | 500 | 600 | 625 | 625 | 132 | 132 | 270 | 97.5 |
| 20. | **Prices** | | | | | | | | | |
| 21. | Typ. Controller Mod. No. | | | 652 | 3327 | 3327 | 7631 | 7631 | 1311-4 | 2841 |
| 22. | Systems | | 305 | 650 | 1401 | 1401 | 1410 | 1410 | 1401 | 360/370 |
| 23. | Price—Purchase | $k | | 46.8 | 10.85 | 10.85 | 42.0 | 42.0 | 24.85 | 26.43 |
| 24. | Rental | $k/mo. | | .975 | .355 | .355 | .835 | .835 | .525 | .525 |
| 25. | Maintenance | $/mo. | | 47 | 45.5 | 45.5 | 28.0 | 28.0 | 40.5 | 56 |
| 26. | Unit Price | $k | 57.0 | 74.8 | 36.0 | 48.5 | 115.5 | 185.5 | 16.51 | 25.51 |
| 27. | Rental | $k/mo. | 1.075 | 1.50 | .965 | 1.515 | 2.1 | 3.5 | .360 | .575 |
| 28. | Maintenance | $/mo. | 224 | 306 | 82.3 | 89.8 | 138 | 238 | 27 | 55 |
| 29. | Price Per 1000 Bytes | $/kby | 11.40 | 6.23 | 3.60 | 2.43 | 4.125 | 3.31 | 8.26 | 3.52 |
| 30. | Maint. Cost Per $100k | $/mo. | 393.0 | 409.1 | 228.6 | 185.2 | 119.5 | 128.3 | 163.5 | 215.6 |
| 31. | Price: Rent Ratio | | 53.0 | 49.9 | 37.3 | 32.0 | 55.0 | 53.0 | 45.9 | 44.4 |
| 32. | Accesses Per $ | k | 1.16 | .694 | 1.04 | .660 | 2.25 | 1.35 | 6.43 | 11.15 |
| 33. | **Physical Char.—Wt.** | lbs. | 1730 | 2090 | 2115 | 2115 | 3625 | 3825 | 390 | 280 |
| 34. | Floor Space | sq. ft. | 14.4 | 12.9 | 13.1 | 13.1 | 19.7 | 19.7 | 5.0 | 5.0 |
| 35. | Volume | cu. ft. | 87.9 | 76.4 | 76.6 | 76.6 | 113.3 | 113.3 | 15.8 | 15.8 |
| 36. | Electrical Load | kva | 4.0 | 4.6 | 4.4 | 4.4 | 7.5 | 9.0 | 0.75 | 0.75 |
| 37. | Heat Dissipation | kb/hr. | 8.1 | 12.7 | 3.24 | 3.24 | 16.7 | 20.0 | 2.0 | 2.0 |
| 38. | Density—Wt. | $lbs/ft.^3$ | 19.7 | 27.3 | 27.6 | 27.6 | 32.0 | 33.8 | 24.6 | 17.7 |
| 39. | Heat Per Cu. Ft. | kb/hr. | .092 | .166 | .042 | .042 | .147 | .176 | .126 | .126 |
| 40. | Capy. Per Floor Sp. | mbpsf. | .347 | .930 | .763 | 1.53 | 1.42 | 2.84 | .400 | 1.45 |
| 41. | Capy. Per Vol. | mbpcf. | .057 | .157 | .131 | .261 | .247 | .494 | .126 | .458 |
| 42. | Price Per Pound | $/lb. | 32.9 | 35.8 | 17.0 | 22.9 | 31.9 | 48.5 | 42.3 | 91.1 |

line 15, and the maximum will be the sum of line 14 and twice line 12.

**Prices.** 21-22. If a controller is required in addition to the device, the controller model number appears on line 21, and the computer system using device and controller appears on line 22. If the device itself includes a controller, the note "incl." appears on line 21. If I could identify no controller, and it was uncertain as to whether the device required a separate controller, I left line 21 blank.

23-28. Lines 23 through 25 give the purchase price, monthly rental, and monthly maintenance cost for the controller, and lines 26 through 28 provide the same information for the device itself. Sales prices are given in thousands of dollars, rental prices in thousands of dollars per month, and maintenance prices in dollars per month. Rental prices include maintenance figures; the maintenance charges are those paid by a user who has purchased a system. For some devices (e.g. IBM 3540) two or more configurations are available each with one controller and a variable number of devices. The prices shown are inferred from system prices, assuming total price equals controller price plus an integral number of spindle prices.

29. The price per thousand bytes of storage capacity is found by dividing the unit sale price on line 26 by maximum capacity on line 18.

30-31. Maintenance cost per $100,000 of sales price is the quotient of lines 28 and 26, multiplied by 100. The sales price/rent ratio is the ratio of line 26 to line 27.

32. Accesses per dollar are found by determining how many accesses can be made, on the average, to data in the file during a month of forty-hour weeks, and then by dividing that number by monthly rental. The result, in thousands of accesses per dollar, is found by dividing 624 by the product of lines 19 and 27.

**Physical Characteristics.** 33-42. The comments made regarding physical characteristics in connection with Table II.2.11.1 are applicable to the data on physical characteristics for moving-head files and all other peripherals.

**Comments on Specific Devices.** Some of the IBM model numbers actually include more than one mechanism. For example, the 2314-1 includes eight drives, the 2319-A2 includes three, and the 3330-11 contains two. In such cases, I have shown prices and physical characteristics on a *per mechanism* basis, dividing the published figures on prices, weights, dimensions, etc. by the number of mechanism per model number. For some devices, the price of a controller is inferred from data on the price of devices alone and the price of devices plus controllers. For example: the price of a controller for the 1311 was found by subtracting the 1311-2 price (device only) from the 1311-1 price (device plus controller); the price for a controller for the 3340 is found by subtracting the price of a 3340-B2 (two mechanisms) from that of a 3340-A2 (two mechanisms plus controller).

## TABLE II.2.12.1 MOVING HEAD FILES ●

| | Manufacturers: Model Number: | | IBM 2310-B1 | IBM 2314-1 | IBM 5444-1 | IBM 5444-2 | IBM 5444-A1 | IBM 5445-2 | IBM 2319-A2 | IBM 3330-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date lst Installed** | mo/yr | /66 | /66 | /69 | /69 | /70 | /70 | /70 | 8/71 |
| 2. | **Unit Characteristics** | | | | | | | | | |
| 3. | Medium–No. Surfaces | | 2 | 20 | 4 | 4 | 4 | 20 | 20 | 19 |
| 4. | Disk Pack Model No. | | 2315 | 2316 | 5440 | 5440 | 5440 | 2316 | 2316 | 3336-1 |
| 5. | Diameter | in. | 14 | 14 | 14 | 14 | 14 | 14 | 14 | |
| 6. | Recording–No. of Tracks | | 200 | 200 | 100 | 200 | 100 | 200 | 200 | 404 |
| 7. | Track Density | tr/in | | 100 | | | | | 100 | 200 |
| 8. | Recording Density | b/in | | 2200 | | | | | 2200 | 4000 |
| 8a. | Area Density | bpsi | | 220,000 | | | | | 220,000 | 800,000 |
| 9. | Records Per Track | | 1 | 1 | 24 | 24 | 24 | 20 | 1 | 1 |
| 10. | Bytes Per Record | | 2560 | 7294 | 256 | 256 | 256 | 256 | 7294 | 13,030 |
| 10a | By. Lost/Addl. Record | | | 101 | | | | - | | 135 |
| 11. | Mechanism Speed | rpm | 1500 | 2400 | 1500 | 1500 | 1500 | 2400 | 2400 | 3600 |
| 12. | Av. Latency | ms | 20 | 12.5 | 20 | 20 | 20 | 12.5 | 12.5 | 8.33 |
| 13. | Seek Time–Av. | ms | 500 | 75 | 163 | 269 | 86 | 60 | 60 | 30 |
| 14. | Maximum | ms | | 130 | 395 | 750 | 165 | 130 | 130 | 55 |
| 15. | Minimum | ms | | 25 | 0 | 0 | 0 | 0 | 25 | 10 |
| 16. | Performance | | | | | | | | | |
| 17. | Transfer Rate–Max. | kbps | 70.0 | 291.8 | 153.6 | 153.6 | 153.6 | 204.8 | 291.8 | 781.8 |
| 17a | Effective | kbps | 64.0 | 222.0 | - | - | - | - | 222.0 | - |
| 18. | Max. Unit Capacity | Mby | 1.024 | 29.176 | 2.457 | 4.915 | 2.457 | 20.48 | 29.176 | 100 |
| 19. | Av. Access Time | ms | 520 | 87.5 | 183 | 289 | 106 | 72.5 | 72.5 | 38.3 |
| 20. | **Prices** | | | | | | | | | |
| 21. | Typ. Controller Mod. No. | | 1133 | incl. | incl. | incl. | incl. | incl. | 2319-A1 | 3830 |
| 22. | Systems | | 1130 | | S/3 | S/3 | S/3 | S/3 | 370 | 370 |
| 23. | Price–Purchase | $k | 11.255 | | | | | | 0 | 95.88 |
| 24. | Rental | $k/mo. | .25 | | | | | | 0 | 2.4 |
| 25. | Maintenance | $/mo. | 12 | | | | | | 0 | 145 |
| 26. | Unit Price | $k | 12.15 | 30.555 | 8.55 | 10.28 | 8.45 | 15.075 | 12.75 | 25.97 |
| 27. | Rental | $k/mo. | .27 | .676 | .164 | .270 | .200 | .335 | .333 | .650 |
| 28. | Maintenance | $/mo. | 50 | 76.9 | 47 | 47 | 65 | 80 | 70 | 85 |
| 29. | Price Per 1000 Bytes | $/kby | 11.87 | 1.05 | 3.48 | 2.09 | 3.44 | .736 | .437 | .260 |
| 30. | Maint. Cost Per $100k | $/mo. | 411.5 | 251.7 | 549.7 | 457.2 | 769.2 | 530.7 | 549.0 | 327.3 |
| 31. | Price: Rent Ratio | | 45.0 | 45.2 | 52.1 | 38.1 | 42.3 | 45.0 | 38.3 | 40.0 |
| 32. | Accesses Per $ | k | 4.45 | 10.57 | 20.83 | 8.01 | 29.48 | 25.73 | 25.89 | 25.17 |
| 33. | **Physical Char.–Wt.** | lbs. | | 525 | | | | | 1100 | 725 |
| 34. | Floor Space | sq. ft. | | 5.08 | | | | | 8.07 | 4.58 |
| 35. | Volume | cu. ft. | | 25.42 | | | | | 40.37 | 22.9 |
| 36. | Electrical Load | kva | | .925 | | | | | 1.8 | 1.7 |
| 37. | Heat Dissipation | kb/hr. | | 2.55 | | | | | 5.5 | 4.7 |
| 38. | Density–Wt. | $lbs/ft.^3$ | | 20.7 | | | | | 27.2 | 31.6 |
| 39. | Heat Per Cu. Ft. | kb/hr. | | .100 | | | | | .136 | .205 |
| 40. | Capy. Per Floor Sp. | mbpsf. | | 5.74 | | | | | 3.61 | 21.8 |
| 41. | Capy. Per Vol. | mbpcf. | | 1.15 | | | | | .722 | 4.36 |
| 42. | Price Per Pound | $/lb. | | 58.2 | | | | | 11.6 | 35.8 |

### TABLE II.2.12.1 MOVING HEAD FILES ●

| | Manufacturers: Model Number: | | IBM 3330-11 | IBM 3340-B2 | IBM 3540 |
|---|---|---|---|---|---|
| 1. | **Date lst Installed** | mo/yr | /74 | 7/73 | /74 |
| 2. | **Unit Characteristics** | | | | |
| 3. | Medium–No. Surfaces | | 19 | 6 | 1 |
| 4. | Disk Pack Model No. | | 3336-11 | 3348 | - |
| 5. | Diameter | in. | | 14 | 7.8 |
| 6. | Recording–No. of Tracks | | 808 | 696 | 73 |
| 7. | Track Density | tr/in | 400 | 300 | 48 |
| 8. | Recording Density | b/in | 4000 | 5500 | 3200 |
| 8a. | Area Density | bpsi | 1.6M | 1.65M | 153.6k |
| 9. | Records Per Track | | 1 | 2 | 26 |
| 10. | Bytes Per Record | | 13030 | 8368 | 128 |
| 10a | By. Lost/Addl. Record | | 135 | 168 | - |
| 11. | Mechanism Speed | rpm | 3600 | 2970 | 360 |
| 12. | Av. Latency | ms | 8.33 | 10.1 | 83.3 |
| 13. | Seek Time–Av. | ms | 30 | 25 | 1925 |
| 14. | Maximum | ms | 55 | 50 | 3750 |
| 15. | Minimum | ms | 10 | 10 | 150 |
| 16. | Performance | | | | |
| 17. | Transfer Rate–Max. | kbps | 781.8 | 828.4 | 20.0 |
| 17a | Effective | kbps | - | - | - |
| 18. | Max. Unit Capacity | Mby | 200 | 69.890 | .243 |
| 19. | Av. Access Time | ms | 38.3 | 35.1 | 2008 |
| 20. | **Prices** | | | | |
| 21. | Typ. Controller Mod. No. | | 3333-11 | 3340-A2 | incl. |
| 22. | Systems | | 370 | 370 | 370 |
| 23. | Price–Purchase | $k | 13.0 | 12.0 | 10.5 |
| 24. | Rental | $k/mo. | .329 | .294 | .265 |
| 25. | Maintenance | $/mo. | 30 | 10 | 15 |
| 26. | Unit Price | $k | 37.0 | 16.2 | 11.5 |
| 27. | Rental | $k/mo. | .923 | .435 | .270 |
| 28. | Maintenance | $/mo. | 85 | 32 | 10 |
| 29. | Price Per 1000 Bytes | $/kby | .185 | .232 | 47.33 |
| 30. | Maint. Cost Per $100k | $/mo. | 230.0 | 197.5 | 87.0 |
| 31. | Price: Rent Ratio | | 40.1 | 37.2 | 42.6 |
| 32. | Accesses Per $ | k | 17.68 | 40.93 | |
| 33. | **Physical Char.–Wt.** | lbs. | | 435 | 380 |
| 34. | Floor Space | sq. ft. | | 4.88 | 7.50 |
| 35. | Volume | cu. ft. | | 18.93 | 16.88 |
| 36. | Electrical Load | kva | | .85 | .60 |
| 37. | Heat Dissipation | kb/hr. | | 2.50 | 1.58 |
| 38. | Density–Wt. | $lbs/ft.^3$ | | 22.98 | 22.51 |
| 39. | Heat Per Cu. Ft. | kb/hr. | | .132 | .094 |
| 40. | Capy. Per Floor Sp. | mbpsf. | | 14.32 | .032 |
| 41. | Capy. Per Vol. | mbpcf. | | 3.69 | .014 |
| 42. | Price Per Pound | $/lb. | | 37.24 | 57.89 |

## TABLE II.2.12.1 MOVING HEAD FILES ●

| | Manufacturers: Model Number: | | CDC 6603 | CDC 828 | CDC 853 | CDC 6638 | Univac 8206 | Univac 6610-0 | Univac 6010-10 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | /62? | /62? | /65? | /69? | /63? | /64 | /69 |
| 2. | **Unit Characteristics** | | | | | | 2 drums | 2 drums | drums |
| 3. | Medium—No. Surfaces | | 24 | | 10 | | 128 | 128 | 128 |
| 4. | Disk Pack Model No. | | | | 851 | | - | - | - |
| 5. | Diameter | in. | | | 14 | 26 | 23.8 | 23.8 | 23.8 |
| 6. | Recording—No. of Tracks | | | | 100 | | 48 | 96 | 96 |
| 7. | Track Density | tr/in | | | 50 | | 53 | 106 | 106 |
| 8. | Recording Density | b/in | | | 1105 | 850 | 1000 | 1000 | 1500 |
| 8a. | Area Density | bpsi | | | 55250 | | 53000 | 106,000 | 159,000 |
| 9. | Records Per Track | | | | 1 | | 64 | 64 | 96 |
| 10. | Bytes Per Record | | | | 4096 | - | 165 | 165 | 165 |
| 10a | By. Lost/Addl. Record | | | | | | | | |
| 11. | Mechanism—Speed | rpm | 950 | | 2400 | 1140 | 870 | 870 | 870 |
| 12. | Av. Latency | ms | 31.6 | | 12.5 | 26.3 | 35 | 35 | 35 |
| 13. | Seek Time—Av. | ms | 110 | | 85 | 55 | 58 | 58 | 58 |
| 14. | Maximum | ms | 160 | | 145 | 110 | 86 | 86 | 86 |
| 15. | Minimum | ms | 60 | | 30 | 0 | 30 | 30 | 30 |
| 16. | Performance | | | | | | | | |
| 17. | Transfer Rate—Max. | kbps | - | | 163.8 | | 153.1 | 153.1 | 229.7 |
| 17a | Effective | kbps | - | | 193.7 | | - | - | - |
| 18. | Max. Unit Capacity | Mby | 80.6 | 33.3 | 4.096 | 168 | 64.88 | 129.76 | 194.6 |
| 19. | Av. Access Time | ms | 141.6 | 195 | 97.5 | 81.3 | 93 | 93 | 93 |
| 20. | **Prices** | | | | | | | | |
| 21. | Typ. Controller Mod. No. | | incl. | 3632 | 3234 | | 8205 | 5009 | 5009-8 |
| 22. | Systems | | 6600 | 3xxx | 3xxx | | 490 | 1108 | 1108 |
| 23. | Price—Purchase | $k | | 77.0 | 25.0 | | 135.0 | 51.06 | 62.22 |
| 24. | Rental | $k/mo. | | 1.7 | .54 | | 2.75 | 1.165 | 1.43 |
| 25. | Maintenance | $/mo. | | 215 | 65 | | 100 | 115 | 135 |
| 26. | Unit Price | $k | 225.0 | 92.0 | 15.5 | 344.5 | 160.0 | 164.64 | 200.8 |
| 27. | Rental | $k/mo. | 5.60 | 2.4 | .35 | 8.995 | 3.3 | 3.75 | 4.615 |
| 28. | Maintenance | $/mo. | 675 | 410 | 48 | 816 | 250 | 300 | 350 |
| 29. | Price Per 1000 Bytes | $/kby | 2.79 | 2.76 | 3.78 | 2.05 | 2.47 | 1.27 | 1.03 |
| 30. | Maint. Cost Per $100k | $/mo. | 300.0 | 445.6 | 309.7 | 236.9 | 156.3 | 182.2 | 174.3 |
| 31. | Price: Rent Ratio | | 40.2 | 38.3 | 44.3 | 38.3 | 48.5 | 43.9 | 43.5 |
| 32. | Accesses Per $ | k | .788 | 1.34 | 18.32 | .855 | 2.04 | 1.79 | 1.46 |
| 33. | **Physical Char.—Wt.** | lbs. | | | | | 5150 | | |
| 34. | Floor Space | sq. ft. | | | | | 29.7 | | |
| 35. | Volume | cu. ft. | | | | | 237.2 | | |
| 36. | Electrical Load | kva | | | | | 12.5 | | |
| 37. | Heat Dissipation | kb/hr. | | | | | 19.5 | | |
| 38. | Density—Wt. | $lbs/ft.^3$ | | | | | 21.7 | | |
| 39. | Heat Per Cu. Ft. | kb/hr. | | | | | .082 | | |
| 40. | Capy. Per Floor Sp. | mbpsf. | | | | | 2.18 | | |
| 41. | Capy. Per Vol. | mbpcf. | | | | | .273 | | |
| 42. | Price Per Pound | $/lb. | | | | | 31.1 | | |

## TABLE II.2.12.2 HEAD-PER-TRACK FILES—NOTES

**Unit Characteristics.** 3-4. Head-per-track files, like moving-head-files, are manufactured either as drums (cylinders), or as a set of disks rotating on a common shaft. If the device is a drum, line 4 so indicates. If it is a disk, line 4 indicates the number of disk surfaces on which data is recorded. In either case, line 3 shows the outside diameter of drum or disks, in inches.

5-5a. The number of data tracks per surface is shown on line 5. A drum, of course, contains only one surface; and for drums the entry on line 5 is the number of tracks per drum. Normally, all the bits required to encode an alphabetic or numeric data character are recorded on and read sequentially from a single track. However, in some head-per-track files the rate at which data can be transferred is increased by recording characters in multiple tracks, and reading them back in parallel, several bits at a time. Line 5a shows the number of tracks required to record a character.

6-7a. Line 6 shows the number of tracks recorded per inch, along the axis of a drum or along the radius of a disk. Line 7 shows the maximum density at which data is recorded along the direction of motion of the device—around the circumference of a drum, or around the innermost track of a disk. The density is given in bits per inch. In some files, steps are taken to *reduce* the data transfer rate between file and processor by "interleaving" records on a track. With an interleave level of three, for example, a sequence of records would be written in every third record location on a track. Where such interleaving is possible, the interleave factor is given on line 7a.

8-9a. The number of records per track and the number of bytes in each record are given on lines 8 and 9. Where records of variable length are permitted, lines 8 and 9 describe the longest records, corresponding to the maximum capacity of the file. For such devices, line 9a shows the number of bytes lost per track for each record added. The IBM 2301, for example, loses 186 bytes (or very nearly 1% of its capacity) for each record added after the first one. If one wanted 1,000 bytes per record on the 2301, one would have to add about 16 more records per track and would lose (16 x 186) 2,976 bytes per track, or almost 15% of the capacity of the file.

10-11. The rotating speed of the mechanism is shown in line 10, and the average access time is shown on line 11. Generally average latency is half the time taken for the file to make one revolution. However, the average delay can be reduced by installing two or more heads on each track so that the maximum wait for an item of data is one-half revolution or less, and the average access time one-quarter or less.

13-14. The maximum character rate, on line 13, is computed assuming that a full track is read in one revolution of the mechanism. It is therefore computed by multiplying the number of records per track by the number of bytes per record, multiplying that product by the mechanism's speed in revolutions per second, and then dividing by the interleave factor. Line 14, the maximum capacity of the file, is found by multiplying lines 4, 5, 8, and 9.

**Price and Physical Characteristics.** The remarks given in describing Table II.2.12.1 are generally applicable here.

24. The file price per thousand bytes is found by dividing line 21 by line 14.

27. The number of accesses possible per dollar is found by dividing the average number of accesses per second by the rent in dollars per second. As usual, I have used the conversion factor of 624,000 seconds per month.

**Comments on Specific Devices.** The IBM 2305-1 has two heads per track. These heads are used not only to reduce average access time, but also to increase the data transfer rate by recording on or reading from both heads in parallel.

### TABLE II.2.12.2 HEAD-PER-TRACK FILES

| | Manufacturer:<br>Model Numbers: | | IBM<br>734 | IBM<br>733 | IBM<br>7320 | IBM<br>2301 | IBM<br>2303 | IBM<br>2305-1 | IBM<br>2305-2 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /58? | /61? | /62? | /63 | /65? | /71 | /71 |
| 2. | **Unit Characteristics** | | | | | | | | |
| 3. | Diameter | in. | | | 12.0 | 11.0 | | | |
| 4. | Number of Surfaces | | drum | 2 drums | drum | drum | drum | drum | drum |
| 5. | Recording—No. of Tr/Sur. | | | | 400 | 800 | 800 | 384 | 768 |
| 5a | Tracks Per Character | | | | 1 | 4 | 1 | 1 | 1 |
| 6. | Track Density | tr/in. | | | | 80 | | | |
| 7. | Recording Density | b/in. | | | | 1250 | 1105 | | |
| 7a | Interleave Factor | | | | 1 | 1 | 1 | 1 | 1 |
| 8. | Records Per Track | | | | 1 | 1 | 1 | 1 | 1 |
| 9. | Bytes Per Record | | | | 2796 | 20483 | 4892 | 14136 | 14660 |
| 9a | By. Lost/Addl. Record | | - | - | - | 186 | 146 | 415 | 415 |
| 10. | Mechanism—Speed | rpm | - | 2400 | 3500 | 3500 | 3400 | 6000 | 6000 |
| 11. | Av. Latency | ms | | 12.5 | 8.6 | 8.6 | 8.75 | 2.5 | 5.0 |
| 12. | Performance | | | | | | | | |
| 13. | Av. Character Rate | kcps | | | 163 | 1195 | 277.2 | 2827 | 1466 |
| 14. | Max. Unit Capacity | Mby | .060 | .049 | 1.12 | 4.096 | 3.91 | 5.428 | 11.259 |
| 15. | **Prices** | | | | | | | | |
| 16. | Typ. Controller Mod. No. | | | | | 2320 | 2841 | 2835-1 | 2835-2 |
| 17. | System | | | | 7094 | 360/370 | 360/70 | 360/370 | 360/370 |
| 18. | Price—Purchase | $k | | | | 112.3 | 26.43 | 119.85 | 99.88 |
| 19. | Rental | $k/mo. | | | | 2.3 | .525 | 3.0 | 2.5 |
| 20. | Maintenance | $/mo. | | | | 75 | 56 | 445 | 380 |

### TABLE II.2.12.2 HEAD-PER-TRACK FILES (continued)

| | Manufacturer: Model Numbers: | | IBM 734 | IBM 733 | IBM 7320 | IBM 2301 | IBM 2303 | IBM 2305-1 | IBM 2305-2 |
|---|---|---|---|---|---|---|---|---|---|
| 21. | Unit Price | $k | 110.0 | 90.0 | 124.0 | 211.3 | 106.7 | 195.76 | 155.8 |
| 22. | Rental | $k/mo. | 2.9 | 2.3 | 2.3 | 4.4 | 2.5 | 4.90 | 3.9 |
| 23. | Maintenance | $/mo. | 248 | 360 | 46 | 225 | 400 | 495 | 470 |
| 24. | Price Per 1000 Bytes | $/kby | 1833.3 | 1836.7 | 110.7 | 51.59 | 27.29 | 36.06 | 13.84 |
| 25. | Maint. Cost Per $100k | $/mo. | 225.5 | 400.0 | 37.1 | 106.5 | 374.9 | 252.9 | 301.6 |
| 26. | Price: Rent Ratio | | 37.9 | 39.1 | 53.9 | 48.0 | 42.7 | 40.0 | 40.0 |
| 27. | Accesses Per $ | k | | 21.74 | 31.60 | 16.52 | 28.57 | 51.02 | 32.05 |
| 28. | **Physical Char.–Wt.** | lbs. | 1930 | 1850 | | 850 | 850 | 1350 | 1350 |
| 29. | Floor Space | sq. ft. | 11.8 | 14.4 | | 6.95 | 6.95 | 10.7 | 10.7 |
| 30. | Volume | cu. ft. | 66.1 | 80.6 | | 37.0 | 37.0 | 53.3 | 53.3 |
| 31. | Electrical Load | kva | 10.4 | | | 1.5 | 1.7 | 4.8 | 4.8 |
| 32. | Heat Dissipation | kb/hr. | 25.2 | 17.4 | | 3.8 | 3.8 | 15.0 | 15.0 |
| 33. | Density–Wt. | lbs/ft.$^3$ | 29.2 | 22.9 | | 23.0 | 23.0 | 25.3 | 25.3 |
| 34. | Heat Per Cu. Ft. | kb/hr. | .381 | .216 | | .103 | .103 | .281 | .281 |
| 35. | Capy. Per Floor Sp. | MBpcf | .005 | .003 | | .589 | .562 | .507 | 1.05 |
| 36. | Capy. Per Vol. | MBpcf | .0009 | .0006 | | .111 | .106 | .102 | .211 |
| 37. | Price Per Pound | $/lb. | 57.0 | 48.6 | | 248.5 | 125.5 | 145.0 | 115.4 |

### TABLE II.2.12.2 HEAD-PER-TRACK FILES

| | Manufacturer: Model Numbers: | | BGH 430 | BGH 475 | BGH 9370-1 | BGH 9370-2 | BGH 9372-6 | Univac 8112 | Univac 6016 | Univac 6015 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /63? | /63? | /65? | /65? | /66? | /61 | /66 | /66 |
| 2. | **Unit Characteristics** | | | | | | | | | |
| 3. | Diameter | in. | | | | | | 24 | 10.5 | 24 |
| 4. | Number of Surfaces | | drum | disk | 1 | 2 | 8 | drum | drum | drum |
| 5. | Recording–No. of Tr/Sur. | | | | 100 | 100 | 125 | 768 | 384 | 1536 |
| 5a | Tracks Per Character | | 1 | 1 | 1 | 1 | 1 | 6 | 3 | 6 |
| 6. | Track Density | tr/in. | | | | | | - | - | - |
| 7. | Recording Density | b/in. | | | 1400 | 1400 | 1400 | 409 | 687 | 547 |
| 7a | Interleave Factor | | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 |
| 8. | Records Per Track | | - | - | 100 | 100 | 100 | 6144 | 2048 | 8192 |
| 9. | Bytes Per Record | | | | 100 | 100 | 100 | 5 | 5 | 5 |
| 9a | By. Lost/Addl. Record | | | | | | | | | |
| 10. | Mechanism–Speed | rpm | 3600 | 1500 | 1745 | 1745 | 1500 | 1800 | 7100 | 1800 |
| 11. | Av. Latency | ms | 8.3 | 20.0 | 17.0 | 17.0 | 20 | 17 | 4.23 | 16.7 |
| 12. | Performance | | | | | | | | | |
| 13. | Av. Character Rate | kcps | 15.4 | 100.0 | 291.0 | 291 | 250 | 307.2 | 1211.7 | 1228.8 |
| 14. | Max. Unit Capacity | Mby | .033 | 9.6 | 1.0 | 2.0 | 10.0 | 3.932 | 1.311 | 10.486 |
| 15. | **Prices** | | | | | | | | | |
| 16. | Typ. Controller Mod. No. | | | | 3371 | 3371 | 9371 | 8122 | 5012 | 5012 |
| 17. | System | | 5500 | 5500 | 2500 | 2500 | 2500 | 490 | 494 | 494 |
| 18. | Price–Purchase | $k | | | 7.2 | 7.2 | 31.2 | 71.0 | 82.52 | 82.52 |
| 19. | Rental | $k/mo. | | | .15 | .15 | .65 | 1.42 | 1.885 | 1.885 |
| 20. | Maintenance | $/mo. | | | 14 | 14 | 96 | 165 | 260 | 260 |
| 21. | Unit Price | $k | 70.55 | 44.55 | 18.0 | 21.6 | 35.1 | 92.0 | 42.435 | 117.21 |
| 22. | Rental | $k/mo. | 1.70 | .99 | .375 | .450 | .675 | 2.00 | .97 | 2.68 |
| 23. | Maintenance | $/mo. | 65 | 115 | 96 | 108 | 120 | 165 | 100 | 260 |
| 24. | Price Per 1000 Bytes | $/kby | 2137.9 | 4.64 | 18.0 | 10.8 | 3.51 | 23.40 | 32.37 | 11.18 |
| 25. | Maint. Cost Per $100k | $/mo. | 92.1 | 258.1 | 533.3 | 500 | 341.9 | 179.3 | 235.7 | 221.8 |
| 26. | Price: Rent Ratio | | 41.5 | 45.0 | 48.0 | 48.0 | 52.0 | 46.0 | 43.7 | 43.7 |
| 27. | Accesses Per $ | k | 44.3 | 31.56 | 98.0 | 81.7 | 46.3 | 18.38 | 152.3 | 13.96 |
| 28. | **Physical Char.–Wt.** | lbs. | | | | | | 1300 | 765 | 1700 |
| 29. | Floor Space | sq. ft. | | | | | | 13.1 | 8.0 | 15.1 |
| 30. | Volume | cu. ft. | | | | | | 70.0 | 42.7 | 80.6 |
| 31. | Electrical Load | kva | | | | | | 2.2 | 2.5 | |
| 32. | Heat Dissipation | kb/hr. | | | | | | 5.125 | .6 | |
| 33. | Density–Wt. | lbs/ft.$^3$ | | | | | | 18.6 | 17.9 | 21.1 |
| 34. | Heat Per Cu. Ft. | kb/hr. | | | | | | .073 | .014 | |
| 35. | Capy. Per Floor Sp. | MBpcf | | | | | | .300 | .164 | .694 |
| 36. | Capy. Per Vol. | MBpcf | | | | | | .056 | .031 | .130 |
| 37. | Price Per Pound | $/lb. | | | | | | 70.8 | 55.5 | 68.9 |

## TABLE II.2.12.3 MAGNETIC TAPE UNITS—NOTES

**Unit Characteristics.** 3-5. The material used in manufacturing tape, the width of the tape, and the length of tape on a tape reel are given in these three lines.

6-10. The number of tracks recorded in parallel across the width of the tape is shown in line 6. The number of bits per inch recorded along the length of the tape is shown in line 7. Many tape units permit recording at several densities, and alternate recording densities for such tapes are shown on lines 8 and 9. Line 10 shows how much space must be left between data blocks. This "wasted" space is necessary because the mechanism cannot record nor read reliably while the tape is accelerating or decelerating. When the tape is at rest, the read head lies over the middle of a gap. When an instruction is given to read one block of data, the tape starts moving and reaches full speed while the gap is still in contact with the read head. The data is then read at full speed, and when the mechanism detects the end of a block, it brakes the tape. The read head thus passes over the inter-block gap while the tape is starting and stopping.

11-14. The approximate times required for the mechanism to accelerate the tape from rest to full speed, and to decelerate it from full speed to rest, are given on lines 11 and 12. The tape speed used to read and write data is shown on line 13 in inches per second; and the speed at which the tape is rewound to its starting position is shown on line 14.

15-16. The mechanism used to move the tape, and that used to isolate or buffer the high-inertia tape reels from the drive mechanism with its very rapid accelerations and decelerations, are shown on lines 15 and 16. P.r. stands for pinch roller, a small idler wheel which is separated from the tape when the tape is not moving, but which presses the tape against a continuously-moving drive wheel when a read or write command is given. Vac. (on line 15) refers to a system where the surface of a constantly-moving drive wheel contains tiny holes. Normally, the non-moving tape rests loosely against this drive wheel. When a read or write command is given, the mechanism creates a vacuum, air pressure forces the tape against the wheel, and friction between wheel and tape causes the tape to move. Vac. in line 16 refers to a system where the tape drive mechanism is isolated from the tape reels by two chambers which employ a vacuum to capture a long loop of tape, and a feedback system to maintain the long loop by controlling the feed and takeup reels.

18. The maximum character rate is the number of alphanumeric characters read or written per second while the tape is moving at full speed and the maximum recording density is in use. It is computed by multiplying line 9 (or 8 or 7) by line line 13, and dividng the result by 1000 to convert to thousands of characters per second. In systems where more than one character is written across the width of the tape (e.g. the Burroughs 548 and 551, where 12 tracks permitted 1.5 characters to be recorded), I made an appropriate correction. Note that the character rate given here is the maximum *instantaneous* data transfer rate. The maximum practical data rate, occurring when the mechanism reads a long series of data blocks without stopping between each one, would be less than the instantaneous rate on line 18 because, during part of the time, the read-write head would be passing over the blank gap between data blocks. Under these circumstances, of course, the actual data rate is a function of block length..

19. Like the maximum *practical* data rate, the maximum reel capacity is a function of block size. It is found by finding the physical length of a block of data (by dividing block length in bytes by the maximum recording density), adding the length of the gap to determine the total number of inches required for the block, dividing the result into tape length to determine how many blocks can be recorded on a complete reel of tape, and then multiplying that number of blocks by the block length. The capacity shown on line 19 is computed assuming each block is 1,000 alpha-numeric characters in length. It is thus computed from lines 5, 7 (or 8 or 9), and 10.

20. Rewind time is found by dividing reel length from line 5, converted to inches, by rewind speed on line 14. The result is then divided by 60 to convert it to minutes.

**Prices and Physical Characteristics.** In general, the comments made in connection with Table II.2.12.1 are applicable to the data on these lines as well.

30. The price per thousand bytes is calculated by dividing the tape unit price on line 27 by the maximum reel capacity on line 19. Note that this price per thousand byte ratio is thus based on 1,000-character blocks. With data recorded on the tape in shorter blocks, the price will be higher; with data recorded in longer blocks, the price will be lower.

**Comments on Specific Devices.** The Burroughs 548 and 551 tape units imposed restrictions on the length of records recorded on tape—as did many other early tape units. I therefore did not use 1,000-character blocks in computing tape capacity. The 548 required records 20 words long, and the 551 permitted records from ten to 100 words long. Each word contained 44 bits. I assumed 44 bits was the equivalent of 5.5 characters, and thus used 110-character blocks for the 548, and 550-character blocks for the 551.

### TABLE II.2.12.3 MAGNETIC TAPE UNITS ●

| | Manufacturer: Model Number: | | IBM 727 | IBM 729-2 | IBM 729-4 | IBM 729-5 | IBM 729-6 | IBM 7330 | IBM 7340-1 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /55? | /57? | /59? | /62? | /62? | /61? | /61? |
| 2. | **Unit Characteristics** | | | | | | | | |
| 3. | Medium—Material | | mylar | mylar | mylar | mylar | mylar | mylar | |
| 4. | Width | in. | .5 | .5 | .5 | .5 | .5 | .5 | 1.0 |
| 5. | Reel Length | ft. | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 | 1800 |
| 6. | Recording—No. of Tracks | | 7 | 7 | 7 | 7 | 7 | 7 | 10 |
| 7. | Density 1 | b/in. | 200 | 200 | 200 | 200 | 200 | 200 | 1511 |
| 8. | Density 2 | b/in. | | 556 | 556 | 556 | 556 | 556 | |
| 9. | Density 3 | b/in. | | | | 800 | 800 | | |
| 10. | Inter-Block Gap | in. | .75 | .75 | .75 | .75 | .75 | .75 | .45 |
| 11. | Transport—Start Time | ms | 10 | 9.0 | 5.8 | 9.0 | 5.8 | 6.3 | 3.0 |
| 12. | Stop Time | ms | 10 | 3.6 | 2.9 | 3.6 | 2.9 | 14.1 | 3.0 |
| 13. | R/W Speed | ips | 75 | 75 | 112.5 | 75 | 112.5 | 36 | 112.5 |
| 14. | Rewind Speed | ips | 400 | 400 | 533 | 400 | 535 | 218 | 300 |
| 15. | Drive Mechanism | | | p.r. | p.r. | p.r. | p.r. | p.r. | |
| 16. | Buffer Mechanism | | | vac. | vac. | vac. | vac. | vac. | |
| 17. | Performance | | | | | | | | |
| 18. | Max. Character Rate | kcps | 15 | 41.67 | 62.5 | 60.0 | 90.0 | 20.02 | 170.0 |
| 19. | Max. Reel Capacity | Mby | 5.00 | 11.30 | 11.30 | 14.4 | 14.4 | 11.30 | 19.43 |
| 20. | Rewind Time | min. | 1.2 | 1.2 | 0.9 | 1.2 | 0.9 | 2.2 | 1.2 |
| 21. | **Prices** | | | | | | | | |
| 22. | Typ. Controller Mod. No. | | 652 | 1401-D | | | | | 7640 |
| 23. | System | | 650 | 1401 | | | | | 7074 |
| 24. | Price—Purchase | $k | 50.4 | 11.25 | | | | | 218.0 |
| 25. | Rental | $k/mo. | 1.05 | .245 | | | | | 3.4 |
| 26. | Maintenance | $/mo. | 58.25 | 3.5 | | | | | 102 |
| 27. | Tape Unit Price | $k | 18.2 | 27.5 | 48.5 | 37.2 | 42.45 | 22.0 | 78.0 |
| 28. | Rental | $k/mo. | .55 | .70 | .90 | .75 | .95 | .45 | 1.30 |
| 29. | Maintenance | $/mo. | 119 | 135 | 128 | 122 | 134 | 52.3 | 130 |
| 30. | Price Per 1000 Bytes | $/kby | 3.64 | 2.43 | 4.29 | 2.58 | 2.95 | 1.95 | 4.01 |
| 31. | Maint. Cost Per $100k | $/mo. | 653.8 | 490.1 | 263.9 | 328.0 | 315.7 | 237.8 | 166.7 |
| 32. | Price: Rent Ratio | | 33.1 | 39.3 | 53.9 | 49.6 | 44.7 | 48.9 | 60.0 |
| 34. | **Physical Char.—Wt.** | lbs. | 950 | 950 | 950 | | | 640 | 1350 |
| 35. | Floor Space | Sq. Ft. | 6.0 | 6.24 | 6.24 | | | 6.24 | 12.1 |
| 36. | Volume | Cu. Ft. | 34.7 | 35.9 | 35.9 | | | 30.2 | 48.3 |
| 37. | Electrical Load | kva | 2.2 | 1.6 | 1.6 | | | 1.1 | 4.0 |
| 38. | Heat Dissipation | kb/hr. | 4.1 | 3.9 | 3.9 | | | 3.415 | 12.0 |
| 39. | Density—Weight | $lbs/ft.^3$ | 27.4 | 26.5 | 26.5 | | | 21.2 | 27.9 |
| 40. | Heat Per Cu. Ft. | kb/hr. | .118 | .109 | .109 | | | .113 | .248 |
| 41. | Price Per Pound | $/lb. | 19.2 | 28.9 | 51.1 | | | 34.4 | 57.8 |

### TABLE II.2.12.3 MAGNETIC TAPE UNITS ●

| | Manufacturer: Model Number: | | IBM 2401-1 | IBM 2401-6 | IBM 2415-1 | IBM 2420-7 | IBM 3410-1 | IBM 3410-3 | IBM 3420-3 | IBM 3420-8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /63? | /65 | /66? | /68 | /70 | /70 | /71 | /74 |
| 2. | **Unit Characteristics** | | | | | | | | | |
| 3. | Medium—Material | | mylar | mylar | mylar | mylar | mylar | mylar | mylar | mylar |
| 4. | Width | in. | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 5. | Reel Length | ft. | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 |
| 6. | Recording—No. of Tracks | | 7/9 | 9 | 7/9 | 9 | 9 | 9 | 9 | 9 |
| 7. | Density 1 | b/in. | 800 | 800 | 800 | 1600 | 1600 | 800 | 800 | 1600 |
| 8. | Density 2 | b/in. | | 1600 | | | | 1600 | 1600 | 6250 |
| 9. | Density 3 | b/in. | | | | | | | | |
| 10. | Inter-Block Gap | in. | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.3 |
| 11. | Transport—Start Time | ms | | | | | 15 | 6 | 4 | 1 |
| 12. | Stop Time | ms | | | | | 35 | 9 | 6 | 2 |
| 13. | R/W Speed | ips | 37.5 | 112.5 | 18.75 | 200 | 12.5 | 50 | 75 | 200 |
| 14. | Rewind Speed | ips | 218 | 480 | 120 | 480 | 160 | 240 | 400 | 640 |
| 15. | Drive Mechanism | | | | | | | | | |
| 16. | Buffer Mechanism | | | | | | | | | |
| 17. | Performance | | | | | | | | | |
| 18. | Max. Character Rate | kcps | 30 | 180 | 15.0 | 320 | 20 | 80 | 120 | 1250 |
| 19. | Max. Reel Capacity | Mby | 15.57 | 23.51 | 15.57 | 23.51 | 23.51 | 23.51 | 23.51 | 62.61 |

## TABLE II.2.12.3 MAGNETIC TAPE UNITS (continued) ●

| | Manufacturer:<br>Model Number: | | IBM<br>2401-1 | IBM<br>2401-6 | IBM<br>2415-1 | IBM<br>2420-7 | IBM<br>3410-1 | IBM<br>3410-3 | IBM<br>3420-3 | IBM<br>3420-8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 20. | Rewind Time | min. | 2.2 | 1.0 | 4.0 | 1.0 | 3.0 | 2.0 | 1.2 | 0.75 |
| 21. | **Prices** | | | | | | | | | |
| 22. | Typ. Controller Mod. No. | | 2803-1 | 2803-2 | incl. | 2803-2 | 3411-1 | 3411-3 | 3803-1 | 3803-2 |
| 23. | System | | 360 | 360 | 370 | 370 | 370 | 370 | 370 | 370 |
| 24. | Price—Purchase | $k | 32.6 | 38.9 | | 38.9 | 17.0 | 26.3 | 25.82 | 43.8 |
| 25. | Rental | $k/mo. | .65 | .825 | | .825 | .405 | .625 | .675 | 1.150 |
| 26. | Maintenance | $/mo. | 20 | 25 | | 25 | 70 | 80 | 95 | 132 |
| 27. | Tape Unit Price | $k | 16.1 | 39.09 | 17.825 | 54.6 | 7.7 | 12.8 | 13.58 | 31.60 |
| 28. | Rental | $k/mo. | .335 | .86 | .375 | 1.05 | .185 | .305 | .355 | .820 |
| 29. | Maintenance | $/mo. | 62 | 98 | 50 | 120 | 45 | 55 | 50 | 81 |
| 30. | Price Per 1000 Bytes | $/kby | 1.03 | 1.66 | 1.14 | 2.32 | .33 | .54 | .58 | .50 |
| 31. | Maint. Cost Per $100k | $/mo. | 385.1 | 250.7 | 280.5 | 219.8 | 584.4 | 429.7 | 368.2 | 256.3 |
| 32. | Price: Rent Ratio | | 48.1 | 45.5 | 47.5 | 52.0 | 41.6 | 42.0 | 38.3 | 38.5 |
| 34. | **Physical Char.—Wt.** | lbs. | 800 | 800 | 700 | 930 | 180 | 180 | 800 | |
| 35. | Floor Space | Sq. Ft. | 6.04 | 6.04 | 6.25 | 6.25 | 5.81 | 5.81 | 6.25 | |
| 36. | Volume | Cu. Ft. | 33.7 | 33.7 | 34.9 | 34.9 | 18.9 | 18.9 | 34.9 | |
| 37. | Electrical Load | kva | 1.6 | 1.6 | 1.1 | 2.0 | 0.4 | 0.4 | 1.8 | |
| 38. | Heat Dissipation | kb/hr. | 3.5 | 3.5 | .625 | 5.0 | 1.15 | 1.15 | 4.0 | |
| 39. | Density—Weight | lbs/ft.³ | 23.7 | 23.7 | 20.1 | 26.6 | 9.52 | 9.52 | 22.9 | |
| 40. | Heat Per Cu. Ft. | kb/hr. | .103 | .103 | .018 | .143 | .061 | .061 | .115 | |
| 41. | Price Per Pound | $/lb. | 20.1 | 48.9 | 25.5 | 58.7 | 42.8 | 71.1 | 17.0 | |

## TABLE II.2.12.3 MAGNETIC TAPE UNITS ●

| | Manufacturer:<br>Model Number: | | BGH<br>548 | BGH<br>551 | BGH<br>422 | BGH<br>423 | BGH<br>424 | BGH<br>425 | BGH<br>9392 | BGH<br>9393-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /55? | /58? | /64 | /64 | /65 | /66 | /68? | /68? |
| 2. | **Unit Characteristics** | | | | | | | | | |
| 3. | Medium—Material | | mylar | mylar | mylar | mylar | mylar | mylar | mylar | mylar |
| 4. | Width | in. | .75 | .75 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 5. | Reel Length | ft. | 2500 | 3500 | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 |
| 6. | Recording—No. of Tracks | | 12 | 12 | 7 | 7 | 7 | 7 | 9 | 9 |
| 7. | Density 1 | b/in. | 100 | 208 | 200 | 200 | 800 | 200 | 800 | 1600 |
| 8. | Density 2 | b/in. | | | 556 | | | 556 | | |
| 9. | Density 3 | b/in. | | | | | | 800 | | |
| 10. | Inter-Block Gap | in. | 0.3 | 0.2 | .75 | .75 | .75 | .75 | .75 | .6 |
| 11. | Transport—Start Time | ms | 6 | 5 | | | | | | |
| 12. | Stop Time | ms | 6 | 5 | | | | | | |
| 13. | R/W Speed | ips | 60 | 120 | 120 | 120 | 83 | 90 | 90 | 90 |
| 14. | Rewind Speed | ips | 120 | 120 | 320 | 320 | 320 | 320 | 300 | 300 |
| 15. | Drive Mechanism | | | | p.r. | p.r. | p.r. | p.r. | p.r. | p.r. |
| 16. | Buffer Mechanism | | | vac. | vac. | vac. | vac. | vac. | vac. | vac. |
| 17. | Performance | | | | | | | | | |
| 18. | Max. Character Rate | kcps | 9.0 | 37.44 | 66.7 | 24.0 | 66.4 | 72.0 | 72.0 | 144 |
| 19. | Max. Reel Capacity | Mby | 3.195 | 5.97 | 11.30 | 5.00 | 14.40 | 14.40 | 14.40 | 23.51 |
| 20. | Rewind Time | min. | 4.17 | 5.83 | 1.5 | 1.5 | 1.5 | 1.5 | 1.6 | 1.6 |
| 21. | **Prices** | | | | | | | | | |
| 22. | Typ. Controller Mod. No. | | 547 | 550 | | | | | 2393-11 | 2393-12 |
| 23. | System | | 205 | 220 | | | | | 2700 | 2700 |
| 24. | Price—Purchase | $k | 28.0 | 45.0 | | | | | 16.8 | 12.0 |
| 25. | Rental | $k/mo. | .875 | 1.20 | | | | | .35 | .25 |
| 26. | Maintenance | $/mo. | | | | | | | 12 | 15 |
| 27. | Tape Unit Price | $k | 13.5 | 21.45 | 36.0 | 31.5 | 38.25 | 38.25 | 20.4 | 19.44 |
| 28. | Rental | $k/mo. | .425 | .635 | .800 | .495 | .850 | .850 | .425 | .405 |
| 29. | Maintenance | $/mo. | | | 155 | 145 | 165 | 165 | 169 | 149 |
| 30. | Price Per 1000 Bytes | $/kby | 4.23 | 3.59 | 3.19 | 6.30 | 2.66 | 2.66 | 1.42 | .83 |
| 31. | Maint. Cost Per $100k | $/mo. | | | 430.6 | 460.3 | 431.3 | 431.3 | 828.4 | 766.5 |
| 32. | Price: Rent Ratio | | 31.8 | 33.8 | 45.0 | 63.6 | 45.0 | 45.0 | 48.0 | 48.0 |
| 34. | **Physical Char.—Wt.** | lbs. | 500 | 650 | | | | | | |
| 35. | Floor Space | Sq. Ft. | 4.08 | 6.03 | | | | | | |
| 36. | Volume | Cu. Ft. | 23.5 | 26.1 | | | | | | |
| 37. | Electrical Load | kva | 5.0 | 5.33 | | | | | | |
| 38. | Heat Dissipation | kb/hr. | 4.1 | 13.6 | | | | | | |
| 39. | Density—Weight | lbs/ft.³ | 21.3 | 24.9 | | | | | | |
| 40. | Heat Per Cu. Ft. | kb/hr. | .175 | .520 | | | | | | |

TABLE II.2.12.3 MAGNETIC TAPE UNITS (continued) ●

| | Manufacturer: Model Number: | | BGH 548 | BGH 551 | BGH 422 | BGH 423 | BGH 424 | BGH 425 | BGH 9392 | BGH 9393-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 41. | Price Per Pound | $/lb. | 27.0 | 33.0 | | | | | | |

TABLE II.2.12.3 MAGNETIC TAPE UNITS ●

| | Manufacturer: Model Number: | | Univac I | Univac IIA | Univac IIIA | Univac IIIC | Univac VIC | Univac VIIIC | Univac 12 | Univac 16 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /54? | /60? | /62? | /64? | /65? | /65? | /70 | /70 |
| 2. | **Unit Characteristics** | | | | | | | | | |
| 3. | Medium–Material | | metal | plas. | mylar | plas. | plas. | plas. | plas. | plas. |
| 4. | Width | in. | .5 | .5 | .5 | .5 | .5 | .5 | 0.5 | 0.5 |
| 5. | Reel Length | ft. | 1500 | 2400 | 3500 | 2400 | 2400 | 2400 | 2400 | 2400 |
| 6. | Recording–No. of Tracks | | | 8 | 9 | 7 | 7/9 | 7/9 | 7 or 9 | 7 or 9 |
| 7. | Density 1 | b/in. | 20 | 125 | 1000 | 200 | 200 | 200 | 200 | 200 |
| 8. | Density 2 | b/in. | 50 | 250 | | 556 | 556 | 556 | 556 | 556 |
| 9. | Density 3 | b/in. | 128 | | | | 800 | 800 | 800 | 8/1600 |
| 10. | Inter-Block Gap | in. | *1.05* | 1.05 | 0.75 | 0.75 | 0.75 | 0.75 | 0.6-0.75 | 0.6-0.75 |
| 11. | Transport–Start Time | ms | | 12.0 | 4.25 | 3.9 | | | 21.8 | 8.3 |
| 12. | Stop Time | ms | | 10.2 | 13.2 | 9.1 | | | 21.8 | 8.3 |
| 13. | R/W Speed | ips | 100 | 100 | 100 | 112.5 | 42.7 | 120 | 42.7 | 120 |
| 14. | Rewind Speed | ips | | 100 | 335 | 335 | 160 | 370 | 160 | 240 |
| 15. | Drive Mechanism | | | p.r. | vac. | vac. | vac. | vac. | vac.. | vac. |
| 16. | Buffer Mechanism | | | vac. | vac. | vac. | vac. | vac. | vac. | vac. |
| 17. | Performance | | | | | | | | | |
| 18. | Max. Character Rate | kcps | 12.8 | 25 | 100 | 62.55 | 34.16 | 96.0 | 34.16 | 192 |
| 19. | Max. Reel Capacity | Mby | 2.301 | 5.703 | 42.0 | 11.30 | 14.40 | 14.40 | 14.40 | 23.51 |
| 20. | Rewind Time | min. | | 4.8 | 2.1 | 1.45 | 3.0 | 1.3 | 3.0 | 2.0 |
| 21. | **Prices** | | | | | | | | | |
| 22. | Typ. Controller Mod. No. | | | | | | 858-00 | 5008-12 | 5017 | |
| 23. | System | | Un.I | 490 | 490 | 490 | 1108 | 1108 | 1100 | |
| 24. | Price–Purchase | $k | | 101.8 | 177.6 | 152.0 | 8.0 | 60.9 | 22.2 | 23.9 |
| 25. | Rental | $k/mo. | | 2.08 | 3.70 | 3.25 | .2 | 1.45 | .600 | .650 |
| 26. | Maintenance | $/mo. | | 170 | 170 | 223 | 50 | 105 | 90 | 100 |
| 27. | Tape Unit Price | $k | 18 | 20.0 | 36.5 | 38.4 | 12.0 | 36.0 | 18.1 | 31.8 |
| 28. | Rental | $k/mo. | | .45 | .75 | .80 | .30 | .80 | .542 | .840 |
| 29. | Maintenance | $/mo. | | 95 | 155 | 62 | 75 | 95 | 107 | 110 |
| 30. | Price Per 1000 Bytes | $/kby | 8.86 | 3.51 | .87 | 3.40 | .83 | 2.50 | 1.26 | 1.35 |
| 31. | Maint. Cost Per $100k | $/mo. | | 475.0 | 424.7 | 161.5 | 625.0 | 263.9 | | |
| 32. | Price: Rent Ratio | | | 44.4 | 48.7 | 48.0 | 40.0 | 45.0 | | |
| 34. | **Physical Char.–Wt.** | lbs. | | 745 | 745 | 810 | 500 | 700 | 700 | 950 |
| 35. | Floor Space | Sq. Ft. | | 6.5 | 6.5 | 7.5 | 4.33 | 5.44 | 4.7 | 5.7 |
| 36. | Volume | Cu. Ft. | | 37.1 | 37.1 | 40.2 | 23.1 | 29.0 | 25.2 | 30.6 |
| 37. | Electrical Load | kva | | 2.63 | 2.75 | 2.75 | 1.9 | 2.75 | 1.5 | 2.0 |
| 38. | Heat Dissipation | kb/hr. | | 7.14 | 7.48 | 7.48 | 3.5 | 5.1 | 3.669 | 6.809 |
| 39. | Density–Weight | $lbs/ft.^3$ | | 20.1 | 20.1 | 20.2 | 21.6 | 24.1 | 27.8 | 31.0 |
| 40. | Heat Per Cu. Ft. | kb/hr. | | .192 | .202 | .186 | .151 | .175 | .145 | .222 |
| 41. | Price Per Pound | $/lb. | | 26.8 | 49.0 | 47.4 | 24.0 | 51.4 | 25.9 | 33.5 |

## TABLE II.2.12.4 LINE PRINTERS—NOTES

A line printer is defined as a printer having a printing mechanism opposite every position on the page where a character might be printed. It is distinguished from character-at-a-time printers, which normally have one printing device which moves along a line printing characters where required. The line printer thus prints in parallel, generally printing many characters simultaneously, while character printer prints serially, one character at a time.

**Unit Characteristics.** 2-3. The number of print positions is the width of the printed page, in characters. It represents the maximum number of characters which can be printed on a line. The character set, on line 3, is the number of different characters which can be printed in a given print positon. Many printers permit the substitution of different character sets for different purposes. For example, if a large amount of numeric data is to be printed, it is often possible to increase printing speed substantially by changing the print mechanism to an all-numeric type set. The number given on line is the maximum character set allowed by the printer.

4-5. Line 4 shows how many characters per inch appear along a line on the page, and line 5 shows how many lines per inch appear on the printed page.

6. All the printers described on these pages except the IBM 3800 operate by rapidly compressing the printing paper and an ink ribbon between an embossed character image and a flat surface. Line 6 describes the device which contains the embossed character.

7-9. Line 7 shows the maximum printing speed for printing alphanumeric data, and line 9 the speed for printing numeric data, both in lines per minute. Line 8 shows the alphanumeric printing speed in thousands of characters per second. It is computed by multiplying line 2 by line 7 and dividing the result by 60,000—thus it assumes that every print position on every line actually contains a character.

10. Most printers make it possible to move the print paper at extra high speed when skipping over lines on which nothing is to be printed. This operation is commonly known as "slewing", and the slewing speed in inches per second is shown on line 10. Often two slewing speeds are possible, a slower one for skipping short distances, and a faster one useable when many lines are to be skipped.

**Prices and Physical Characteristics.** The remarks appearing under this heading in connection with the notes on Table II.2.12.1 are generally applicable here.

21. The number of characters output per dollar is found by dividing the printing speed on line 8, in thousands of characters per second, by printer rental on line 17. To get the result in millions of characters, the quotient of line 8 and line 17 is multiplied by 0.624.

## TABLE II.2.12.4 LINE PRINTERS ●

| | Manufacturers: Model Numbers: | | IBM 407-C1 | IBM 716 | IBM 720-2 | IBM 370 | IBM 7400-1 | IBM 1403-1 | IBM 1403-2 | IBM 1403-6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /53? | /55? | /55? | /57? | /60? | /60? | /64 | /64 |
| | **Unit Characteristics** | | | | | | | | | |
| 2. | Print Positions | | 120 | 120 | 120 | 80 | 120 | 100 | 132 | 120 |
| 3. | Character Set | | 47 | 47 | 47 | | 47 | 48 | 48 | 48 |
| 4. | Spacing—Horizontal | ch/in. | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 5. | Vertical | li/in. | 6-8 | 6-8 | 6-8 | 6 | 6-8 | 6-8 | 6-8 | 6-8 |
| 6. | Mechanism | | | | | | | chain | chain | chain |
| | Performance | | | | | | | | | |
| 7. | Rated Print Speed—Alpha | lpm | 150 | 150 | 500 | 30 | 150 | 600 | 600 | 340 |
| 8. | In Char. Per Sec. | kcps | 0.30 | 0.30 | 1.00 | .040 | 0.30 | 1.00 | 1.32 | .68 |
| 9. | Numeric Only | lpm | - | - | - | - | - | - | - | - |
| 10. | Slewing Speed | ips | 10 | 10 | 70 | 25-6 | 10 | 33-75 | 33-75 | 33-75 |
| | **Prices** | | | | | | | | | |
| 11. | Typ. Controller Mod. No. | | | | 760 | | | 2821 | 5540 | incl. |
| 12. | System | | 650 | 704 | 705 | 305 | 707x | 360 | 140x | 14xx |
| 13. | Price—Purchase | $k | | | 111 | | | | 2.45 | |
| 14. | Rental | $k/mo. | | | 2.5 | | | | .06 | |
| 15. | Maintenance | $/mo. | | | 486 | | | | .75 | |
| 16. | Printer Price | $k | 51.0 | 54.2 | 93.0 | 22.1 | 41.5 | 30.3 | 34.0 | 29.0 |
| 17. | Rental | $k/mo. | 1.0 | 1.2 | 1.9 | .35 | .95 | .725 | .775 | .40 |
| 18. | Maintenance | $/mo. | 132 | 116 | 503 | 80 | 40.5 | 172 | 131 | 95.0 |
| 19. | Maint. Cost Per $100k | $/mo. | 258.8 | 214.0 | 540.9 | 362.0 | 97.6 | 567.7 | 385.3 | 327.6 |
| 20. | Price: Rent Ratio | | 51.0 | 45.2 | 48.9 | 63.1 | 43.7 | 41.8 | 43.9 | 72.5 |
| 21. | Output Char. Per $ | M | .188 | .156 | .329 | .071 | .197 | .862 | 1.06 | 1.06 |
| 22. | **Physical Char.**—Wt. | lbs. | | 1910 | 1750 | 985 | 1600 | | 750 | |
| 23. | Floor Space | Sq. Ft. | | 12.3 | 24.8 | 12.7 | 12.9 | | 9.3 | |
| 24. | Volume | Cu. Ft. | | 48.1 | 126.1 | 49.6 | 52.7 | | 41.2 | |
| 25. | Electrical Load | kva | | 3.1 | 3.9 | | 1.7 | | 1.0 | |
| 26. | Heat Dissipation | kb/hr. | | 7.85 | 11.32 | .9 | 4.8 | | 3.0 | |
| 27. | Density—Wt. | lbs/ft.$^3$ | | 39.7 | 13.9 | 19.9 | 30.3 | | 18.2 | |
| 28. | Heat Per Cu. Ft. | kb/hr. | | .163 | .090 | .018 | .091 | | .073 | |
| 29. | Price Per Pound | $/lb. | | 28.4 | 53.1 | 22.4 | 25.9 | | 45.3 | |

## TABLE II.2.12.4 LINE PRINTERS ●

| | Manufacturers: Model Numbers: | | IBM 1403-N1 | IBM 1445-N1 | IBM 2203-A | IBM 3211 | IBM 5203-1 | IBM 5203-3 | IBM 3203-2 | IBM 3800 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /64 | /65 | /65 | /70 | /69 | /70 | /74 | /74 |
| | **Unit Characteristics** | | | | | | | | | |
| 2. | Print Positions | | 132 | 113 | 120 | 132 | 96 | 96 | 132 | 132-204 |
| 3. | Character Set | | 48 | 56 | 63 | 48 | 48 | 48 | | 256 |
| 4. | Spacing—Horizontal | ch/in. | 10 | 8 | 10 | 10 | 10 | 10 | 10 | 10-15 |
| 5. | Vertical | li/in. | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 |
| 6. | Mechanism | | train | | bar | train | chain | train | train | xerox |
| | Performance | | | | | | | | | |
| 7. | Rated Print Speed—Alpha | lpm | 1100 | 190 | 300 | 2000 | 100 | 300 | 1200 | 13360 |
| 8. | In Char. Per Sec. | kcps | 2.42 | .358 | .6 | 4.4 | .16 | .48 | 2.64 | 45.4 |
| 9. | Numeric Only | lpm | - | 525 | 750 | - | - | - | - | 45.4 |
| 10. | Slewing Speed | ips | 33-75 | 15 | 15 | 9-90 | 12-17 | 12-17 | 24-55 | 1840 |
| | **Prices** | | | | | | | | | |
| 11. | Typ. Controller Mod. No. | | 2821-2 | incl. | | 3811 | 3970 | 3972 | | incl |
| 12. | System | | 360 | 360 | | 360 | S3/10 | S3/10 | 370 | 370 |
| 13. | Price—Purchase | $k | 28.8 | | | 30.6 | 2.925 | 4.525 | | |
| 14. | Rental | $k/mo. | .60 | | | .75 | .055 | .095 | | |
| 15. | Maintenance | $/mo. | 32 | | | 115 | 16 | 13 | | |
| 16. | Printer Price | $k | 41.2 | 62.0 | 23.0 | 69.36 | 10.6 | 17.4 | 49.0 | 310.0 |
| 17. | Rental | $k/mo. | .90 | 1.425 | .51 | 1.7 | .23 | .435 | 1.234 | 7.344 |
| 18. | Maintenance | $/mo. | 138 | 92.5 | 71.5 | 365 | 67 | 127 | 240 | 445* |
| 19. | Maint. Cost Per $100k | $/mo. | 335.0 | 149.2 | 310.9 | 526.2 | 632.1 | 729.9 | 489.8 | 143.5 |
| 20. | Price: Rent Ratio | | 45.8 | 43.5 | 45.1 | 40.8 | 46.1 | 40.0 | 39.7 | 42.2 |
| 21. | Output Char. Per $ | M | 1.68 | .157 | .735 | 1.618 | .435 | .690 | 1.34 | 3.86 |
| 22. | **Physical Char.**—Wt. | lbs. | 1250 | 825 | | 1750 | 550 | 550 | 710 | 3000 |
| 23. | Floor Space | Sq. Ft. | 11.5 | 11.6 | | 11.5 | 7.8 | 7.8 | 7.8 | 32.2 |
| 24. | Volume | Cu. Ft. | 51.2 | 25.2 | | 51.2 | 27.0 | 27.0 | 30.1 | 161.1 |
| 25. | Electrical Load | kva | 1.5 | 1.1 | | 4.9 | .7 | 1.1 | 2.1 | 6.8 |
| 26. | Heat Dissipation | kb/hr. | 4.5 | 3.2 | | 12.18 | 2.0 | 3.3 | 6.2 | 22.2 |
| 27. | Density—Wt. | $lbs/ft.^3$ | 24.4 | 32.8 | | 34.2 | 20.4 | 20.4 | 23.6 | 18.6 |
| 28. | Heat Per Cu. Ft. | kb/hr. | .088 | .127 | | .238 | .074 | .122 | .206 | .138 |
| 29. | Price Per Pound | $/lb. | 33.0 | 75.2 | | 39.6 | 19.27 | 31.64 | 69.01 | 103.3 |

* IBM 3800 requires additional maintenance charge of $2.30 per thousand feet of paper printed.

## TABLE II.2.12.4 LINE PRINTERS ●

| | Manufacturers: Model Numbers: | | BGH 272 | BGH 9240-4 | BGH 9240-5 | BGH 9240-6 |
|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /61? | /64? | /64? | /66? |
| | **Unit Characteristics** | | | | | |
| 2. | Print Positions | | 120 | 120 | 120 | 120 |
| 3. | Character Set | | 51 | 64 | 64 | 37 |
| 4. | Spacing—Horizontal | ch/in. | 10 | 12 | 12 | 12 |
| 5. | Vertical | li/in. | 6 | 6-8 | 6-8 | 6-8 |
| 6. | Mechanism | | | drum | drum | drum |
| | Performance | | | | | |
| 7. | Rated Print Speed—Alpha | lpm | 1225 | 475 | 700 | 1040 |
| 8. | In Char. Per Sec. | kcps | 2.45 | .95 | 1.4 | 2.08 |
| 9. | Numeric Only | lpm | 1500 | - | - | - |
| 10. | Slewing Speed | ips | 25 | 25-40 | 25-40 | 25-40 |
| | **Prices** | | | | | |
| 11. | Typ. Controller Mod. No. | | 261 | 2242-1 | 2242-1 | 2242-1 |
| 12. | System | | 220 | 2700 | | |
| 13. | Price—Purchase | $k | 125 | 3.76 | | |
| 14. | Rental | $k/mo. | 3.45 | .08 | | |
| 15. | Maintenance | $/mo. | | 12 | | |
| 16. | Printer Price | $k | 84.55 | 19.5 | 31.0 | 43.0 |
| 17. | Rental | $k/mo. | 2.255 | .475 | .625 | .900 |
| 18. | Maintenance | $/mo. | | 174 | 179 | 195 |
| 19. | Maint. Cost Per $100k | $/mo. | | 892.3 | 577.4 | 453.5 |
| 20. | Price: Rent Ratio | | 37.5 | 41.0 | 49.6 | 47.8 |
| 21. | Output Char. Per $ | M | .679 | 1.25 | 1.40 | 1.44 |
| 22. | **Physical Char.**—Wt. | lbs. | 1200 | | | |
| 23. | Floor Space | Sq. Ft. | 14.0 | | | |

### TABLE II.2.12.4 LINE PRINTERS (continued)

| | Manufacturers: Model Numbers: | | BGH 272 | BGH 9240-4 | BGH 9240-5 | BGH 9240-6 |
|---|---|---|---|---|---|---|
| 24. | Volume | Cu. Ft. | 66.5 | | | |
| 25. | Electrical Load | kva | | | | |
| 26. | Heat Dissipation | kb/hr. | | | | |
| 27. | Density—Wt. | lbs/ft$^3$ | 18.0 | | | |
| 28. | Heat Per Cu. Ft. | kb/hr. | | | | |
| 29. | Price Per Pound | $/lb. | | | | |

### TABLE II.2.12.4 LINE PRINTERS ●

| | Manufacturers: Model Numbers: | | Univac HSP | Univac 7912 | Univac 4152 | Univac 0755-5 | Univac 0758 | Univac 0768 |
|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /52? | /58? | /62 | /64? | /67? | |
| | **Unit Characteristics** | | | | | | | |
| 2. | Print Positions | | 120 | 100 | 128 | 128 | 132 | 132 |
| 3. | Character Set | | | 51 | 51 | 63 | 63 | 63 |
| 4. | Spacing—Horizontal | ch/in. | | 10 | 10 | 10 | 10 | 10 |
| 5. | Vertical | li/in. | | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 |
| 6. | Mechanism | | | drum | | drum | drum | drum |
| | Performance | | | | | | | |
| 7. | Rated Print Speed—Alpha | lpm | 600 | 600 | 700 | 700 | 1200 | 900 |
| 8. | In Char. Per Sec. | kcps | 1.2 | 1.0 | 1.49 | 1.49 | 2.64 | 1.98 |
| 9. | Numeric Only | lpm | - | | 922 | 922 | 1600 | 100 |
| 10. | Slewing Speed | ips | | 20 | 22 | 20 | 33 | 33 |
| | **Prices** | | | | | | | |
| 11. | Typ. Controller Mod. No. | | | | | | 5011 | incl. |
| 12. | System | | | SS80 | VIII | 1050 | 1108 | 9300 |
| 13. | Price—Purchase | $k | | | | | 30.02 | |
| 14. | Rental | $k/mo. | | | | | .718 | |
| 15. | Maintenance | $/mo. | | | | | 213 | |
| 16. | Printer Price | $k | 130 | 41.1 | 79.0 | 36.0 | 43.5 | 40.68 |
| 17. | Rental | $k/mo. | 3.3 | .935 | 1.65 | .80 | .992 | .981 |
| 18. | Maintenance | $/mo. | 1015 | 335 | 350 | 240 | 326 | 337 |
| 19. | Maint. Cost Per $100k | $/mo. | 780.8 | 815.1 | 443.0 | 666.7 | 749.4 | 828.4 |
| 20. | Price: Rent Ratio | | 39.4 | 44.0 | 47.9 | 45.0 | 43.9 | 41.5 |
| 21. | Output Char. Per $ | M | .227 | .668 | .564 | 1.16 | 1.66 | 1.26 |
| 22. | **Physical Char.**—Wt. | lbs. | | | | | | |
| 23. | Floor Space | Sq. Ft. | | | | | | |
| 24. | Volume | Cu. Ft. | | | | | | |
| 25. | Electrical Load | kva | | | | | | |
| 26. | Heat Dissipation | kb/hr. | | | | | | |
| 27. | Density—Wt. | lbs/ft.$^3$ | | | | | | |
| 28. | Heat Per Cu. Ft. | kb/hr. | | | | | | |
| 29. | Price Per Pound | $/lb. | | | | | | |

## TABLE II.2.12.5 PUNCHED CARD UNITS—NOTES

**Unit Characteristics.** Some units described on these pages are card readers only, some are card punches only, and some are combination reader/punches. If the unit contains a card reader, its characteristics are shown on lines 3 to 7; if it contains a punch, the punch characteristics are given on lines 8 through 11.

3-4. Card reader speed, in cards per minute and in thousands of characters per second, is shown here. The speed given is the maximum, and assumes that cards are read successively with no processor-imposed delay between adjacent cards. The character-per-second speed on line 4 assumes that cards are read at the maximum speed of line 3, and that each card contains a full 80 or 96 characters of data.

5. Some readers contain a rotating clutch, and have the property that a card-reading cycle can only begin when the clutch is at certain prescribed points of its rotating cycle. For such readers, the clutch makes one revolution in the time necessary to read one card. When the processor issues a first card reading command, there ensues a (variable) delay while the clutch rotates to the point where a read cycle may begin. If the processor issues a second read command soon enough, a second card will be read during the very next rotation of the clutch, and the reader will read cards at its maximum rate. On the other hand, if the processor introduces a delay, the reader will not operate at maximum speed, and the read cycle for the second card will start at the first clutch point reached after the processor issues the second read command. If there is only one clutch point per revolution, and if the processor just fails to issue the command in time, the result will be the reader operates at half its maximum speed. Some readers provide more than one clutch point per revolution of the clutch, with consequently less read speed degradation caused by processor delays. Line 5 specifies the number of clutch points in the reader. For the readers designated "none", the reading mechanisms are asynchronous, and there is a fixed (relatively small) delay between issuance of a processor command and the start of a read cycle. For such readers, a slight delay in processor response results in only a minor degradation in read speed.

6-7. The most widely-used tabulating card contains 80 digit-positions, or columns, and each column contains twelve hole-positions, or rows. (The Remington-Rand card had provision for 90 columns, but is not widely used.) Most cards are read column by column, being driven short edge first past 12 read heads. But some readers have been designed to read the card row by row, so that the card moves long edge first past 80 read heads. Line 6 states how many read heads exist, not counting duplicate stations which may be introduced to double-read a card for checking purposes. Line 7 describes the reading mechanism. In older punches, each read head consisted of a wire brush which made an electrical contact through a hole in the card. Newer readers employ a photoelectric system, which uses a photo-sensitive device to detect the passage of light through a hole.

8-9. Maximum card-punching speed in cards per minute and in thousands of characters per second, are shown here. The card-punching speed given is that for punching a full 80 columns, with no delay imposed between cards by the processor. (Some punches—the IBM 1442-N1 and the Univac 603-4—accelerate a card after the last row has been punched, and thus handle more cards per minute at fewer columns punched per card. For such punches, however, the maximum *character-punching* rate occurs when the full 80 columns are punched.)

10-11. The comments on lines 5 and 6 above, regarding card reader operation, are also applicable to these two lines.

12-15. Each punched card unit is provided with feed hoppers and output stackers, which store cards ready to be read or punched and cards which have been read or punched. The number of hoppers and stackers are shown on lines 12 and 14, and the capacity of each is shown on lines 13 and 15. If there is more than one hopper or stacker, and the multiple devices have different capacities, I show the average capacities on lines 13 and 15.

**Prices and Physical Characteristics.** The remarks given in the description of Table II.2.12.1 are generally applicable here.

26-27. The number of characters read or punched per dollar are computed from reading and punching speeds on lines 4 and 9, and unit rental on line 22. Specifically the results are found by dividing line 4 or 9 by line 22, and multiplying the result by 624. Note that the calculation is based on the assumption that the unit operates at full speed, either reading or punching. I thus penalize units that both read and punch by attributing the cost of both functions to each one.

## TABLE II.2.12.5 PUNCHED CARD UNITS

| | Manufacturer: Model Number: | | IBM 533 | IBM 537 | IBM 721 | IBM 711-2 | IBM 323 | IBM 543 | IBM 7500-1 | IBM 7550-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /54? | /54? | /55? | /55? | /57? | /57? | /60? | /60? |
| | **Unit Characteristics** | | | | | | | | | |
| 2. | Card Reader | | | | | | | | | |
| 3. | Speed (maximum) | cpm | 200 | 155 | - | 250 | - | 250 | 500 | - |
| 4. | Char. Per Second | kcps | .267 | .207 | | .333 | | .333 | .667 | |
| 5. | Number of Clutch Points | | | | | | | - | | |
| 6. | Number of Read Heads | | | | | | | | | |
| 7. | Read System | | | | | | | | | |
| | Card Punch | | | | | | | - | - | |
| 8. | Speed (maximum) | cpm | 100 | 155 | 100 | - | 100 | | | 250 |
| 9. | Char. Per Second | kcps | .133 | .207 | .133 | | .133 | | | .333 |
| 10. | Number of Clutch Points | | | | | | | | | |
| 11. | Number of Punch Heads | | | | | | | | | |
| 12. | Feed Hopper—Number | | 1 | 1 | 1 | 1 | | | 1 | 1 |
| 13. | Capacity, Each | | 800 | 800 | 600 | 800 | | | 1200 | 1200 |
| 14. | Output Stacker—Number | | 1 | 1 | 1 | 1 | | | 1 | 1 |
| 15. | Capacity, Each | | 800 | 800 | 600 | 600 | | | 900 | 1900 |
| | **Prices** | | | | | | | | | |
| 16. | Controller Model No. | | | | | | incl. | | 7603-1 | 7603-1 |
| 17. | System | | 650 | 650 | 70x | 70x | 305 | 650 | 707x | 707x |
| 18. | Price—Purchase | $k | | | | | | | 46.05 | |
| 19. | Rental | $k/mo. | | | | | | | 1.0 | |
| 20. | Maintenance | $/mo. | | | | | | | 22.8 | |
| 21. | Reader/Punch Price | $k | 25.0 | 40.0 | 25.0 | 32.0 | 12.25 | 14.65 | 18.00 | 24.6 |
| 22. | Rental | $k/mo. | .550 | .700 | .600 | .800 | .225 | .325 | .400 | .550 |
| 23. | Maintenance | $/mo. | 53 | 54 | 62 | 63 | 15 | 29.3 | 44.8 | 36.8 |
| 24. | Maint. Cost Per $100k | $/mo. | 212.0 | 135.0 | 248.9 | 196.9 | 122.4 | 200.0 | 248.0 | 149.6 |
| 25. | Price: Rent Ratio | | 45.5 | 57.1 | 41.7 | 40.0 | 54.4 | 45.1 | 45.0 | 44.7 |
| 26. | Char. Per $—Read | kby/$ | 303.4 | 184.8 | - | 260.1 | - | 640.4 | 1042.2 | - |
| 27. | Punch | kby/$ | 151.1 | 184.8 | 138.5 | - | 369.4 | - | - | 378.4 |
| 28. | **Physical Char.—Wt.** | lbs. | 1295 | 1230 | 670 | 560 | 760 | 615 | 1000 | 1000 |
| 29. | Floor Space | Sq. Ft. | 10.2 | 10.2 | 7.2 | 6.7 | 9.8 | 7.0 | 7.0 | 7.0 |
| 30. | Volume | Cu. Ft. | 41.8 | 42.7 | 30.1 | 17.7 | 41.6 | 24.7 | 25.3 | 25.3 |
| 31. | Electrical Load | kva | | | 3.5 | 0.7 | | | 1.5 | 1.5 |
| 32. | Heat Dissipation | kb/hr. | 2.5 | 1.68 | 9.0 | 1.7 | 2.5 | 1.68 | 4.4 | 4.8 |
| 33. | Density—Weight | $lbs/ft.^3$ | 31.0 | 28.8 | 22.3 | 31.5 | 18.3 | 24.9 | 39.6 | 39.6 |
| 34. | Heat Per Cu. Ft. | kb/hr. | .060 | .039 | .299 | .096 | .060 | .068 | .174 | .190 |
| 35. | Price Per Pound | $/lb. | 19.3 | 32.5 | 37.3 | 57.1 | 16.1 | 23.8 | 18.0 | 24.6 |

## TABLE II.2.12.5 PUNCHED CARD UNITS

| | Manufacturer: Model Number: | | IBM 1622-1 | IBM 1402-2 | IBM 1402-N1 | IBM 1442-N1 | IBM 2501-B2 | IBM 2520-B1 | IBM 2520-B2 | IBM 2540-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /60? | 9/60 | /60 | /62? | /64 | /64 | /64 | /66 |
| | **Unit Characteristics** | | | | | | | | | |
| 2. | Card Reader | | | | | | | | | |
| 3. | Speed (maximum) | cpm | 250 | 800 | 1000 | 400 | 1000 | 500 | - | 1000 |
| 4. | Char. Per Second | kcps | .333 | 1.067 | 1.333 | .533 | 1.333 | .667 | | 1.333 |
| 5. | Number of Clutch Points | | | 1 | | None | 1 | | | 3 |
| 6. | Number of Read Heads | | | 12 | | 12 | 12 | 12 | | 2x12 |
| 7. | Read System | | | brushes | | photo | photo | photo | | brush |
| | Card Punch | | | | | | | | | |
| 8. | Speed (maximum) | cpm | 125 | 250 | 250 | 91 | - | 500 | 500 | 300 |
| 9. | Char. Per Second | kcps | .167 | .333 | .333 | .121 | | .667 | .667 | .400 |
| 10. | Number of Clutch Points | | | 4 | | None | | | | 4 |
| 11. | Number of Punch Heads | | | 12 | | 12 | | 80 | 80 | 12 |
| 12. | Feed Hopper—Number | | | 2 | 2 | 1 | 1 | 1 | 1 | 2 |
| 13. | Capacity, Each | | | 2100av. | 2100av. | 1200 | 1200 | 1200 | 1200 | 2225av. |
| 14. | Output Stacker—Number | | 5 | 5 | 5 | 2 | 1 | 2 | 2 | 5 |
| 15. | Capacity, Each | | | 1000 | 1000 | 1300 | 1300 | 1300 | 1300 | 1350 |
| | **Prices** | | | | | | | | | |
| 16. | Controller Model No. | | incl. | incl. | | incl. | incl. | incl. | incl. | 2821 |
| 17. | System | | 1620 | 1401 | 1401 | 360/370 | 360/370 | 360/370 | 360/370 | 360/370 |
| 18. | Price—Purchase | $k | | | | | | | | 45.1 |

**TABLE II.2.12.5 PUNCHED CARD UNITS (continued)**

| | Manufacturer: Model Number: | | IBM 1622-1 | IBM 1402-2 | IBM 1402-N1 | IBM 1442-N1 | IBM 2501-B2 | IBM 2520-B1 | IBM 2520-B2 | IBM 2540-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 19. | Rental | $k/mo. | | | | | | | | .970 |
| 20. | Maintenance | $/mo. | | | | | | | | 41 |
| 21. | Reader/Punch Price | $k | 30.0 | 32.7 | 35.0 | 26.25 | 14.82 | 42.0 | 37.2 | 33.95 |
| 22. | Rental | $k/mo. | .615 | .615 | .660 | .525 | .320 | .875 | .775 | .660 |
| 23. | Maintenance | $/mo. | 50.0 | 69.0 | 90.0 | 54.0 | 55.5 | 128 | 120 | 115 |
| 24. | Maint. Cost Per $100k | $/mo. | 166.7 | 211.0 | 257.1 | 205.7 | 374.5 | 304.8 | 322.6 | 338.7 |
| 25. | Price: Rent Ratio | | 48.8 | 53.2 | 53.0 | 50.0 | 46.3 | 48.0 | 48.0 | 51.4 |
| 26. | Char. Per $—Read | kby/$ | 338.4 | 1084.3 | 1262.3 | 634.5 | 2603.5 | 474.3 | - | 1262.3 |
| 27. | Punch | kby/$ | 169.7 | 338.4 | 315.3 | 144.0 | - | 474.3 | 537.9 | 378.8 |
| 28. | **Physical Char.—Wt.** | lbs. | 1305 | 1300 | | | 440 | 770 | 770 | 1050 |
| 29. | Floor Space | Sq. Ft. | 12.1 | 12.1 | | | 5.0 | 7.2 | 7.2 | 11.7 |
| 30. | Volume | Cu. Ft. | 46.3 | 46.3 | | | 18.8 | 29.9 | 29.9 | 43.8 |
| 31. | Electrical Load | kva | 1.46 | | | | 0.5 | 1.6 | 1.6 | 1.2 |
| 32. | Heat Dissipation | kb/hr. | 5.5 | 6.2 | | | 1.2 | 4.0 | 4.0 | 3.0 |
| 33. | Density—Weight | $lbs/ft.^3$ | 28.2 | 28.1 | | | 23.5 | 25.8 | 25.8 | 24.0 |
| 34. | Heat Per Cu. Ft. | kb/hr. | .119 | .134 | | | .064 | .134 | .134 | .068 |
| 35. | Price Per Pound | $/lb. | 23.0 | 25.2 | | | 33.7 | 54.5 | 48.3 | 32.3 |

**TABLE II.2.12.5 PUNCHED CARD UNITS**

| | Manufacturer: Model Number: | | IBM 2596 | IBM 5424-A1 | IBM 5424-A2 | IBM 3505-B1 | IBM 3505-B2 | IBM 3525-P1 | IBM 3525-P3 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /70 | /70 | /70 | /72 | /72 | /72 | /72 |
| | **Unit Characteristics** | | | | | | | | |
| 2. | Card Reader | | | | | | | | |
| 3. | Speed (maximum) | cpm | 500 | 250 | 500 | 800 | 1200 | - | - |
| 4. | Char. Per Second | kcps | .8 | .4 | .8 | 1.067 | 1.600 | | |
| 5. | Number of Clutch Points | | - | | | None | None | | |
| 6. | Number of Read Heads | | 6 | 6 | 6 | | | | |
| 7. | Read System | | | | | Photo | Photo | | |
| | Card Punch | | | | | | | | |
| 8. | Speed (maximum) | cpm | 120 | 60 | 120 | - | - | 100 | 300 |
| 9. | Char. Per Second | kcps | .192 | .096 | .192 | | | .133 | .400 |
| 10. | Number of Clutch Points | | | | | | | 4 | 4 |
| 11. | Number of Punch Heads | | 6 | 6 | 6 | | | 80 | 80 |
| 12. | Feed Hopper—Number | | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 13. | Capacity, Each | | 2000 | 2000 | 2000 | 3000 | 3000 | 1200 | 1200 |
| 14. | Output Stacker—Number | | 4 | 4 | 4 | 2 | 2 | 2 | 2 |
| 15. | Capacity, Each | | 600 | 600 | 600 | 1750 | 1750 | 1200 | 1200 |
| | **Prices** | | | | | | | | |
| 16. | Controller Model No. | | Incl. | 4100 | 4101 | Incl. | Incl. | | |
| 17. | System | | 360/370 | S3 | S3 | | | | |
| 18. | Price—Purchase | $k | | 4.200 | 5.325 | | | | |
| 19. | Rental | $k/mo. | | .080 | .095 | | | | |
| 20. | Maintenance | $/mo. | | 60 | 60 | | | | |
| 21. | Reader/Punch Price | $k | 29.575 | 9.45 | 12.575 | 28.25 | 29.25 | 20.0 | 21.6 |
| 22. | Rental | $k/mo. | .845 | .270 | .405 | .565 | .670 | .40 | .61 |
| 23. | Maintenance | $/mo. | 330 | 140 | 200 | 85 | 115 | 60 | 100 |
| 24. | Maint. Cost Per $100k | $/mo. | 1115.8 | 1481.5 | 1590.4 | 300.9 | 393.2 | 300.0 | 463.0 |
| 25. | Price: Rent Ratio | | 35.0 | 35.0 | 31.0 | 50.0 | 43.7 | 50.0 | 35.4 |
| 26. | Char. Per $—Read | kby/$ | 592.0 | 925.0 | 1235.2 | 1180.3 | 1492.5 | - | - |
| 27. | Punch | kby/$ | 142.0 | 222.2 | 296.3 | - | - | 207.8 | 409.8 |
| 28. | **Physical Char.—Wt.** | lbs. | 575 | - | | 900 | 900 | 850 | 850 |
| 29. | Floor Space | Sq. Ft. | 9.0 | 7.0 | | 12.5 | 12.5 | 10.4 | 10.4 |
| 30. | Volume | Cu. Ft. | 41.1 | 31.9 | | 45.8 | 45.8 | 39.1 | 39.1 |
| 31. | Electrical Load | kva | 1.7 | .8 | | 1.9 | 1.9 | 1.6 | 1.6 |
| 32. | Heat Dissipation | kb/hr. | 4.5 | 2.0 | | 4.6 | 4.6 | 4.4 | 4.4 |
| 33. | Density—Weight | $lbs/ft.^3$ | 14.0 | - | | 19.6 | 19.6 | 21.8 | 21.8 |
| 34. | Heat Per Cu. Ft. | kb/hr. | .110 | .063 | | .100 | .100 | .113 | .113 |
| 35. | Price Per Pound | $/lb. | 51.4 | - | | 31.4 | 32.5 | 23.5 | 25.4 |

## TABLE II.2.12.5 PUNCHED CARD UNITS

| | Manufacturer: / Model Number: | | BGH 292 | BGH 293 | BGH 122 | BGH 124 | BGH 129 | BGH 303 | BGH 304 | BGH 9110 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /56? | /56? | /60? | /60? | /60? | /60? | /60? | /61 |
| | **Unit Characteristics** | | | | | | | | | |
| 2. | Card Reader | | | | | | | | | |
| 3. | Speed (maximum) | cpm | - | 300 | 200 | 800 | 1200 | - | - | 200 |
| 4. | Char. Per Second | kcps | | .400 | .266 | 1.067 | 1.600 | | | .267 |
| 5. | Number of Clutch Points | | | | None | | | | | None |
| 6. | Number of Read Heads | | | | 12 | | | | | 12 |
| 7. | Read System | | | | Photo | | | | | Photo |
| | Card Punch | | | | | | | | | |
| 8. | Speed (maximum) | cpm | 100 | - | - | - | - | 100 | 300 | - |
| 9. | Char. Per Second | kcps | .133 | | | | | .133 | .400 | |
| 10. | Number of Clutch Points | | | | | | | | | |
| 11. | Number of Punch Heads | | | | | | | | | |
| 12. | Feed Hopper—Number | | 1 | 2 | 1 | 1 | | 1 | | 1 |
| 13. | Capacity, Each | | 800 | 1000 | 500 | 2400 | | 800 | | 500 |
| 14. | Output Stacker—Number | | 2 | 1 | 1 | 1 | | 2 | | 1 |
| 15. | Capacity, Each | | 800 | 1000 | 500 | 2400 | | 800 | | 500 |
| | **Prices** | | | | | | | | | |
| 16. | Controller Model No. | | | | | | | | | 2110-2 |
| 17. | System | | | | | | | | | 2700 |
| 18. | Price—Purchase | $k | | | | | | | | 2.59 |
| 19. | Rental | $k/mo. | | | | | | | | .054 |
| 20. | Maintenance | $/mo. | | | | | | | | 8 |
| 21. | Reader/Punch Price | $k | 5.8 | 14.0 | 9.9 | 18.0 | 27.0 | 20.25 | 29.25 | 8.4 |
| 22. | Rental | $k/mo. | .129 | .311 | .22 | .40 | .60 | .45 | .65 | .175 |
| 23. | Maintenance | $/mo. | (OEM) | (OEM) | 40 | 75 | 115 | 65 | 115 | 41 |
| 24. | Maint. Cost Per $100k | $/mo. | | | 404.0 | 416.7 | 425.9 | 321.0 | 393.2 | 488.1 |
| 25. | Price: Rent Ratio | | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 48.0 |
| 26. | Char. Per $—Read | kby/$ | - | 803.9 | 755.7 | 1666.7 | 1666.7 | - | - | 953.6 |
| 27. | Punch | kby/$ | 644.3 | - | - | - | - | 184.7 | 384.6 | - |
| 28. | **Physical Char.—Wt.** | lbs. | | | | | | | | |
| 29. | Floor Space | Sq. Ft. | 8.2 | 8.5 | | | | | | |
| 30. | Volume | Cu. Ft. | 31.1 | 33.8 | | | | | | |
| 31. | Electrical Load | kva | 1.2 | 1.2 | | | | | | |
| 32. | Heat Dissipation | kb/hr. | | | | | | | | |
| 33. | Density—Weight | lbs/ft.$^3$ | | | | | | | | |
| 34. | Heat Per Cu. Ft. | kb/hr. | | | | | | | | |
| 35. | Price Per Pound | $/lb. | | | | | | | | |

## TABLE II.2.12.5 PUNCHED CARD UNITS

| | Manufacturer: / Model Number: | | BGH 9111 | BGH 9113 | BGH 9112 | BGH 9210 | BGH 9211 | Univac 4940 | Univac 7936 | Univac 7935 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /63 | /64? | /65? | /66? | /66? | /57? | /59 | /59 |
| | **Unit Characteristics** | | | | | | | | | |
| 2. | Card Reader | | | | | | | | | |
| 3. | Speed (maximum) | cpm | 800 | 475 | 1400 | - | - | 300 | - | 600 |
| 4. | Char. Per Second | kcps | 1.067 | .633 | 1.867 | | | .40 | | .80 |
| 5. | Number of Clutch Points | | None | None | None | | | | | 1 |
| 6. | Number of Read Heads | | 12 | 12 | 12 | | | | | 80 |
| 7. | Read System | | Photo | Photo | Photo | | | | | Brush |
| | Card Punch | | | | | | | | | |
| 8. | Speed (maximum) | cpm | - | - | - | 100 | 300 | 150 | 150 | - |
| 9. | Char. Per Second | kcps | | | | .133 | .400 | .20 | .20 | |
| 10. | Number of Clutch Points | | | | | None | 1 | | 1 | |
| 11. | Number of Punch Heads | | | | | 80 | 80 | | | |
| 12. | Feed Hopper—Number | | 1 | 1 | 1 | 1 | 1 | | 1 | 1 |
| 13. | Capacity, Each | | 3600 | 3600 | 3600 | 800 | 3000 | | 600 | 1000 |
| 14. | Output Stacker—Number | | 1 | 1 | 1 | 1 | 3 | | 2 | 3 |
| 15. | Capacity, Each | | 3000 | 3000 | 3000 | 800 | 1500av. | | 1200 | 1200 |
| | **Prices** | | | | | | | | | |
| 16. | Controller Model No. | | 2110-2 | 2110-2 | 2110-2 | 2212-2 | 2212-2 | Incl | Incl. | Incl. |
| 17. | System | | 2700 | 2700 | 2700 | 2700 | 2700 | UFC | SS80 | SS80 |
| 18. | Price—Purchase | $k | | | | 2.59 | | | | |
| 19. | Rental | $k/mo. | | | | .054 | | | | |
| 20. | Maintenance | $/mo. | | | | 8 | | | | |

**TABLE II.2.12.5 PUNCHED CARD UNITS (continued)**

| | Manufacturer: Model Number: | | BGH 9111 | BGH 9113 | BGH 9112 | BGH 9210 | BGH 9211 | Univac 4940 | Univac 7936 | Univac 7935 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21. | Reader/Punch Price | $k | 16.25 | 12.48 | 21.6 | 18.425 | 25.75 | 55.0 | 32.0 | 11.2 |
| 22. | Rental | $k/mo. | .325 | .300 | .450 | .35 | .515 | 1.3 | .725 | .255 |
| 23. | Maintenance | $/mo. | 85 | 72 | 129 | 67 | 175 | - | 200 | 55 |
| 24. | Maint. Cost Per $100k | $/mo. | 523.1 | 576.9 | 597.2 | 363.6 | 679.6 | - | 625.0 | 491.1 |
| 25. | Price: Rent Ratio | | 50.0 | 41.6 | 48.0 | 52.6 | 50.0 | 42.3 | 44.1 | 43.9 |
| 26. | Char. Per $—Read | kby/$ | 2051.9 | 1318.7 | 2593.1 | - | - | 192.3 | - | 1960.8 |
| 27. | Punch | kby/$ | - | - | - | 237.5 | 485.4 | 96.2 | 172.4 | - |
| 28. | **Physical Char.—Wt.** | lbs. | | | | | | 2840 | | |
| 29. | Floor Space | Sq. Ft. | | | | | | 24.9 | | |
| 30. | Volume | Cu. Ft. | | | | | | 132.6 | | |
| 31. | Electrical Load | kva | | | | | | 2.0 | | |
| 32. | Heat Dissipation | kb/hr. | | | | | | 6.0 | | |
| 33. | Density—Weight | lbs/ft.$^3$ | | | | | | 21.4 | | |
| 34. | Heat Per Cu. Ft. | kb/hr. | | | | | | .045 | | |
| 35. | Price Per Pound | $/lb. | | | | | | 19.4 | | |

**TABLE II.2.12.5 PUNCHED CARD UNITS**

| | Manufacturer: Model Number: | | Univac 706-0 | Univac 600 | Univac 0711-1 | Univac 0711-2 | Univac 0603-4 | Univac 0604 |
|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /64? | /64? | /67 | /67 | /67 | /67 |
| | **Unit Characteristics** | | | | | | | |
| 2. | Card Reader | | | | | | | |
| 3. | Speed (maximum) | cpm | 800 | - | 400 | 600 | - | - |
| 4. | Char. Per Second | kcps | 1.067 | | .533 | .800 | | |
| 5. | Number of Clutch Points | | None | 1 | | | | |
| 6. | Number of Read Heads | | | | 12 | 12 | | |
| 7. | Read System | | Photo | | Photo | Photo | | |
| | Card Punch | | | | | | | |
| 8. | Speed (maximum) | cpm | - | 300 | - | - | 75 | 200 |
| 9. | Char. Per Second | kcps | | .40 | | | .100 | .267 |
| 10. | Number of Clutch Points | | | | | | | |
| 11. | Number of Punch Heads | | | | | | 12 | 80 |
| 12. | Feed Hopper—Number | | 1 | 1 | 1 | 1 | 1 | 1 |
| 13. | Capacity, Each | | 3000 | 1000 | 1200 | 1200 | 1200 | 1000 |
| 14. | Output Stacker—Number | | 1 | 2 | 1 | 1 | 2 | 2 |
| 15. | Capacity, Each | | 2500 | 1000 | 1500 | 1500 | 750 | 1000 |
| | **Prices** | | | | | | | |
| 16. | Controller Model No. | | 5010 | 5010 | incl. | incl. | incl. | |
| 17. | System | | 1108 | 1108 | 9200 | 9200 | 9200 | 9300 |
| 18. | Price—Purchase | $k | 33.75 | | | | | |
| 19. | Rental | $k/mo. | .750 | | | | | |
| 20. | Maintenance | $/mo. | 230 | | | | | |
| 21. | Reader/Punch Price | $k | 15.2 | 26.6 | 4.735 | 6.63 | 6.63 | 9.92 |
| 22. | Rental | $k/mo. | .38 | .665 | .110 | .159 | .152 | .241 |
| 23. | Maintenance | $/mo. | 100 | 295 | 30 | 72 | 77 | 96 |
| 24. | Maint. Cost Per $100k | $/mo. | 657.9 | 1109.0 | 633.6 | 1086.0 | 1161.4 | 967.7 |
| 25. | Price: Rent Ratio | | 40.0 | 40.0 | 43.0 | 41.7 | 43.6 | 41.2 |
| 26. | Char. Per $—Read | kby/$ | 1754.9 | - | 3028.4 | 3144.7 | - | - |
| 27. | Punch | kby/$ | - | 375.9 | - | - | 1097.9 | 692.4 |
| 28. | **Physical Char.—Wt.** | lbs. | | | | | | |
| 29. | Floor Space | Sq. Ft. | | | | | | |
| 30. | Volume | Cu. Ft. | | | | | | |
| 31. | Electrical Load | kva | | | | | | |
| 32. | Heat Dissipation | kb/hr. | | | | | | |
| 33. | Density—Weight | lbs/ft.$^3$ | | | | | | |
| 34. | Heat Per Cu. Ft. | kb/hr. | | | | | | |
| 35. | Price Per Pound | $/lb. | | | | | | |

## TABLE II.2.12.6 IBM 1403 LINE PRINTER—NOTES

This table provides basic timing data about the operation of the IBM 1403 line printer. It is derived from AuerCTR. Three operating parameters are of importance, and are given in the three columns of the table. The first is the time required to print one line and space up ready to print the next line. This time is dependent on the time taken for the complete set of printing elements, numeric or alphanumeric, to pass by the paper. It is thus a function of the mechanism's speed, and of the number of characters in the character set to be printed. When printing in the alphanumeric mode, the 1403-1 printing chain requires 80 milliseconds to pass the paper. Another 20 milliseconds are required to move the paper up ready to print the next line, for a total of 100 milliseconds as shown. The alphanumeric chain can be replaced by an all-numeric chain in which a 16-digit character set is repeated three times. The printing cycle thus requires only one-third of 80 milliseconds plus the 20 milliseconds necessary to space the paper, for a total of 46.7 milliseconds. The 1403-3 mechanism employes a "train" of linked printing elements which moves much faster than the chain of the 1403-1, permitting a complete print cycle, including paper movement, of 54.5 milleseconds.

When lines are to be skipped on the printed page, the printer provides special facilities for moving the paper at speeds much faster than that possible when the printer prints one line at a time. The 1403 mechanism skips paper at the rate of 33 inches per second for skips of eight lines or less, and at 75 inches per second for skips longer than eight lines. For short skips, the time necessary to accelerate the paper is negligible, and the 33 inch per second skipping speed requires either 5.05 or 2.22 milliseconds to skip one line, depending upon whether the printer is printing six or eight lines to the inch. For longer skips, the per-line time is smaller, as shown in the table; but 22.4 milliseconds are required to accelerate the paper to the higher speed.

Suppose our printing cycle involves L lines, and that we must print on the first pL of these lines, and then space (1-p) L lines. The time required to complete an L-line cycle has three components: the first is pL multiplied by the time required to print one line and space up to the next line; the second is the time required to get up to slewing speed, if more than eight lines are to be skipped; and the third component is (1-p) L multiplied by the time required to slew one line. Making use of this calculation, and the parameters in the table, one can compute the effective printing speed for any combination of p and L.

## TABLE II.2.13.1 KEYBOARD DATA ENTRY EQUIPMENT—NOTES

**Sources.** Information on the IBM 11, 16, 31, and 52 comes from an IBM document "Principles of Operation—Card Punching and Verifying Machines", (Form 52-3176-4, Copyright 1946). Specifications on the IBM 24-1 and 26-1 comes from IBM's "Principles of Operation—Card Punch Type 24 and Printing Card Punch Type 26" (Form 22-5759-2, Copyright 1951). Data on the other IBM machines comes from the IBM Consultants Manual. Information on the machines from all other manufacturers excluding Univac comes from AlriJ70. The data on the Unityper machine is from private correspondence with Sperry-Rand. Prices for the IBM equipment come from IBM's GSA price catalogues.

**Date First Installed.** For the early IBM equipment, my dates are guesses based on the copyright dates of the brochures referred to above. For the IBM 29 and later machines, my dates are based on the first appearance of prices in IBM's GSA catalogues—the 29-822, for example, appears in the 1964 catalogue but not the 1963 catalogue. Dates for the other products in the table come from AlriJ70.

**Input Keyboards.** 2-4. Line 2 specifies whether the keyboard is numeric or alphanumeric. Lines 3 and 4 indicate the minimum and maximum number of keyboards available. For stand-alone systems, the minimum and maximum are of course both equal to 1.

**Output.** 5-6. These two lines indicate whether the unit output is a punched card or a magnetic tape. For some items (e.g., the IBM 52) the sole function is verification, and I have interpreted that to mean there is neither a punched card nor magnetic tape output.

7-9. Where a magnetic output is possible, the characteristics of the output medium are shown on these lines.

10-11. The minimum and maximum record size are given on these two lines.

**Features.** 12-17. Internal storage capacity specifies the number of characters which can be stored internally to the system between keyboard and the output medium. For stand-alone systems, internal storage, if available, is generally in the form of electronic circuits; for shared processor, it may be in the form of a moving-head-file.

The edit feature refers to the ability of the keyboard operator to make changes while typing, as he catches errors. "Display" and "print" refer to the ability of the system to display or print keyboard entries. A unit operates in the "verify" mode when it can compare keyboard entries with previously-prepared output and provide some sort of signal when differences are detected. And a unit which is able to copy a previously-output record is said to have the "duplicate" feature.

**Prices.** 18. This line shows the effective date of the prices. Note that, for the early IBM units, the only prices I have are those from the 1963 GSA catalogue.

19-22. For systems which require some form of shared processor, its prices appear here. For key-to-tape systems, I have included the cost of a "spooler", used to combine the inconveniently short tapes generated by the keyboards. For IBM's 3741 and 3742, I have included the price of the 3747 data converter, which transfers data disk to conventional one-half inch computer tape. For key-to-disk systems I have included the price of the minicomputer and peripherals which control the keyboards.

23-24. Keyboard prices are shown on these lines. For IBM 3742, which basically is a single station having two keyboards, the prices shown are one-half the system price. (Note that the minimum number of keyboards allowed is two, as shown on line 3.)

25-28. The ratios shown on these lines are computed from the appropriate data on lines 19 through 24.

TABLE II.2.12.6 IBM 1403 LINE PRINTER ASSUMED TIMING CHARACTERISTICS

| | Print One Line And Space Up To Next Line (ms) | Accelerate To Slewing Speed (ms) | Slew One Line (ms) |
|---|---|---|---|
| **1403-1 (600 lpm)** | | | |
| Alphabetic Printing | 100.0 | | |
| Numeric Printing | 46.7 | | |
| **1403-3 (1100 lpm)** | 54.5 | | |
| **1403-1 or 1403-3** | | | |
| Slew Less Than 9 Lines | | | |
| At 6 Lines Per Inch | | 0 | 5.05 |
| At 8 Lines Per Inch | | 0 | 3.79 |
| Slew More Than 8 Lines | | | |
| At 6 Lines Per Inch | | 22.4 | 2.22 |
| At 8 Lines Per Inch | | 22.4 | 1.67 |

TABLE II.2.13.1 KEYBOARD DATA ENTRY EQUIPMENT

| | Manufacturer Model Number | | IBM 11 | IBM 16 | IBM 31 | IBM 52 | IBM 24-1 | IBM 26-1 | IBM 29-A22 | IBM 59-2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | /45? | /45? | /45? | /40's | /51? | /51? | /64 | /64 |
| 2. | **Input Keyboard** | | num. | num. | alpha | num. | alpha | alpha | alpha | alpha |
| 3. | Keyboards-Min. | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4. | Max. | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | **Output** | | | | | | | | | |
| 5. | Card | | yes | yes | yes | no | yes | yes | yes | no |
| 6. | Magnetic Medium | | no | no | no | no | no | no | no | no |
| 7. | Type | | | | | | | | | |
| 8. | No. of Tracks | | | | | | | | | |
| 9. | Maximum Density | bpi | | | | | | | | |
| 10. | Format—Minimum Record | by. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11. | Maximum Record | by. | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| | **Features** | | | | | | | | | |
| 12. | Internal Storage Capy. | by. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13. | Edit | | no | no | no | no | no | no | no | no |
| 14. | Display | | no | no | no | no | no | no | no | no |
| 15. | Print | | no | no | no | no | no | yes | yes | no |
| 16. | Verify | | no | no | no | yes | no | no | no | yes |
| 17. | Duplicate | | no | yes | yes | no | yes | yes | yes | no |
| 18. | **Prices (date)** | | (1963) | (1963) | (1963) | (1963) | (1963) | (1963) | (1964) | (1964) |
| 19. | Shared Processor—Purch. | $k | - | - | - | - | - | - | - | - |
| 20. | Rental | $/mo | - | - | - | - | - | - | - | - |
| 21. | Maintenance | $/mo | - | - | - | - | - | - | - | - |
| 22. | Keyboard—Purchase | $k | 0.60 | 1.00 | 1.40 | 1.00 | 2.35 | 3.825 | 3.60 | 3.45 |
| 23. | Rental | $/mo | 7.50 | 23.00 | 30.00 | 18.00 | 40.00 | 60.00 | 69.00 | 66.00 |
| 24. | Maintenance | $/mo | 1.00 | 8.00 | 11.25 | 4.75 | 12.50 | 13.00 | 18.00 | 16.75 |
| | Ratios | | | | | | | | | |
| 25. | Processor—Price: Rent | | - | - | - | - | - | - | - | - |
| 26. | Maint. Per $100k | $/mo | - | - | - | - | - | - | - | - |
| 27. | Keyboard—Price: Rent | | 80.0 | 43.4 | 46.7 | 55.6 | 58.8 | 63.8 | 52.2 | 52.3 |
| 28. | Maint. Per $100k | $/mo | 167 | 800 | 804 | 475 | 532 | 340 | 500 | 486 |

TABLE II.2.13.1 KEYBOARD DATA ENTRY EQUIPMENT

| | Manufacturer Model Number | | IBM 50 | IBM 129-3 | IBM 5496-1 | IBM 3741-1 | IBM 3742 |
|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | /69 | /70 | /70 | /74 | /74 |
| 2. | **Input Keyboard** | | alpha | alpha | alpha | alpha | alpha |
| 3. | Keyboards-Min. | | 1 | 1 | 1 | 1 | 2 |
| 4. | Max. | | 1 | 1 | 1 | 1 | 2 |
| | **Output** | | | | | | |
| 5. | Card | | no | yes | yes | no | no |
| 6. | Magnetic Medium | | yes | no | no | yes | yes |

## TABLE II.2.13.1 KEYBOARD DATA ENTRY EQUIPMENT (continued)

| | Manufacturer<br>Model Number | | IBM<br>50 | IBM<br>129-3 | IBM<br>5496-1 | IBM<br>3741-1 | IBM<br>3742 |
|---|---|---|---|---|---|---|---|
| 7. | Type | | cart. | | | disk | disk |
| 8. | No. of Tracks | | 8 | | | | |
| 9. | Maximum Density | bpi | | | | | |
| 10. | Format—Minimum Record | by. | - | 1 | 1 | 1 | 80 |
| 11. | Maximum Record | by. | - | 80 | 96 | 128 | 80 |
| | **Features** | | | | | | |
| 12. | Internal Storage Capy. | by. | 0 | 80 | 96 | 128 | 80 |
| 13. | Edit | | no | yes | yes | yes | yes |
| 14. | Display | | yes | no | yes | yes | yes |
| 15. | Print | | no | yes | yes | no | no |
| 16. | Verify | | yes | yes | yes | yes | yes |
| 17. | Duplicate | | no | yes | yes | no | no |
| 18. | **Prices (date)** | | (1969) | (1971) | (1971) | (1973) | (1973) |
| 19. | Shared Processor—Purch. | $k | - | - | - | 18.6 | 18.6 |
| 20. | Rental | $/mo | - | - | - | 441 | 441 |
| 21. | Maintenance | $/mo | - | - | - | 54 | 54 |
| 22. | Keyboard—Purchase | $k | 9.605 | 7.35 | 7.60 | 6.00 | 3.475 |
| 23. | Rental | $/mo | 175 | 150 | 155 | 159 | 94 |
| 24. | Maintenance | $/mo | 66 | 43 | 54 | 39 | 24 |
| | Ratios | | | | | | |
| 25. | Processor—Price: Rent | | - | - | - | 42.2 | 42.2 |
| 26. | Maint. Per $100k | $/mo | - | - | - | 290 | 290 |
| 27. | Keyboard—Price: Rent | | 54.9 | 49.0 | 49.0 | 37.7 | 37.0 |
| 28. | Maint. Per $100k | $/mo | 687 | 585 | 711 | 650 | 691 |

## TABLE II.2.13.1 KEYBOARD DATA ENTRY EQUIPMENT

| | Manufacturer<br>Model Number | | BGH<br>N7200 | CMC<br>9 | HIS<br>K700 | HIS<br>Kplx | Inf'x<br>2901 | MDS<br>1100 | Univac<br>U'typer I | Univac<br>U'typer II |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 12/68 | 7/69 | 7/68 | 1/71 | 1/70 | 4/65 | /51? | /55 |
| 2. | **Input Keyboard** | | alpha | alpha | alpha | alpha | alpha | alpha | alpha | alpha |
| 3. | Keyboards-Min. | | 1 | 10 | 1 | 8 | 8 | 1 | 1 | 1 |
| 4. | Max. | | any | 32 | any | 64 | 8 | any | 1 | 1 |
| | **Output** | | | | | | | | | |
| 5. | Card | | no | no | no | no | no | no | no | no |
| 6. | Magnetic Medium | | yes | yes | yes | yes | yes | yes | yes | yes |
| 7. | Type | | mylar | mylar | mylar | mylar | mylar | mylar | metal | mylar |
| 8. | No. of Tracks | | 7 | 7 | 7 | 9 | 9 | 7 | 8 | 8 |
| 9. | Maximum Density | bpi | 800 50 | 800 | 800 | 800 | 800 | 800 | 50 | 50 |
| 10. | Format—Minimum Record | by. | | 1 | 80 | 1 | 16 | 10 | 120 | 120 |
| 11. | Maximum Record | by. | 160 | 240 | 400 | 400 | 125 | 180 | 120 | 120 |
| | **Features** | | | | | | | | | |
| 12. | Internal Storage Capy. | by. | | 7.25M | | 3.5M | .688M | | 0 | 0 |
| 13. | Edit | | yes | yes | yes | yes | yes | yes | no | no |
| 14. | Display | | yes | yes | yes | yes | yes | yes | no | no |
| 15. | Print | | no | no | no | no | no | no | yes | yes |
| 16. | Verify | | yes | yes | yes | yes | yes | yes | no | yes |
| 17. | Duplicate | | no | no | no | no | no | no | no | no |
| 18. | **Prices (date)** | | (1970) | (1970) | (1970) | | (1970) | (1970) | (1953) | (1955) |
| 19. | Shared Processor—Purch. | $k | 7.6 | 66.5 | 7.6 | | 25.5 | 7.6 | | |
| 20. | Rental | $/mo | 180 | 1375 | 180 | | 560 | 180 | | |
| 21. | Maintenance | $/mo | - | 206 | - | | 50 | - | | |
| 22. | Keyboard—Purchase | $k | 8.79 | 3.15 | 7.5 | | 1.2 | 7.2 | 22.0 | 4.5 |
| 23. | Rental | $/mo | 170 | 85 | 152 | | 50 | 140 | 390 | 90 |
| 24. | Maintenance | $/mo | | 13 | 21 | | 4 | 20 | | |
| | Ratios | | | | | | | | | |
| 25. | Processor—Price: Rent | | 42 | 48.4 | 42 | | 45.5 | 42 | | |
| 26. | Maint. Per $100k | $/mo | - | 310 | - | | 196 | - | | |
| 27. | Keyboard—Price: Rent | | 51.7 | 37.1 | 49.3 | | 24 | 51.4 | 56.4 | 50.0 |
| 28. | Maint. Per $100k | $/mo | | 413 | 280 | | 333 | 278 | | |

## TABLE II.2.14.1 DATA TRANSMISSION FACILITIES I (LEASED LINES)—NOTES

The study of data communication costs is extraordinarily complicated, in part because of the variety of facilities and arrangements which are offered, but mostly because the facilities are offered by a very large number of local monopolies, each regulated by one or more government agencies, and each providing different combinations of services under tariffs which change from time to time. The data in this table comes from a combination of sources: from private communications with representatives of the new specialized common carriers; from similar conversations with representatives of the American Telephone and Telegraph Company in New York and Pacific Telephone and General Telephone in Los Angeles; and from published papers on communication economics (ReagF71-1 and, NordK71). Nevertheless, the sources are incomplete and in some cases contradictory, and as a result the table may in some instances be in error.

**Columns.** Each column describes a different data service. Columns 1 through 20 describe early services provided by AT&T, and are arranged in increasing order of bit rate. Within each bit rate, I have provided data on how the costs have changed, when that data is available. Columns 21 through 23 describe AT&T's "high-low" tariff, introduced in 1974 to replace the voice-grade 3002 service. The 3002 facility provided service between any two U.S. locations at a rate which depended only on mileage, as shown in columns 13 and 14. The "high-low" tariff reflects the fact that it costs the telephone company less to serve some areas than others. For 369 major "high-density" cities, the "high" tariffs apply. For other cities, the "low" tariffs apply, though a user may connect two distant low-density cities by paying low-density tariffs to nearby high-density cities, and then connecting those cities with a low-cost high-tariff line. The "short-haul" tariff is for cities less than 25 miles apart. Early in 1976 the FCC reversed its previous tentative approval of AT&T's hi-low tariff.

Columns 24 to 28 refer to AT&T's Dataphone Digital Service (DDS), first available in New York, Chicago, Boston, Washington D.C., and Philadelphia early in 1975. The tariff shown was approved temporarily for those five cities only, and for another 13 major cities added later in the year. The rates shown in columns 26 and 27 apply to those cities for high-bit-rate transmissions. For 2400 and 4800 bps, rates are available in tabular form and seem nearly to follow the formula described by column 28.

Columns 31 to 34 refer to Data Transmission Co.'s (Datran's) Dataline Services, which are comparable to AT&T's DDS. The service was first available in Texas in late 1973, and by January 1975 was provided at 18 cities: New York, Boston, Philadelphia, Baltimore, Washington D.C., Pittsburgh, Cleveland, Detroit, Colombus, Chicago, St. Louis, Kansas City, Tulsa, Oklahoma City, Dallas, Houston, Los Angeles, and San Francisco.

The DDS and Dataline costs shown in columns 24 to 28 and 31 to 34 give service within a radius of about five miles of a specified central location in each city. For distances greater than five miles (but still within the city) there is an additional charge, as shown in columns 35 to 38. Datran is able to provide service to cities off its main network by connecting those cities to network cities via AT&T (or other common carrier) private lines. However, a slightly higher basic tariff, not shown here, then applies. Datran will add other cities to its network as time goes on, and of course AT&T will also be adding cities to its DDS network.

**Rows.** The effective date is the date the service was first available at the given price. The tariff is the number of the F.C.C. tariff which covered or covers the service.

I generally provide three measures of line speed—words per minute, bits per second, and characters per second. I have taken bits per second as the governing speed for each facility. Characters per second is derived from bits per second taking into account the number of equal-length information and space bits in each character. Thus, for example, the 75 and 100 word per minute services used five-bit characters with a start bit and a 1.5-bit long stop space. Later data services used characters containing 7 or 8 information bits plus 3 or 2 start and stop bits. Generally speaking, words per minute and characters per second are related by the ratio of six characters per word (and, of course, 60 seconds per minute).

Line costs per mile are, for lower-speed facilities, higher for short distances than they are for longer distances. Rates are therefore shown over a range of distances. Furthermore, total line costs per month are given for three sample mileages—30, 300, and 3000 miles. In addition to the cost of the lines themselves, there is normally a monthly terminal cost at each end of the line, and a one-time installation cost for each end of the line. These figures are given, along with a total terminal-installation monthly charge for two ends of a line, under two assumptions regarding the amortization of the one-time installation costs: a 12-month and a 48-month amortization period. Finally, the total monthly cost of the 30-, 300-, and 3000-mile lines are given, assuming the shorter amortization period. For column 1, for example, the 30-mile cost of $84.70 per month is the sum of the $33.00 line cost and the $51.70 terminal/installation charge.

### TABLE II.2.14.1 DATA TRANSMISSION FACILITIES I—LEASED LINES ●

| Column | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplier | | ATT | ATT | ATT | ATT | ATT | ATT | ATT | ATT | ATT | ATT |
| Effective Date | mo/yr | /53 | /53 | /67? | /67? | /53 | /67? | 3/65 | 3/65 | /67? | /67? |
| Tariff | | 208 | 208 | 260 | 260 | 208 | 260 | 260 | 260 | 260 | 260 |
| Service | | Sch. 2 | Sch. 2 | 1002 | 1002 | Sch. 3 | 1005 | 1006 | 1006 | 1006 | 1006 |
| Speed—Words | wpm | 75 | 75 | 75 | 75 | 100 | 100 | | | | |
| Bits | bps | 55 | 55 | 55 | 55 | 75 | 75 | 150 | 150 | 150 | 150 |
| Characters | cps | 7.3 | 7.3 | 7.3 | 7.3 | 10 | 10 | 15 | 15 | 15 | 15 |
| Line Costs/mi. | | | | | | | | | | | |
| Duplex | | Half | Full | Half | Full | Half | Half | Half | Full | Half | Full |
| 1st 25 mi. | $/mo | 1.10 | | 1.40 | | | | | | | |
| Next 75 mi. | $/mo | 1.10 | Half | 1.40 | Half | 75 | 1002 | Sch.2 | Half | 1002 | Half |
| Next 150 mi. | $/mo | 1.10 | Duplex | .98 | Duplex | wpm | Plus | Plus | Duplex | Plus | Plus |
| Next 250 mi. | $/mo | .55 | Plus | .56 | Plus | Plus | 10% | 25% | Plus | 25% | 10% |
| Next 500 mi. | $/mo | .44 | 10% | .42 | 10% | 10% | | | 10% | | |
| Next 500 mi. | $/mo | .385 | | .28 | | | | | | | |
| Addtl. Mi. | $/mo | .385 | | .28 | | | | | | | |
| Line Cost/mo. | | | | | | | | | | | |
| 30 Miles | $/mo | 33.0 | 36.3 | 42.0 | 46.2 | 36.3 | 46.2 | 41.3 | 45.4 | 52.5 | 57.8 |
| 300 Miles | $/mo | 302.5 | 332.8 | 315.0 | 346.5 | 332.8 | 346.5 | 378.1 | 415.9 | 393.8 | 433.1 |
| 3000 Miles | $/mo | 1402.5 | 1542.8 | 1197.0 | 1316.7 | 1542.8 | 1316.7 | 1753.1 | 1928.4 | 1496.3 | 1645.9 |
| Termin. Cost | $/mo | 25.0 | 27.5 | 25.0 | 27.5 | 27.5 | 27.5 | 31.3 | 34.4 | 31.3 | 34.4 |
| Instaln. Cost | $ | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Term/Inst. Chg. | | | | | | | | | | | |
| Amort. 12 mo. | $/mo | 51.7 | 56.7 | 51.7 | 56.7 | 56.7 | 56.7 | 64.3 | 70.5 | 64.3 | 70.5 |
| Amort. 48 mo. | $/mo | 50.4 | 55.4 | 50.4 | 55.4 | 55.4 | 55.4 | 63.0 | 69.2 | 63.0 | 69.2 |
| Tot. Cost—1 yr. | | | | | | | | | | | |
| 30 mi. | $/mo | 84.7 | 93.0 | 93.7 | 102.9 | 93.0 | 102.9 | 105.6 | 115.9 | 116.8 | 128.3 |
| 300 mi. | $/mo | 354.2 | 389.5 | 366.7 | 403.2 | 389.5 | 403.2 | 442.4 | 486.4 | 458.1 | 503.6 |
| 3000 mi. | $/mo | 1454.2 | 1599.5 | 1248.7 | 1373.4 | 1599.5 | 1373.4 | 1817.4 | 1998.9 | 1560.3 | 1716.4 |

### TABLE II.2.14.1 DATA TRANSMISSION FACILITIES I—LEASED LINES ●

| Column | | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplier | | ATT | ATT | ATT | ATT | ATT | ATT | ATT | ATT | ATT | ATT |
| Effective Date | mo/yr | 10/57 | 10/57 | /67? | /67? | /66 | /66 | /67 | /66 | /67 | ? |
| Tariff | | 237 | 237 | 260 | 260 | 260 | 260 | 260 | 260 | 260 | ? |
| Service | | Sch. 4 | Sch. 4 | 3002 | 3002 | 8000 | 5700 | 5700 | 5800 | 5800 | |
| Speed—Words | wpm | Voice Grade | Voice Grade | Voice Grade | Voice Grade | Wide Band | Telpak C | Telpak C | Telpak D | Telpak D | Voice Grade |
| Bits | bps | 4000 | 4000 | 9600 | 9600 | 48k | 240k | 240k | 1M | 1M | 4000 |
| Characters | cps | | | | | | | | | | |
| Line Costs/mi. | | | | | | | | | | | |
| Duplex | | Half | Full | Half | Full | Full | Full | Full | Full | Full | Full |
| 1st 25 mi. | $/mo | 2.02 | | 3.00 | | 15.00 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Next 75 mi. | $/mo | 2.02 | Half | 2.10 | Half | 15.00 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Next 150 mi. | $/mo | 2.02 | Duplex | 1.50 | Plus | 15.00 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Next 250 mi. | $/mo | 1.717 | Plus | 1.05 | 10% | 10.50 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Next 500 mi. | $/mo | 1.616 | 10% | 0.75 | | 7.50 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Next 500 mi. | $/mo | 1.616 | | 0.75 | | 7.50 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Addtl. Mi. | $/mo | 1.616 | | 0.75 | | 7.50 | 25.00 | 30.00 | 45.00 | 85.00 | 4.02 |
| Line Cost/mo. | | | | | | | | | | | |
| 30 Miles | $/mo | 60.6 | 66.7 | 85.5 | 94.1 | 450 | 750 | 900 | 1350 | 2550 | 120.5 |
| 300 Miles | $/mo | 590.9 | 650.0 | 510.0 | 561.0 | 4275 | 7500 | 9000 | 13500 | 25500 | 1204.5 |
| 3000 Miles | $/mo | 4974.2 | 5471.7 | 2595.0 | 2854.5 | 25125 | 75k | 90k | 135k | 255k | NA |
| Termin. Cost | $/mo | 12.5 | 13.8 | 12.5 | 13.8 | | | | | | 20 |
| Instaln. Cost | $ | 10.0 | 10.0 | 10.0 | 10.0 | | 100.0 | 100.0 | 100.0 | 100.0 | 10 |
| Term/Inst. Chg. | | | | | | | | | | | |
| Amort. 12 mo. | $/mo | 26.7 | 29.3 | 26.7 | 29.3 | | 16.7 | 16.7 | 16.7 | 16.7 | 41.8 |
| Amort. 48 mo. | $/mo | 25.4 | 28.0 | 25.4 | 28.0 | | 4.2 | 4.2 | 4.2 | 4.2 | 40.4 |
| Tot. Cost—1 yr. | | | | | | | | | | | |
| 30 mi. | $/mo | 87.3 | 86.0 | 112.2 | 123.4 | 450 | 767 | 917 | 1367 | 2567 | 162.3 |
| 300 mi. | $/mo | 617.6 | 679.3 | 536.7 | 590.3 | 4275 | 7517 | 9017 | 13517 | 25517 | 1246.3 |
| 3000 mi. | $/mo | 5000.9 | 5501.0 | 2621.7 | 2977.8 | 25125 | 75k | 90k | 135k | 255k | NA |

## TABLE II.2.14.1 DATA TRANSMISSION FACILITIES I—LEASED LINES ●

| Column<br>Supplier<br>Effective Date<br>Tariff<br>Service | mo/yr | 21<br>ATT<br>/74<br>260<br>Hi | 22<br>ATT<br>/74<br>260<br>Lo | 23<br>ATT<br>/74<br>260<br>Short | 24<br>ATT<br>1/75<br>260,267<br>DDS | 25<br>ATT<br>1/75<br>260,267<br>DDS | 26<br>ATT<br>1/75<br>260,267<br>DDS | 27<br>ATT<br>1/75<br>260,267<br>DDS | 28<br>ATT<br>1/75<br>260,267<br>DDS |
|---|---|---|---|---|---|---|---|---|---|
| Speed—Words | wpm | Voice Grade | Voice Grade | Voice Grade | | | | | |
| Bits | bps | 9600 | 9600 | 9600 | 2400 | 4800 | 9600 | 56k | 2.4k,4.8k |
| Characters | cps | | | | | | | | |
| Line Costs/mi. | | | | | | | | | |
| Duplex | | Full | Full | Full | Full | Full | Full | Full | Full |
| 1st 25 mi. | $/mo | .85 | 2.50 | 3.0 | .60 | .90 | 1.30 | 6.00 | .85 |
| Next 75 mi. | $/mo | .85 | 2.50 | N/A | .60 | .90 | 1.30 | 6.00 | .85 |
| Next 150 mi. | $/mo | .85 | 2.50 | | .60 | .90 | 1.30 | 6.00 | .85 |
| Next 250 mi. | $/mo | .85 | 2.50 | | .60 | .90 | 1.30 | 6.00 | .85 |
| Next 500 mi. | $/mo | .85 | 2.50 | | .60 | .90 | 1.30 | 6.00 | .85 |
| Next 500 mi. | $/mo | .85 | 2.50 | | .60 | .90 | 1.30 | 6.00 | .85 |
| Addtl. Mi. | $/mo | .85 | 2.50 | | .60 | .90 | 1.30 | 6.00 | .85 |
| Line Cost/mo. | | | | | | | | | |
| 30 Miles | $/mo | 25.5 | 75 | 90 | 18 | 27 | 39 | 180 | 25.5 |
| 300 Miles | $/mo | 255 | 750 | - | 180 | 270 | 390 | 1800 | 255 |
| 3000 Miles | $/mo | 2500 | 7500 | - | 1800 | 2700 | 3900 | 18000 | 2550 |
| Termin. Cost | $/mo | 60 | 40 | 18 | 75 | 105 | 140 | 262.5 | 115 |
| Instaln. Cost | $ | 50 | 50 | 50 | 100 | 100 | 100 | 150 | 100 |
| Term/Inst. Chg. | | | | | | | | | |
| Amort. 12 mo. | $/mo | 128.3 | 88.3 | 44.3 | 166.7 | 226.7 | 296.7 | 550 | 246.7 |
| Amort. 48 mo. | $/mo | 122.1 | 82.1 | 38.1 | 154.2 | 214.2 | 284.2 | 531.3 | 234.2 |
| Tot. Cost—1 yr. | | | | | | | | | |
| 30 mi. | $/mo | 153.8 | 163.3 | 134.3 | 184.7 | 253.7 | 335.7 | 730 | 272.2 |
| 300 mi. | $/mo | 383.3 | 838.3 | - | 346.7 | 496.7 | 686.7 | 2350 | 501.7 |
| 3000 mi. | $/mo | 2678.3 | 7588.3 | - | 1966.7 | 2926.7 | 4196.7 | 18550 | 2796.7 |

## TABLE II.2.14.1 DATA TRANSMISSION FACILITIES I—LEASED LINES ●

| Column<br>Supplier<br>Effective Date<br>Tariff<br>Service | mo/yr | 31<br>Datran<br>12/73<br>D.No.1<br>D'line I | 32<br>Datran<br>12/73<br>D.No.1<br>D'line I | 33<br>Datran<br>12/73<br>D.No.1<br>D'line I | 34<br>Datran<br>12/73<br>D.No.1<br>D'line I | 35<br>ATT/Dat.<br>12/73<br>-<br>Loop | 36<br>ATT/Dat.<br>12/73<br>-<br>Loop | 37<br>ATT/Dat.<br>12/73<br>-<br>Loop | 38<br>ATT/Dat.<br>12/73<br>-<br>Loop |
|---|---|---|---|---|---|---|---|---|---|
| Speed—Words | wpm | | | | | | | | |
| Bits | bps | 2400 | 4800 | 9600 | 56000 | 2400 | 4800 | 9600 | 56000 |
| Characters | cps | | | | | | | | |
| Line Costs/mi. | | | | | | | | | |
| Duplex | | Full | Full | Full | Full | Full | Full | Full | Full |
| 1st 25 mi. | $/mo | .36 | .54 | .81 | 3.60 | .6 | .9 | 1.30 | 6.00 |
| Next 75 mi. | $/mo | .36 | .54 | .81 | 3.60 | NA | NA | NA | NA |
| Next 150 mi. | $/mo | .36 | .54 | .81 | 3.60 | | | | |
| Next 250 mi. | $/mo | .36 | .54 | .81 | 3.60 | | | | |
| Next 500 mi. | $/mo | .36 | .54 | .81 | 3.60 | | | | |
| Next 500 mi. | $/mo | .36 | .54 | .81 | 3.60 | | | | |
| Addtl. Mi. | $/mo | .36 | .54 | .81 | 3.60 | | | | |
| Line Cost/mo. | | | | | | | | | |
| 30 Miles | $/mo | 10.8 | 16.2 | 24.3 | 108 | 18 | 27 | 39 | 180 |
| 300 Miles | $/mo | 108 | 162 | 243 | 1080 | NA | NA | NA | NA |
| 3000 Miles | $/mo | 1080 | 1620 | 2430 | 10800 | | | | |
| Termin. Cost | $/mo | 60.7 | 87.7 | 119.2 | 235 | 25 | 25 | 20 | 50 |
| Instaln. Cost | $ | 150 | 200 | 200 | 200 | 0 | 0 | 0 | 0 |
| Term/Inst. Chg. | | | | | | | | | |
| Amort. 12 mo. | $/mo | 146.4 | 208.7 | 271.7 | 503.3 | 25 | 25 | 20 | 50 |
| Amort. 48 mo. | $/mo | 127.7 | 183.7 | 246.7 | 478.3 | 25 | 25 | 20 | 50 |
| Tot. Cost—1 yr. | | | | | | | | | |
| 30 mi. | $/mo | 157.2 | 224.9 | 296.0 | 611.3 | 43 | 52 | 59 | 230 |
| 300 mi. | $/mo | 254.7 | 370.7 | 514.7 | 1583.3 | - | - | - | - |
| 3000 mi. | $/mo | 1226.4 | 1828.7 | 2701.7 | 11303.3 | - | - | - | - |

## TABLE II.2.14.2 DATA TRANSMISSION FACILITIES II (DIALED LINES)—NOTES

If a user's data transmission volume is too low to warrant the expense of a full-time private line, or if he wants to transmit and receive data from and to a variety of locations on a single line, he can make use of various facilities, provided by communications companies, which perform automatic line switching. This table describes the tariffs applicable to these facilities.

**Direct Dialing (DD).** Columns 1 through 14 describe the rates for voice quality circuits, effective during two different eras: columns 1 to 8 represent rates which were effective through the end of 1974, columns 9 to 14 have applied since 1975. They are interstate rates, not applicable to costs of calls between two points in a single state. (The rate for such calls is generally higher than the interstate rate.) The rates are applicable during four different portions of the week, and each portion is described in a pair of columns. Columns 1 and 2 cover days, defined as 8:00 a.m. to 5:00 p.m. Monday through Friday. Columns 3 and 4 cover evenings, defined as 5:00 p.m. through 11:00 p.m., Sunday through Friday. Columns 5 and 6, nights, defined as 11:00 p.m. to 8:00 a.m. daily. And columns 7 and 8, weekends, defined as 8:00 a.m. to 11:00 p.m. on Saturdays, and 8:00 a.m. to 5:00 p.m. on Sundays. Columns 9-14 cover similar periods, as indicated. All times refer to the time of day at the point where the call is originated. The cost of each call is higher during the first minutes of the call than during subsequent minutes, and the pertinent rates are shown in the pairs of columns.

**WATS.** Wide Area Telephone Service is the terminology applied to a special and very complicated tariff useful to subscribers who make extensive use of the DD network. Columns 15 through 18 give a simplified picture of the tariff for such services, as of the end of 1973. The service was available at least as early as 1964. The range of monthly rates for full-time service is given in columns 9 and 10, and typical rates for "measured-time" WATS, with a minimum of ten hours per month, are shown in columns 11 and 12. The rate between any two specific points is a very complex function of the location of those points—see, for example, NordK71.

**Data Phone 50 Service (8802).** This experimental, very high-speed switched data service is currently (1976) available only in Chicago, Los Angeles, San Francisco, New York City, and Washington D.C., though users outside these areas can dial into the network via Series 5000 or 8000 private lines (see Table II.2.14.1). In practice, such private lines must be installed to connect a user's office with the switching terminal, even in cities in which the service is provided. In addition to the line costs shown in column 19, there are other costs similar to those applicable to private lines: a $275 per month charge per terminal for station terminals, plus a one time $125 installation charge; and another $150 per month plus $100 installation charge at each end of the line to terminate the Series 5000 or 8000 channel extensions.

**Speed.** This row in the table shows the nominal data transfer capacity for the various services.

**Cost.** The main body of the table shows the cost, in dollars, for the indicated mileage and for a length of time specified in the row "Line Costs Per:". For example, the first entries in columns 1 and 2 state that between 1970 and 1974 the first three minutes of a ten-mile DD call, in daytime hours, cost $.17 and each additional minute $.05. The corresponding first two entries in columns 15 and 16 show that it would cost from $500 to $650 per month for full-time WATS service covering a ten-mile radius—though the table also points out that $500 per month can buy WATS services over a radius of as much as 300 miles in some locations.

Columns 20 to 22 show the costs of transmitting data on Datran's network, to which a switch was added early in 1975. The cities served are those identified in the notes to columns 31 to 34 of Table II.2.14.1. Note there is a uniform cost per minute per mile, and in addition local and installation costs. There is no "Data Set" in the telephone-company meaning of that term, but there is an equivalent piece of equipment which must be installed.

### TABLE II.2.14.2 DATA TRANSMISSION FACILITIES II—DIALED LINES (1970?-1974) ●

| Column | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Service | | Direct Dial (DD) | | | | | | | |
| Speed | bps | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k |
| Time | | Days | | Evenings | | Nights | | Weekends | |
| Minimum Period | | 3 Minutes | | 3 Minutes | | 1 Minute | | 3 Minutes | |
| Line Costs Per: | | 3 Min. | Addl. Minute | 3 Min. | Addl. Minute | First Minute | Addl. Minute | 3 Min. | Addl. Minute |
| 10 Miles | $ | .17 | .05 | .13 | .04 | .10 | .03 | .10 | .03 |
| 16 Miles | $ | .23 | .07 | .17 | .05 | .10 | .04 | .14 | .04 |
| 22 Miles | $ | .30 | .08 | .24 | .05 | .10 | .05 | .20 | .05 |
| 30 Miles | $ | .35 | .10 | .28 | .08 | .10 | .05 | .20 | .05 |
| 40 Miles | $ | .40 | .12 | .32 | .09 | .12 | .07 | .26 | .07 |
| 50 Miles | $ | | | | | | | | |
| 55 Miles | $ | .45 | .13 | .36 | .10 | .14 | .08 | .30 | .08 |
| 70 Miles | $ | .50 | .15 | .40 | .10 | .15 | .09 | .33 | .09 |
| 85 Miles | $ | .55 | .16 | .40 | .10 | .15 | .10 | .35 | .10 |
| 100 Miles | $ | .60 | .17 | .40 | .10 | .15 | .10 | .35 | .10 |
| 124 Miles | $ | .65 | .18 | .45 | .14 | .15 | .10 | .35 | .10 |
| 150 Miles | $ | .70 | .20 | .50 | .15 | .20 | .13 | .46 | .13 |
| 196 Miles | $ | .75 | .21 | .55 | .15 | .20 | .14 | .48 | .14 |
| 244 Miles | $ | .80 | .22 | .55 | .15 | .20 | .14 | .48 | .14 |
| 300 Miles | $ | .85 | .25 | .55 | .15 | .20 | .15 | .50 | .15 |

TABLE II.2.14.2 DATA TRANSMISSION FACILITIES II—DIALED LINES (1970?-1974) (Continued) ●

| Column | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Service | | | | | Direct Dial (DD) | | | | |
| Speed | bps | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k |
| Time | | Days | | Evenings | | Nights | | Weekends | |
| Minimum Period | | 3 Minutes | | 3 Minutes | | 1 Minute | | 3 Minutes | |
| Line Costs Per: | | 3 Min. | Addl. Minute | 3 Min. | Addl. Minute | First Minute | Addl. Minute | 3 Min. | Addl. Minute |
| 354 Miles | $ | .90 | .25 | .55 | .15 | .20 | .15 | .50 | .15 |
| 430 Miles | $ | .95 | .25 | .60 | .20 | .20 | .15 | .50 | .15 |
| 500 Miles | $ | | | | | | | | |
| 600 Miles | $ | | | | | | | | |
| 675 Miles | $ | 1.00 | .30 | .60 | .20 | .20 | .15 | .50 | .15 |
| 750 Miles | $ | | | | | | | | |
| 925 Miles | $ | 1.05 | .35 | .65 | .20 | .20 | .15 | .50 | .15 |
| 1000 Miles | $ | | | | | | | | |
| 1200 Miles | | | | | | | | | |
| 1360 Miles | $ | 1.15 | .35 | .70 | .20 | .25 | .20 | .65 | .20 |
| 1500 Miles | $ | | | | | | | | |
| 1910 Miles | $ | 1.25 | .40 | .75 | .25 | .25 | .20 | .65 | .20 |
| 2000 Miles | $ | | | | | | | | |
| 2500 Miles | $ | | | | | | | | |
| 3000 Miles | $ | 1.35 | .45 | .85 | .25 | .35 | .20 | .70 | .20 |

TABLE II.2.14.2 DATA TRANSMISSION FACILITIES II—DIALED LINES (1975- ) ●

| Column | | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| Service | | | | Direct Dial (DD) | | | |
| Speed | bps | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k | 4.8k |
| Time | | Days | | Evenings | | Nights/Weekends | |
| Minimum Period | | 3 Minutes | | 3 Minutes | | 1 Minute | |
| Line Costs Per: | | 1 Min. | Addl. Minute | 1 Min. | Addl. Minute | First Minute | Addl. Minute |
| 10 Miles | $ | .16 | .06 | .10 | .04 | .06 | .02 |
| 16 Miles | $ | .21 | .09 | .14 | .06 | .08 | .04 |
| 22 Miles | $ | .25 | .11 | .16 | .07 | .10 | .04 |
| 30 Miles | $ | .29 | .14 | .19 | .09 | .12 | .06 |
| 40 Miles | $ | .33 | .18 | .21 | .12 | .13 | .07 |
| 50 Miles | $ | | | | | | |
| 55 Miles | $ | .37 | .22 | .24 | .14 | .15 | .09 |
| 70 Miles | $ | .39 | .24 | .25 | .16 | .16 | .10 |
| 85 Miles | $ | .40 | .25 | .26 | .16 | .16 | .10 |
| 100 Miles | $ | .41 | .26 | .27 | .17 | .16 | .10 |
| 124 Miles | $ | .42 | .27 | .27 | .18 | .17 | .11 |
| 150 Miles | $ | .43 | .28 | .28 | .18 | .17 | .11 |
| 196 Miles | $ | .44 | .29 | .29 | .19 | .18 | .12 |
| 244 Miles | $ | .45 | .30 | .29 | .20 | .18 | .12 |
| 300 Miles | $ | .46 | .31 | .30 | .20 | .18 | .12 |
| 354 Miles | $ | .47 | .32 | .31 | .21 | .19 | .13 |
| 430 Miles | $ | .48 | .33 | .31 | .21 | .19 | .13 |
| 500 Miles | $ | | | | | | |
| 600 Miles | $ | | | | | | |
| 675 Miles | $ | .49 | .34 | .32 | .22 | .20 | .14 |
| 750 Miles | $ | | | | | | |
| 925 Miles | $ | .50 | .35 | .33 | .23 | .20 | .14 |
| 1000 Miles | $ | | | | | | |
| 1200 Miles | | | | | | | |
| 1360 Miles | $ | .52 | .36 | .34 | .23 | .21 | .14 |
| 1500 Miles | $ | | | | | | |
| 1910 Miles | $ | .54 | .38 | .35 | .25 | .22 | .15 |
| 2000 Miles | $ | | | | | | |
| 2500 Miles | $ | | | | | | |
| 3000 Miles | $ | .56 | .40 | .36 | .26 | .22 | .16 |

### TABLE II.2.14.2 DATA TRANSMISSION FACILITIES II—DIALED LINES ●

| Column | | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|
| Service | | WATS(1964?-1975) | | WATS(1964?-1975) | | 8802 |
| Speed | bps | 4.8k | | 4.8k | | 50k |
| Time | | Full Time | | Measured Time | | Any |
| Minimum Period | | 1 Month | | 10 Hours | | 1 Minute |
| Line Costs Per: | | Month Minimum | Month Maximum | Hour | Addl.Hr. | Minute |
| 10 Miles | $ | 500 | 650 | 13 | 10 | .50 |
| 16 Miles | $ | 500 | 650 | 13 | 10 | .50 |
| 22 Miles | $ | 500 | 650 | 13 | 10 | .50 |
| 30 Miles | $ | 500 | 650 | 13 | 10 | .50 |
| 40 Miles | $ | 500 | 750 | 13 | 10 | .50 |
| 50 Miles | $ | 500 | 750 | 13 | 10 | .50 |
| 55 Miles | $ | 500 | 750 | 13 | 10 | .80 |
| 70 Miles | $ | 500 | 750 | 13 | 10 | .80 |
| 85 Miles | $ | 500 | 850 | 13 | 10 | .80 |
| 100 Miles | $ | 500 | 850 | 13 | 10 | .80 |
| 124 Miles | $ | 500 | 950 | 13 | 10 | .80 |
| 150 Miles | $ | 500 | 1050 | 17 | 12.8 | .80 |
| 196 Miles | $ | 500 | 1150 | 17 | 12.8 | 1.25 |
| 244 Miles | $ | 500 | 1250 | 18 | 13.5 | 1.25 |
| 300 Miles | $ | 500 | 1250 | 19 | 14.2 | 1.25 |
| 354 Miles | $ | 650 | 1250 | 20 | 15.0 | 1.75 |
| 430 Miles | $ | 650 | 1250 | 21 | 15.8 | 1.75 |
| 500 Miles | $ | 750 | 1350 | 22 | 16.5 | 1.75 |
| 600 Miles | $ | 850 | 1350 | 22 | 16.5 | 1.75 |
| 675 Miles | $ | 950 | 1450 | 23 | 17.3 | 2.25 |
| 750 Miles | $ | 1050 | 1550 | 23 | 17.3 | 2.25 |
| 925 Miles | $ | 1150 | 1650 | 23 | 17.3 | 2.25 |
| 1000 Miles | $ | 1250 | 1750 | 25 | 18.8 | 2.25 |
| 1200 Miles | $ | 1350 | 1750 | 27 | 20.2 | 2.25 |
| 1360 Miles | $ | 1450 | 1750 | 27 | 20.2 | 2.75 |
| 1500 Miles | $ | 1550 | 1850 | 29 | 21.6 | 2.75 |
| 1910 Miles | $ | 1750 | 1900 | 31 | 23.2 | 2.75 |
| 2000 Miles | $ | 1750 | 1900 | 31 | 23.2 | 2.75 |
| 2500 Miles | $ | 1850 | 1900 | 31 | 23.2 | 3.25 |
| 3000 Miles | $ | 1900 | 1900 | 31.5 | 23.6 | 3.25 |

### TABLE II.2.14.2 DATA TRANSMISSION FACILITIES II—DIALED LINES ●

| Column | | 20 | 21 | 22 |
|---|---|---|---|---|
| Service | | Datran's Datadial | | |
| Speed | bps | 2400 | 4800 | 9600 |
| Usage Cost* | $/Min./Mi. | .00015 | .0002 | .0003 |
| Local Costs | | | | |
| "Data Set" | $/Mo | 80 | 90 | 100 |
| Service Loop | | | | |
| 5 Miles | $/Mo. | 50 | 50 | 50 |
| Over 5 Miles | $/Mo. | 85 | 85 | 85 |
| Installation | $ | 150 | 200 | 200 |
| System Costs | | | | |
| Two Sets | $/Mo. | 160 | 180 | 200 |
| Two Loops | $/Mo. | 100 | 100 | 100 |
| Installa.(12 Mo.) | $/Mo. | 25 | 33.3 | 33.3 |
| Total | $/Mo. | 285 | 313.3 | 333.3 |

* Usage cost is subject to 1-cent minimum charge per call and minimum distance of 100 miles. Off-peak discount of 20% applies 7pm-8am daily and all day Saturday and Sunday.

## TABLE II.2.14.3 DIRECT DIAL AVERAGE COST PER MINUTE—NOTES

The entries in this table were computed directly from Table II.2.14.2. Note that the cost per minute of 30-, 300-, and 3000-mile calls is shown, and rates are given for calls of various duration placed during each of the four tariffed time periods—days, evenings, nights, and weekends. The 1972 cost for a one half minute, 30-mile, day call, for example, is computed by noting, from Table II.2.14.2, that a minimum charge for such a call would be $.35, and by dividing that charge by the one-half minute call duration. A three-minute call would also cost $.35, and its cost per minute would be $.35 divided by 3 or $.116. A ten-minute call would cost $.35 for the first three minutes, and $.10 per minute for the next seven, for a total of $1.05—and a net cost of $.105 per minute. As a given call gets very long, the effect of the extra charge during the first three minutes becomes negligible, and the cost per minute approaches $.10.

Other entries in the table were computed in a similar fashion.

### TABLE II.2.14.3 DIRECT DIAL AVERAGE COST PER MINUTE ●

| | 1970?-1974 Rates Distance (miles) | | | 1975- Rates Distance (miles) | | |
|---|---|---|---|---|---|---|
| | 30 | 300 | 3000 | 30 | 300 | 3000 |
| Days | | | | | | |
| One-Half Minute | $.70 | $1.70 | $2.70 | $.58 | $.92 | $1.12 |
| 1 Minute | .35 | .85 | 1.35 | .29 | .46 | .56 |
| 2 Minutes | .175 | .425 | .675 | .215 | .385 | .48 |
| 3 Minutes | .116 | .283 | .45 | .19 | .36 | .453 |
| 5 Minutes | .11 | .27 | .45 | .17 | .34 | .432 |
| 10 Minutes | .105 | .26 | .45 | .155 | .325 | .416 |
| Long Call | .10 | .25 | .45 | .14 | .31 | .40 |
| Evenings | | | | | | |
| One-Half Minute | .56 | 1.10 | 1.70 | .38 | .60 | .72 |
| 1 Minute | .28 | .55 | .85 | .19 | .30 | .36 |
| 2 Minutes | .14 | .275 | .425 | .14 | .25 | .31 |
| 3 Minutes | .09 | .183 | .283 | .123 | .233 | .293 |
| 5 Minutes | .088 | .17 | .27 | .11 | .22 | .28 |
| 10 Minutes | .084 | .16 | .26 | .109 | .21 | .27 |
| Long Call | .08 | .15 | .25 | .09 | .20 | .26 |
| Nights | | | | | | |
| One-Half Minute | .20 | .40 | .70 | .24 | .36 | .44 |
| 1 Minute | .10 | .20 | .35 | .12 | .18 | .22 |
| 2 Minutes | .075 | .175 | .275 | .09 | .15 | .19 |
| 3 Minutes | .067 | .167 | .25 | .08 | .14 | .18 |
| 5 Minutes | .06 | .16 | .23 | .072 | .132 | .172 |
| 10 Minutes | .055 | .155 | .215 | .066 | .126 | .166 |
| Long Call | .05 | .15 | .20 | .06 | .12 | .16 |
| Weekends | | | | | | |
| One-Half Minute | .40 | 1.00 | 1.40 | Same | Same | Same |
| 1 Minute | .20 | .50 | .70 | as | as | as |
| 2 Minutes | .10 | .25 | .35 | Nights | Nights | Nights |
| 3 Minutes | .067 | .167 | .233 | | | |
| 5 Minutes | .06 | .16 | .22 | | | |
| 10 Minutes | .055 | .155 | .21 | | | |
| Long Call | .05 | .15 | .20 | | | |

## TABLE II.2.14.4 DATA SET PRICES—NOTES

The sources for data provided by this table are the same as those described in connection with Table II.2.14.1. Each column contains prices on data sets (or Modems) designed to transmit and receive data at some specified rate. Columns 1 through 17 present information on early data sets, and columns 18 through 29 provide more recent figures. Within each set of columns, the data sets are listed in order of increasing speed.

**Supplier.** For most entries, the supplier is the Long Lines Department of American Telephone and Telegraph (AT&T), and the rates are thus applicable to interstate transmissions of data. To illustrate the differences which exist between interstate and intrastate rates, I show figures for General Telephone and Electronics (GT&E) and Pacific Telephone (PT&T), both operating in California. I also show figures on one of the specialized common carriers—Datran.

**Effective Date.** For each data set model number, the first date shown is the date the service was first available, and the last date shown is the starting date of the rate currently effective. For some data sets, there has been no change in rate and there is therefore only one entry. (For some rates, I was unable to determine when a new tariff went into effect, and consequently I have identified those dates with a question mark.)

**Speed.** The data transmission rate is shown in bits per second. The letter k means thousands.

**PL/DD.** The lower-speed data sets are generally useable either on private lines or on the direct dial network, and often different rates are applicable for the two types of service. For the higher-speed services, the telephone companies require that special circuits be installed on private lines to assure accurate data transmission. Where such facilities are required, they are identified in the row labelled "Conditioning". A dash on this row means that no conditioning is required; "NA" indicates that conditioning is not applicable on direct dialed lines; and other entries refer to designations of the various conditioning facilities, whose prices are given in Table II.2.14.5.

**Prices.** Most applications of data transmission require that data be both transmitted and received at a given location, and the monthly cost of a single data set in that service is shown on the "send-receive" line of the table. In some applications, a user may want a system in which he transmits or receives only at a given location; and I have shown the corresponding rates for such service when I could determine what they were. In addition to the monthly service charge, there is normally a one-time installation price, and it also is shown in the table.

**System Prices.** For purposes of illustration, I assume that a simple "system" requires a data set, with appropriate conditioning, at each end of a line. The monthly charge for two data sets and for two conditioning facilities, where required, are shown in the table. They are followed by the installation costs for two data sets and two conditioning facilities, amortized over a 12-month period. And the last row on the table is the sum of the previous monthly prices, for service and amortized installation.

## TABLE II.2.14.5 LINE CONDITIONING PRICES—NOTES

This short table shows installation and monthly charges for line conditioning. The 4A, 4B, and 4C facilities were actually identical to the C1, C2, and C3 services which replaced them.

### TABLE II.2.14.4 DATA SET PRICES ●

| Column | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplier | | ATT | | ATT | | ATT | ATT | ATT | GTEL(Ca.) | ATT | ATT |
| Effective Date | mo/yr. | /62 | | /61 | | /61 | /67? | /62 | /67? | /62 | /69 |
| Model No. | | 103A | | 202C | | 202C | 202C | 201A | 201A | 201B | 203A |
| Speed | bps | 75-300 | | 1200 | | 1800 | 1800 | 2000 | 2000 | 2400 | 4800 |
| PL/DD | | PL | DD | PL | DD | PL | PL | PL,DD | PL | PL | PL |
| Conditioning | | - | NA | - | NA | 4B | C2 | - | - | C2 | C2 |
| Prices | | | | | | | | | | | |
| Send-Rec. | $/mo | 20 | 25 | 30 | 35 | 30 | 45 | 72 | 105 | 72 | 200 |
| Send Only | $/mo | | | | | | | | | | |
| Rec. Only | $/mo | | | | | | | | | | |
| Installation | $ | 25 | 25 | 50 | 50 | 50 | 75 | 100 | 120 | 100 | 200 |
| System Prices | | | | | | | | | | | |
| Two Sets | $/mo | 40 | 50 | 60 | 70 | 60 | 90 | 144 | 210 | 144 | 400 |
| Two Condit. | $/mo | 0 | - | 0 | - | 75 | 38 | 0 | 0 | 38 | 38 |
| Installn.(12 mo.) | | | | | | | | | | | |
| Data Sets | $/mo | 4.2 | 4.2 | 8.3 | 8.3 | 8.3 | 12.5 | 16.7 | 20 | 16.7 | 33.3 |
| Condit. | $/mo | 0 | - | 0 | - | 4.2 | 0 | 0 | 0 | 0 | 0 |
| Total Costs | $/mo | 44.2 | 54.2 | 68.3 | 78.3 | 147.5 | 140.5 | 160.7 | 230 | 198.7 | 471.3 |

### TABLE II.2.14.4 DATA SET PRICES ●

| Column | | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|
| Supplier | | PTT | ATT | ATT | ATT | ATT | ATT | ATT | ATT | PTT |
| Effective Date | mo/yr. | ? | /74 | /66 | /66 | /73? | /66 | /73? | /74? | /74? |
| Model No. | | 203A | 209A | 303B | 301B | 301B | 303D | 303D | 202T | 2025 |
| Speed | bps | 4800 | 9600 | 19.2k | 40.8k | 40.8k | 230.4k | 230.4k | 1200 | 1200 |
| PL/DD | | DD | PL | PL | PL | PL | PL | PL | PL | DD |
| Conditioning | | - | D1 | - | - | - | - | - | - | - |
| Prices | | | | | | | | | | |
| Send-Rec. | $/mo | 220 | 230 | 425 | 250 | 425 | 455 | 650 | 14 | 35 |
| Send Only | $/mo | 105 | | | | | | | | |
| Rec. Only | $/mo | 190 | | | | | | | | |
| Installation | $ | 460 | 200 | 200 | 200 | 200 | 300 | 200 | 25 | 50 |
| System Prices | | | | | | | | | | |
| Two Sets | $/mo | 440 | 460 | 850 | 500 | 850 | 910 | 1300 | 28 | 70 |
| Two Condit. | $/mo | - | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Installn.(12 mo.) | | | | | | | | | | |
| Data Sets | $/mo | 76.7 | 33.3 | 33.3 | 33.3 | 33.3 | 50 | 33.3 | 4.2 | 8.3 |
| Condit. | $/mo | - | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Costs | $/mo | 516.7 | 545.3 | 883.3 | 533.3 | 883.3 | 960 | 1333 | 32.2 | 78.3 |

### TABLE II.2.14.4 DATA SET PRICES ●

| Column | | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplier | | | Datran | | | ATT | PTT | ATT | PTT | ATT | ATT |
| Effective Date | mo/yr. | | 12/73 | | | /72? | /74? | /72? | /74? | 1/75 | 1/75 |
| Model No. | | | Datalink | | | 201C | 201C | 208A | 208B | DSU | DSU |
| Speed | bps | 2400 | 4800 | 9600 | 56k | 2400 | 2400 | 4800 | 4800 | 2.4-9.6k | 56k |
| PL/DD | | | Dataline I | | | PL | DD | PL | DD | (DDS) | (DDS) |
| Conditioning | | - | - | - | - | - | - | - | - | - | - |
| Prices | | | | | | | | | | | |
| Send-Rec. | $/mo | 20.3 | 20.3 | 20.3 | 25 | 55 | 65 | 125 | 115 | 15 | 20 |
| Send Only | $/mo | | | | | | | | | | |
| Rec. Only | $/mo | | | | | | | | | | |
| Installation | $ | 0 | 0 | 0 | 0 | 75 | 100 | 150 | 220 | 25 | 25 |
| System Prices | | | | | | | | | | | |
| Two Sets | $/mo | 40.6 | 40.6 | 40.6 | 50 | 110 | 130 | 250 | 230 | 30 | 40 |
| Two Condit. | $/mo | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Installn.(12 mo.) | | | | | | | | | | | |
| Data Sets | $/mo | | | | | 12.5 | 16.7 | 25 | 36.7 | 4.2 | 4.2 |
| Condit. | $/mo | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 |
| Total Costs | $/mo | 40.6 | 40.6 | 40.6 | 50 | 122.5 | 116.7 | 275 | 256.7 | 34.2 | 44.2 |

### TABLE II.2.14.5 LINE CONDITIONING PRICES ●

| Designation | | 4A | 4B | 4C | C1 | C2 | C3 | D1 |
|---|---|---|---|---|---|---|---|---|
| Tariff | | 237 | 237 | 237 | 260 | 260 | 260 | |
| Effective Date | | 2/62 | 2/62 | 3/64 | /67? | /67? | /67? | /74 |
| Installation | $ | 10 | 25.0 | 50 | 0 | 0 | 0 | 150 |
| Monthly Charge | $/mo. | 10 | 37.5 | 56 | 5 | 19 | 30 | 13.5 |
| For DD | $/mo. | | | | 10 | 28 | | |

## TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I—NOTES

This table combines data from all the previous tables in this section to show the prices of a variety of data transmission systems. Each system consists of a communication line (either private or dialed-up) and two data sets. Auxiliary charges for terminations are included, as are installation costs, which are amortized over 12 months. Each column describes a particular service, and the services are listed in two groups. The first set of columns shows prices current in about 1972 for a range of speeds from 55 to 3600 bps. The second set shows prices current in 1976 over the range 300 to 9600 bps. (Table II.2.14.7 is essentially a continuation of this table, and shows prices for data rates 9600 bits per second and higher.)

The prices given in this table are as of the date shown at the top of each column. That date is generally the *later* of the two dates, given in previous tables, for lines and data sets.

1-2. Line 1 identifies the data set required for the service, if one is necessary. Line 2 is the price of two data sets with necessary conditioning, and is copied directly from the last line in the appropriate column of Table II.2.14.4.

**30-Mile Service.** 3-4. The full monthly cost for private-line systems is shown on line 3. It is the sum of the cost of a 30-mile transmission line, from Table II.2.14.1, and the price of a pair of data sets, from line 2 above. Line 4 shows the total number of bits which could be transmitted in a month at the given data rate. One month is assumed to be one-twelfth of a 365-day year, and contains 2.628 million seconds.

5-14. Line 6 shows the time, in minutes, necessary to transmit one million bits at the specified line speed. Lines 8, 10, 12, and 14, representing the time necessary to transmit 4, 16, 64, and 256 million bits, are each four times greater than their predecessor. Line 5 shows, for direct dial transmission facilities, the cost of transmitting one million bits. It is found by multiplying the "long call" cost per minute for 30-mile lines from Table II.2.14.3 (taking into account whether the column refers to day calls or night calls) by the transmission time in line 6, and adding the resulting line costs to the data set price from line 2 above. The figures shown on line 7, 9, 11, and 13 are similarly computed, based on the transmission times given in lines 8, 10, 12, and 14. *Note: In using the "long call" rate from Table II.2.14.3, I am obviously assuming that each call made in the month over which the prescribed number of bits is transmitted is ten minutes long or longer. If transmissions are made via a series of very short calls, the costs will be much higher.*

**300-Mile Service.** 15. This line shows the full monthly cost of a private line system, and is found by adding the appropriate 300-mile private line rate to the data set price in line 2.

16-20. These monthly costs are computed from the transmit times of lines 6, 8, 10, 12, and 14 above in the same way as odd-numbered lines 5 through 13 were computed, except that the rates used were for 300- rather than 30-mile lines.

**3000-Mile Service.** 21. This system cost is computed from the monthly cost of a 3000-mile private line, plus data set prices from line 2.

22-26. These lines were computed as were lines 16 through 20, except the rates used were for 3000-mile lines.

**System Price Per Million Bits.** 27-31. These rates are computed by dividing lines 5, 7, 9, 11, and 13 by the number 1, 4, 16, 64, and 256, respectively.

32. This private line price is the ratio of line 3 to line 4.

33-37, 39-43. These numbers are computed from lines 16-20 and lines 22-26 in the same way that line 27 to 31 were computed.

38,44. Line 38 is the ratio of line 15 to line 4, and line 44 the ratio of line 21 to line 4.

### TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I ●

| | Date<br>Speed<br>DD/PL<br>Line | bps | /67?<br>55<br>DD<br>Days | /67?<br>55<br>DD<br>Nites | /67?<br>55<br>PL<br>1002 | /62<br>150<br>DD<br>Days | /62<br>150<br>DD<br>Nites | /65<br>150<br>PL<br>1006 | /62<br>300<br>DD<br>Days | /62<br>300<br>DD<br>Nites | /67?<br>300<br>PL<br>3002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Data Set | | - | - | - | 103 | 103 | 103 | 103 | 103 | 103 |
| 2. | Price | $/mo | 0 | 0 | 0 | 80 | 80 | 70 | 80 | 80 | 70 |
| | **System Prices** | | | | | | | | | | |
| | **30 Miles** | | | | | | | | | | |
| 3. | Full Month–Cost | $/mo | | | 93.7 | | | 186.8 | | | 182.2 |
| 4. | Bits Transmitted | Mb/mo | | | 144.5 | | | 394.2 | | | 788.4 |
| 5. | 1M Bits–Cost | $/mo | 30.3 | 15.2 | | 91.1 | 85.6 | | 85.6 | 82.8 | |
| 6. | Time To Transmit | min. | 303 | 303 | | 111.1 | 111.1 | | 55.6 | 55.6 | |
| 7. | 4M Bits–Cost | $/mo | 121.2 | 60.6 | | 124.4 | 102.2 | | 102.2 | 91.1 | |
| 8. | Time To Transmit | min. | 12121 | 212 | | 444.4 | 444.4 | | 222.4 | 222.4 | |
| 9. | 16M Bits–Cost | $/mo | 484.8 | 242.4 | | 257.8 | 168.9 | | 168.9 | 124.5 | |
| 10. | Time To Transmit | min. | 4848 | 4848 | | 1778 | 1778 | | 889.6 | 889.6 | |
| 11. | 64M Bits–Cost | $/mo | 1939 | 969.7 | | 791.1 | 435.6 | | 435.6 | 257.9 | |
| 12. | Time To Transmit | min. | 19394 | 19394 | | 7111 | 7111 | | 3558.4 | 3558.4 | |
| 13. | 256M Bits–Cost | $/mo | | 3879 | | 2924 | 1502.2 | | 1502.2 | 791.7 | |
| 14. | Time To Transmit | min. | 77576 | 77576 | | 28444 | 28444 | | 14233.6 | 14233.6 | |

**TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I (continued) ●**

| | Date<br>Speed<br>DD/PL<br>Line | bps | /67?<br>55<br>DD<br>Days | /67?<br>55<br>DD<br>Nites | /67?<br>55<br>PL<br>1002 | /62<br>150<br>DD<br>Days | /62<br>150<br>DD<br>Nites | /65<br>150<br>PL<br>1006 | /62<br>300<br>DD<br>Days | /62<br>300<br>DD<br>Nites | /67?<br>300<br>PL<br>3002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **300 Miles** | | | | | | | | | | |
| 15. | Cost–Full Month | $/mo | | | 366.7 | | | 528.1 | | | 606.7 |
| 16. | 1M Bits | $/mo | 75.8 | 45.5 | | 107.8 | 96.7 | | 93.9 | 88.3 | |
| 17. | 4M Bits | $/mo | 303.0 | 181.8 | | 191.1 | 146.7 | | 130.6 | 113.4 | |
| 18. | 16M Bits | $/mo | 1212 | 727.3 | | 524.4 | 346.6 | | 302.4 | 213.4 | |
| 19. | 64M Bits | $/mo | 4848 | 2909 | | 1858 | 1146.6 | | 969.6 | 613.8 | |
| 20. | 256M Bits | $/mo | 19394 | 11636 | | 7191 | 4346.2 | | 3638.4 | 2215.0 | |
| | **3000 Miles** | | | | | | | | | | |
| 21. | Cost–Full Month | $/mo | | | 1248.7 | | | 1630.3 | | | 2691.7 |
| 22. | 1M Bits | $/mo | 136.4 | 60.6 | | 130.0 | 102.2 | | 105 | 91.1 | |
| 23. | 4M Bits | $/mo | 545.5 | 242.4 | | 280.0 | 168.9 | | 180 | 124.5 | |
| 24. | 16M Bits | $/mo | 2182 | 969.7 | | 880.0 | 435.5 | | 480 | 257.9 | |
| 25. | 64M Bits | $/mo | 8727 | 3879 | | 3280.0 | 1502.1 | | 1680 | 791.1 | |
| 26. | 256M Bits | $/mo | 34906 | 15515 | | 12878.7 | 5768.3 | | 6480 | 2924.4 | |
| | **Price Per MBits** | | | | | | | | | | |
| 27. | **30 Miles**–1M Bits | $ | 30.3 | 15.2 | | 91.1 | 85.6 | | 85.6 | 82.8 | |
| 28. | 4M Bits | $ | 30.3 | 15.2 | | 31.1 | 25.6 | | 25.6 | 22.8 | |
| 29. | 16M Bits | $ | 30.3 | 15.2 | | 16.1 | 10.6 | | 10.6 | 7.8 | |
| 30. | 64M Bits | $ | 30.3 | 15.2 | | 12.4 | 6.8 | | 6.8 | 4.0 | |
| 31. | 256M Bits | $ | 30.3 | 15.2 | | 11.4 | 5.9 | | 5.9 | 3.1 | |
| 32. | Full Month | $ | - | - | .648 | | | .474 | | | .231 |
| 33. | **300 Mi.**–1M Bits | $ | 75.8 | 45.5 | | 107.8 | 96.7 | | 93.9 | 88.3 | |
| 34. | 4M Bits | $ | 75.8 | 45.5 | | 47.8 | 36.7 | | 32.7 | 28.4 | |
| 35. | 16M Bits | $ | 75.8 | 45.5 | | 32.8 | 21.7 | | 18.9 | 13.3 | |
| 36. | 64M Bits | $ | 75.8 | 45.5 | | 29.0 | 17.9 | | 15.2 | 9.6 | |
| 37. | 256M Bits | $ | 75.8 | 45.5 | | 28.1 | 17.0 | | 14.2 | 8.7 | |
| 38. | Full Month | $ | | | 2.54 | | | 1.34 | | | .770 |
| 39. | **3000 Mi.**–1M Bits | $ | 136.4 | 60.6 | | 130.0 | 102.2 | | 105.0 | 91.1 | |
| 40. | 4M Bits | $ | 136.4 | 60.6 | | 70.0 | 42.2 | | 45.0 | 31.1 | |
| 41. | 16M Bits | $ | 136.4 | 60.6 | | 55.0 | 27.2 | | 30.0 | 16.1 | |
| 42. | 64M Bits | $ | 136.4 | 60.6 | | 51.3 | 23.5 | | 26.3 | 12.4 | |
| 43. | 256M Bits | $ | 136.4 | 60.6 | | 50.3 | 22.5 | | 25.3 | 11.4 | |
| 44. | Full Month | $ | | | 8.64 | | | 4.14 | | | 3.41 |

**TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I ●**

| | Date<br>Speed<br>DD/PL<br>Line | bps | /61<br>1200<br>DD<br>Days | /61<br>1200<br>DD<br>Nites | /67?<br>1800<br>PL<br>3002 | /62<br>2000<br>DD<br>Days | /62<br>2000<br>DD<br>Nites | /67?<br>2000<br>PL<br>3002 | /69<br>3600<br>DD<br>Days | /69<br>3600<br>DD<br>Nites | /69<br>3600<br>PL<br>3002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Data Set | | 202C | 202C | 202C | 201A | 201A | 201A | 203 | 203 | 203 |
| 2. | Price | $/mo | 78.3 | 78.3 | 140.5 | 160.7 | 160.7 | 160.7 | 516.7 | 516.7 | 471.3 |
| | **System Prices** | | | | | | | | | | |
| | **30 Miles** | | | | | | | | | | |
| 3. | Full Month–Cost | $/mo | - | - | 252.7 | - | - | 272.9 | | | 583.5 |
| 4. | Bits Transmitted | Mb/mo | - | - | 4730 | - | - | 5256 | | | 9461 |
| 5. | 1M Bits–Cost | $/mo | 79.7 | 79.0 | | 161.5 | 161.1 | | 517.2 | 516.9 | |
| 6. | Time To Transmit | min. | 13.89 | 13.89 | | 8.33 | 8.33 | | 4.63 | 4.63 | |
| 7. | 4M Bits–Cost | $/mo | 83.8 | 81.0 | | 164.0 | 162.4 | | 518.6 | 517.6 | |
| 8. | Time To Transmit | min. | 55.6 | 55.6 | | 33.3 | 33.3 | | 18.5 | 18.5 | |
| 9. | 16M Bits–Cost | $/mo | 100.5 | 89.4 | | 179.0 | 167.4 | | 524.1 | 520.4 | |
| 10. | Time To Transmit | min. | 222.2 | 222.2 | | 133.3 | 133.3 | | 74.1 | 74.1 | |
| 11. | 64M Bits–Cost | $/mo | 167.2 | 122.7 | | 214.0 | 187.4 | | 546.3 | 531.5 | |
| 12. | Time To Transmit | min. | 888.9 | 888.9 | | 533.3 | 533.3 | | 296.3 | 296.3 | |
| 13. | 256M Bits–Cost | $/mo | 433.9 | 256.1 | | 374.0 | 267.3 | | 635.2 | 576.0 | |
| 14. | Time To Transmit | min. | 3556 | 3556 | | 2133.3 | 2133.3 | | 1185.2 | 1185.2 | |

## TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I (Continued) ●

| | Date<br>Speed<br>DD/PL<br>Line | bps | /61<br>1200<br>DD<br>Days | /61<br>1200<br>DD<br>Nites | /67?<br>1800<br>PL<br>3002 | /62<br>2000<br>DD<br>Days | /62<br>2000<br>DD<br>Nites | /67?<br>2000<br>PL<br>3002 | /69<br>3600<br>DD<br>Days | /69<br>3600<br>DD<br>Nites | /69<br>3600<br>PL<br>3002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **300 Miles** | | | | | | | | | | |
| 15. | Cost—Full Month | $/mo | | | 677.2 | | | 697.4 | | | 1008.0 |
| 16. | 1M Bits | $/mo | 81.7 | 80.4 | | 162.8 | 161.9 | | 517.9 | 517.4 | |
| 17. | 4M Bits | $/mo | 92.2 | 86.6 | | 169.0 | 165.7 | | 521.3 | 519.5 | |
| 18. | 16M Bits | $/mo | 133.8 | 111.6 | | 194.0 | 180.7 | | 535.2 | 527.8 | |
| 19. | 64M Bits | $/mo | 300.5 | 211.6 | | 294.0 | 240.7 | | 590.8 | 561.1 | |
| 20. | 256M Bits | $/mo | 967.2 | 611.7 | | 694.0 | 480.7 | | 813.0 | 694.5 | |
| | **3000 Miles** | $/mo | | | | | | | | | |
| 21. | Cost—Full Month | $/mo | | | 2762.2 | | | 2782.4 | | | 3093.0 |
| 22. | 1M Bits | $/mo | 84.6 | 81.0 | | 164.4 | 162.4 | | 518.8 | 517.6 | |
| 23. | 4M Bits | $/mo | 103.3 | 89.4 | | 175.7 | 167.4 | | 525.0 | 520.4 | |
| 24. | 16M Bits | $/mo | 178.3 | 122.7 | | 220.7 | 187.4 | | 550.0 | 531.5 | |
| 25. | 64M Bits | $/mo | 478.3 | 256.1 | | 400.7 | 267.3 | | 650.0 | 576.0 | |
| 26. | 256M Bits | $/mo | 1678 | 789.5 | | 1120.7 | 587.2 | | 1050.0 | 753.8 | |
| | **Price Per MBits** | | | | | | | | | | |
| 27. | **30 Miles**—1M Bits | $ | 79.7 | 79.0 | | 161.5 | 161.1 | | 517.2 | 516.9 | |
| 28. | 4M Bits | $ | 21.0 | 20.3 | | 41.0 | 40.6 | | 129.7 | 129.4 | |
| 29. | 16M Bits | $ | 6.3 | 5.6 | | 10.9 | 10.5 | | 32.8 | 32.5 | |
| 30. | 64M Bits | $ | 2.6 | 1.9 | | 3.3 | 2.9 | | 8.5 | 8.3 | |
| 31. | 265M Bits | $ | 1.7 | 1.0 | | 1.5 | 1.0 | | 2.5 | 2.3 | |
| 32. | Full Month | $ | | | .053 | | | .052 | | | .062 |
| 33. | **300 Mi.**—1M Bits | $ | 81.7 | 80.4 | | 162.8 | 161.9 | | 517.9 | 517.4 | |
| 34. | 4M Bits | $ | 23.1 | 21.7 | | 42.3 | 41.4 | | 130.3 | 129.9 | |
| 35. | 16M Bits | $ | 8.4 | 7.0 | | 12.1 | 11.3 | | 33.5 | 33.0 | |
| 36. | 64M Bits | $ | 4.7 | 3.3 | | 4.6 | 3.8 | | 9.2 | 8.8 | |
| 37. | 256M Bits | $ | 3.8 | 2.4 | | 2.7 | 1.9 | | 3.2 | 2.7 | |
| 38. | Full Month | $ | | | .143 | | | .133 | | | .107 |
| 39. | **3000 Mi.**—1M Bits | $ | 84.6 | 81.0 | | 164.4 | 162.4 | | 518.8 | 517.6 | |
| 40. | 4M Bits | $ | 25.8 | 22.4 | | 43.9 | 41.9 | | 131.3 | 130.1 | |
| 41. | 16M Bits | $ | 11.1 | 7.7 | | 13.8 | 11.7 | | 34.4 | 33.2 | |
| 42. | 64M Bits | $ | 7.5 | 4.0 | | 6.3 | 4.2 | | 10.2 | 9.0 | |
| 43. | 256M Bits | $ | 6.6 | 3.1 | | 4.4 | 2.3 | | 4.1 | 2.9 | |
| 44. | Full Month | $ | | | .584 | | | .529 | | | .327 |

## TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I ●

| | Date<br>Speed<br>DD/PL<br>Line | bps | /75<br>300<br>DD<br>Days | /74<br>300<br>PL<br>Hi | /75?<br>1200<br>DD<br>Days | /74<br>1200<br>PL<br>Hi | /75<br>2400<br>Ddial<br>Days | /73<br>2400<br>Dline<br>I | /75<br>2400<br>DD<br>Days | /74<br>2400<br>PL<br>Hi | /75<br>2400<br>DDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Data Set | | 103A | 103A | 202S | 202T | | Dlink | 201C | 201C | DSU |
| 2. | Price | $/mo | 54.2 | 44.2 | 78.3 | 32.2 | 285 | 40.6 | 116.7 | 122.5 | 34.2 |
| | **System Prices** | | | | | | | | | | |
| | 30 Miles | | | | | | N/A | | | | |
| 3. | Full Month—Cost | $/mo | | 198.0 | | 186.0 | | 197.8 | | 276.3 | 218.9 |
| 4. | Bits Transmitted | Mb/mo | | 788.4 | | 3153.8 | | 6307 | | 6307 | 6307 |
| 5. | 1M Bits—Cost | $/mo | 62.0 | | 80.2 | | | | 117.7 | | |
| 6. | Time To Transmit | min. | 55.55 | | 13.89 | | 6.94 | | 6.94 | | |
| 7. | 4M Bits—Cost | $/mo | 85.3 | | 86.1 | | | | 120.6 | | |
| 8. | Time To Transmit | min. | 222.2 | | 55.55 | | 27.78 | | 27.78 | | |
| 9. | 16M Bits—Cost | $/mo | 178.6 | | 109.4 | | | | 132.3 | | |
| 10. | Time o Transmit | min. | 888.9 | | 222.2 | | 111.1 | | 111.1 | | |
| 11. | 64M Bits—Cost | $/mo | 552.0 | | 202.7 | | | | 178.9 | | |
| 12. | Time To Transmit | min. | 3555. | 6 | 888.9 | | 444.4 | | 444.4 | | |
| 13. | 256M Bits—Cost | $/mo | 2045. | 3 | 576.1 | | | | 365.6 | | |
| 14. | Time To Transmit | min. | 14222 | | 3555.6 | | 1777.7 | | 1777.7 | | |
| | **300 Miles** | | | | | | | | | | |
| 15. | Cost—Full Month | $/mo | | 427.5 | | 415.5 | | 295.3 | | 505.8 | 380.9 |
| 16. | 1M Bits | $/mo | 71.4 | | 82.6 | | 285.3 | | 118.8 | | |

### TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I (Continued) ●

| | Date<br>Speed<br>DD/PL<br>Line | bps | /75<br>300<br>DD<br>Days | /74<br>300<br>PL<br>Hi | /75?<br>1200<br>DD<br>Days | /74<br>1200<br>PL<br>Hi | /75<br>2400<br>Ddial<br>Days | /73<br>2400<br>Dline<br>I | /75<br>2400<br>DD<br>Days | /74<br>2400<br>PL<br>Hi | /75<br>2400<br>DDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17. | 4M Bits | $/mo | 123.1 | | 95.5 | | 286.2 | | 125.3 | | |
| 18. | 16M Bits | $/mo | 329.8 | | 147.2 | | 290.0 | | 151.1 | | |
| 19. | 64M Bits | $/mo | 1156. | 4 | 353.9 | | 305.0 | | 254.5 | | |
| 20. | 256M Bits | $/mo | 4463. | 1 | 1180.5 | | 365.0 | | 667.8 | | |
| | **3000 Miles** | | | | | | | | | | |
| 21. | Cost—Full Month | $/mo | | 2722. | 5 | 2710.5 | | 1267 | | 2800.8 | 2000.9 |
| 22. | 1M Bits | $/mo | 76.4 | | 83.9 | | 288.1 | | 119.5 | | |
| 23. | 4M Bits | $/mo | 143.1 | | 100.5 | | 297.5 | | 127.8 | | |
| 24. | 16M Bits | $/mo | 409.8 | | 167.2 | | 335.0 | | 161.1 | | |
| 25. | 64M Bits | $/mo | 1476. | 4 | 433.9 | | 485.0 | | 294.5 | | |
| 26. | 256M Bits | $/mo | 5743. | 1 | 1500.5 | | 1085.0 | | 827.8 | | |
| | **Price Per MBits** | | | | | | | | | | |
| 27. | **30 Miles**—1M Bits | $ | 62.0 | | 80.2 | | - | | 117.7 | | |
| 28. | 4M Bits | $ | 21.3 | | 21.5 | | - | | 30.2 | | |
| 29. | 16M Bits | $ | 11.2 | | 6.84 | | - | | 8.27 | | |
| 30. | 64M Bits | $ | 8.63 | | 3.17 | | - | | 2.80 | | |
| 31. | 265M Bits | $ | 7.99 | | 2.25 | | - | | 1.43 | | |
| 32. | Full Month | $ | | .251 | | .059 | | .031 | | .044 | .035 |
| 33. | **300 Mi.**—1M Bits | $ | 71.4 | | 82.6 | | 285.3 | | 118.8 | | |
| 34. | 4M Bits | $ | 30.8 | | 23.9 | | 71.6 | | 31.3 | | |
| 35. | 16M Bits | $ | 20.6 | | 9.20 | | 18.1 | | 9.44 | | |
| 36. | 64M Bits | $ | 18.1 | | 5.53 | | 4.77 | | 3.98 | | |
| 37. | 256M Bits | $ | 17.4 | | 4.61 | | 1.43 | | 2.61 | | |
| 38. | Full Month | $ | | .542 | | .132 | | .047 | | .080 | .060 |
| 39. | **3000 Mi.**—1M Bits | $ | 76.4 | | 83.9 | | 288.1 | | 119.5 | | |
| 40. | 4M Bits | $ | 35.8 | | 25.1 | | 74.4 | | 32.0 | | |
| 41. | 16M Bits | $ | 25.6 | | 10.5 | | 20.9 | | 10.1 | | |
| 42. | 64M Bits | $ | 23.1 | | 6.78 | | 7.58 | | 4.60 | | |
| 43. | 256M Bits | $ | 22.4 | | 5.86 | | 4.24 | | 3.23 | | |
| 44. | Full Month | $ | | 3.45 | | .859 | | .201 | | .444 | .317 |

### TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I ●

| | Date<br>Speed<br>DD/PL<br>Line | bps | /75<br>4800<br>Ddial<br>Days | /73<br>4800<br>Dline<br>I | /75<br>4800<br>DD<br>Days | /74<br>4800<br>PL<br>Hi | /75<br>4800<br>DDS | /75<br>9600<br>Ddial<br>Days | /73<br>9600<br>Dline<br>I | /74<br>9600<br>PL<br>Hi | /75<br>9600<br>DDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Data Set | | | Dlink | 208B | 208A | D50 | | Dlink | 209A | D50 |
| 2. | Price | $/mo | 313.3 | 40.6 | 256.7 | 275 | 34.2 | 333.3 | 40.6 | 545.3 | 34.2 |
| | **System Prices** | | | | | | | | | | |
| | **30 Miles** | | N/A | | | | | N/A | | | |
| 3. | Full Month—Cost | $/mo | | 265.5 | | 428.8 | 287.9 | | 336.6 | 699.1 | 369.9 |
| 4. | Bits Transmitted | Mb/mo | | 12615 | | 12615 | 12615 | | 25230 | 25230 | 25230 |
| 5. | 1M Bits—Cost | $/mo | | | 257.2 | | | | | | |
| 6. | Time To Transmit | min. | 3.47 | | 3.47 | | | 1.74 | | | |
| 7. | 4M Bits—Cost | $/mo | | | 258.6 | | | | | | |
| 8. | Time To Transmit | min. | 13.89 | | 13.89 | | | 6.94 | | | |
| 9. | 16M Bits—Cost | $/mo | | | 264.5 | | | | | | |
| 10. | Time o Transmit | min. | 55.55 | | 55.55 | | | 27.78 | | | |
| 11. | 64M Bits—Cost | $/mo | | | 287.8 | | | | | | |
| 12. | Time To Transmit | min | 222.2 | | 222.2 | | | 111.1 | | | |
| 13. | 256M Bits—Cost | $/mo | | | 381.1 | | | | | | |
| 14. | Time To Transmit | min | 888.9 | | 888.9 | | | 444.4 | | | |
| | **300 Miles** | | | | | | | | | | |
| 15. | Cost—Full Month | $/mo | | 411.3 | | 658.3 | 530.9 | | 555.3 | 928.6 | 720.9 |
| 16. | 1M Bits | $/mo | 313.5 | | 257.8 | | | 333.5 | | | |
| 17. | 4M Bits | $/mo | 314.1 | | 261.0 | | | 333.9 | | | |
| 18. | 16M Bits | $/mo | 316.6 | | 273.9 | | | 335.8 | | | |
| 19. | 64M Bits | $/mo | 326.6 | | 325.6 | | | 343.3 | | | |
| 20. | 256M Bits | $/mo | 366.6 | | 532.3 | | | 373.3 | | | |
| | **3000 Miles** | $/mo | | | | | | | | | |
| 21. | Cost—Full Month | $/mo | | 1869. | 3 | 2953.3 | 2960.9 | | 2742.3 | 3223.6 | 4230.9 |
| 22. | 1M Bits | $/mo | 315.4 | | 258.1 | | | 334.9 | | | |

**TABLE II.2.14.6 SYSTEM PRICES FOR DATA TRANSMISSION I (Continued) ●**

| | Date<br>Speed<br>DD/PL<br>Line | bps | /75<br>4800<br>Ddial<br>Days | /73<br>4800<br>Dline<br>I | /75<br>4800<br>DD<br>Days | /74<br>4800<br>PL<br>Hi | /75<br>4800<br>DDS | /75<br>9600<br>Ddial<br>Days | /73<br>9600<br>Dline<br>I | /74<br>9600<br>PL<br>Hi | /75<br>9600<br>DDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 23. | 4M Bits | $/mo | 321.6 | | 262.2 | | | 339.5 | | | |
| 24. | 16M Bits | $/mo | 346.6 | | 278.9 | | | 358.3 | | | |
| 25. | 64M Bits | $/mo | 446.6 | | 345.6 | | | 433.3 | | | |
| 26. | 256M Bits | $/mo | 846.6 | | 612.3 | | | 733.3 | | | |
| | **Price Per MBits** | | | | | | | | | | |
| 27. | **30 Miles**—1M Bits | $ | - | | 257.2 | | | - | | | |
| 28. | 4M Bits | $ | - | | 64.7 | | | - | | | |
| 29. | 16M Bits | $ | - | | 16.5 | | | - | | | |
| 30. | 64M Bits | $ | - | | 4.50 | | | - | | | |
| 31. | 265M Bits | $ | - | | 1.49 | | | - | | | |
| 32. | Full Month | $ | | .021 | | .034 | .023 | | .013 | .028 | .015 |
| 33. | **300 Mi.**—1M Bits | $ | 313.5 | | 257.8 | | | 333.5 | | | |
| 34. | 4M Bits | $ | 78.5 | | 65.2 | | | 83.5 | | | |
| 35. | 16M Bits | $ | 19.8 | | 17.1 | | | 21.0 | | | |
| 36. | 64M Bits | $ | 5.10 | | 5.09 | | | 5.36 | | | |
| 37. | 256M Bits | $ | 1.43 | | 2.08 | | | 1.46 | | | |
| 38. | Full Month | $ | | .033 | | .052 | .042 | | .022 | .037 | .029 |
| 39. | **3000 Mi.**—1M Bits | $ | 315.4 | | 258.1 | | | 334.9 | | | |
| 40. | 4M Bits | $ | 80.4 | | 65.6 | | | 84.9 | | | |
| 41. | 16M Bits | $ | 21.7 | | 17.4 | | | 22.4 | | | |
| 42. | 64M Bits | $ | 6.98 | | 5.40 | | | 6.77 | | | |
| 43. | 256M Bits | $ | 3.31 | | 2.39 | | | 2.86 | | | |
| 44. | Full Month | $ | | .148 | | .234 | .235 | | .109 | .128 | .168 |

## TABLE II.2.14.7 SYSTEM PRICES FOR DATA TRANSMISSION II—NOTES

This table provides the same kind of data regarding high-speed lines that the previous table provides on low-speed lines.

1-2. The model number of the required data set is shown on line 1, and its system price, from Table II.2.14.4, is shown on line 2.

3. The number of bits transmitted per month is found by multiplying line speed in bits per second (from the top of the table) by 2.628 million, the number of seconds in a month.

4, 6, 8. System prices are found by adding the data set price of line 2 to the appropriate line price from Table II.2.14.1.

5, 7, 9. The price per million bits is found by dividing system prices per month from lines 4, 6, and 8 by the bits transmitted per month in line 3.

**TABLE II.2.14.7 SYSTEM PRICES FOR DATA TRANSMISSION II**

| | Date<br>Speed<br>Duplex<br>Line | | /74<br>9600<br>Half<br>3002 | /66<br>19200<br>Full<br>8000 | /73?<br>40800<br>Full<br>8000 | /75<br>56000<br>Full<br>DDS | /73<br>56000<br>Full<br>D'lineI | /73?<br>230400<br>Full<br>5700 |
|---|---|---|---|---|---|---|---|---|
| 1. | Data Set | | 209 | 303B | 301B | DSU | D'link | 303D |
| 2. | Price | $/mo | 545.3 | 883.3 | 883.3 | 44.2 | 50 | 1333 |
| 3. | Bits Transmitted | Mb/mo | 25229 | 50458 | 107222 | 147169 | 147169 | 605491 |
| | **30 Miles** | | | | | | | |
| 4. | System Price | $/mo | 657.5 | 1333 | 1333 | 774.2 | 661.3 | 2250 |
| 5. | Price Per MBits | $ | .0261 | .0264 | .0124 | .0053 | .0045 | .00372 |
| | **300 Miles** | | | | | | | |
| 6. | System Price | $/mo | 1082 | 5158 | 5158 | 2394 | 1633 | 10350 |
| 7. | Price Per MBits | $ | .0429 | .102 | .0481 | .016 | .0011 | .0171 |
| | **3000 Miles** | | | | | | | |
| 8. | System Price | $/mo | 3167 | 26008 | 26008 | 18594 | 11353 | 91333 |
| 9. | Price Per MBits | $ | .126 | .515 | .243 | .126 | .077 | .151 |

## TABLE II.2.14.8 POSTAL DATA COMMUNICATIONS COSTS—NOTES

First-Class letter postage is from an article in *U.S. News and World Report* ("Postal Hike—And More Subsidy, Too." Sept. 22, 1975, p. 38). Magnetic tape average capacity is from Table II.1.22.1, line 34.

Cost per million bytes is based on the postage rates above and the following estimates of mailing weight (including package) and capacity: magnetic tape, 36 ounces for a 2400-foot reel, and the average capacity from the previous line; continuous forms, 43 11-inch by 14-inch pages weighing ten ounces and containing 60 lines per page and 132 bytes per line; continuous forms photocopied to both sides of 8 1/2-inch by 11-inch pages, 43 pages weighing four ounces; punch cards, eight eighty-byte cards (pre-1968) or sixteen 96-byte cards per ounce; microfiche, ten fiche each containing 0.468 million bytes (Table II.3.22.1) in a two-ounce package.

## TABLE II.2.15.1 THE USE OF PROGRAMMING AIDS I—NOTES

The data in this table comes from three sources. The 1964 data is from an article by Harder (HardE68), and is there presented in a table with no further information as to the source. "Primary language" and "principal compiler" are not defined. Furthermore, Harder's comments are not consistent with the entries in the table: regarding the second column, he says, "A survey of some 200 U.S. installations showed FORTRAN some eight to one ahead as the principal compiler, and ALGOL prominent." The surveys were described as having been taken in 1964, though the article was published in 1968.

The data in the 1968 column comes from a survey reported in the June 19, 1968 issue of *Computerworld.* That periodical sent a survey to 150 IBM 360/50 installations, asking, "Could you estimate the percentage breakdown of programming language used in terms of machine time?" The article tabulated the replies in three columns. The first showed that 54% of the users regarded a language as "strongly dominant", meaning that more than 70% of the computer time involved used that language. COBOL was named by 32% of the installations, emulation by 16%, FORTRAN by 5% and PL-I by 1%. Another 34% of the installations said that a language was "dominant": 18% named COBOL, 9% emulation, 3% FORTRAN, and 4% PL-I. Finally, 25% of the installations stated they used a second language more than 30% of the time. Eleven per cent named COBOL, 7% emulation, 4% FORTRAN, and 3% PL-I. I computed the figures shown in Table II.2.15.1 by assuming the "strongly dominant" languages were used an average of 80% of the time, the "dominant" languages 60% of the time, and the "second" languages 40% of the time. For example, the figure of 41% of machine time devoted to COBOL was computed by saying that, of 100 installations, 32 use COBOL 80% of the time, 18 use COBOL 60% of the time, and 11 use COBOL 40% of the time. I multiplied each percentage by the number of installations involved, and added the resulting products to get 41%.

*Computerworld's* inclusion of emulation as a "language" is of course not proper. Presumably the 360/50's are running second-generation programs written in the Autocoder language.

The 1970 data comes from CalifEDP70. This very interesting report provided data on software usage by 128 computers operated by state and local governments in California. It included the following IBM 360's: twenty 20's, five 25's, nine 30's, fourteen 40's, and nine 50's. In addition to the 25 1401's, the other IBM computers included six 1130's and three 1620's. Other machines included ten from Honeywell (including five 200's), seven from Burroughs (including four 3500's), seven from UNIVAC, six from RCA (including four 370/45's), three from NCR, and one from CDC. The tabulations showed a distribution of usage, and I computed the percentages shown by making assumptions regarding average usage in each percentile. For example, the report showed that, of the 128 systems, ten used COBOL from one to twenty percent of the time, eight from 20 to 40%, three from 40 to 60%, eighteen from 60 to 80% and thirty from 80 to 100%. I converted these 69 installations with variable COBOL usage to 44.5 installations having 100% usage, by assuming the five installation groups averaged 10%, 30%, 50%, 70%, and 90% COBOL usage. The 44.5 installations then represent 34.8% of all 128 computers. Among the "other" software explicitly mentioned in the report are SPS, Easycoder, Faster, and Neat.

### TABLE II.2.14.8 POSTAL DATA COMMUNICATIONS COSTS

| | Units | 1955 | 1958 | 1963 | 1968 | 1971 | 1974 | 1976 |
|---|---|---|---|---|---|---|---|---|
| First Class Letter | | | | | | | | |
| Postage per Ounce | cents | 3 | 4 | 5 | 6 | 8 | 10 | 13 |
| Postage per Pound | $ | 0.48 | 0.64 | 0.80 | 0.96 | 1.28 | 1.60 | 2.08 |
| Magnetic Tape—Av. Capy. | Mby | 5.0 | 5.0 | 12.4 | 16.5 | 17.5 | 17.7 | 20 |
| Mail Costs per Million Bytes | | | | | | | | |
| Magnetic Tape | $ | 0.22 | 0.29 | 0.15 | 0.13 | 0.16 | 0.20 | 0.23 |
| Continuous Forms | $ | 0.75 | 1.00 | 1.25 | 1.50 | 2.00 | 2.50 | 3.25 |
| Reduced | $ | | | | 0.60 | 0.80 | 1.00 | 1.30 |
| Punch Cards | $ | 46.90 | 62.50 | 78.10 | 39.10 | 52.10 | 65.10 | 84.60 |
| Microfiche | cents | 1.3 | 1.7 | 2.1 | 2.6 | 3.4 | 4.3 | 5.6 |

## TABLE II.2.15.1 THE USE OF VARIOUS PROGRAMMING AIDS II—NOTES

The 1969-1972 data in this table is based on responses to a survey conducted during the summer and fall of 1972 (PhilA73). A total of 390 questionaires were sent to a cross-section of computer installations across the country, and 164 were returned. The questionaire asked the users to estimate the percent of total programming man-hours which were employed at each site on each of seven named languages. Replies were requested for two time-frames: for the past 12 months, and for the past 13-36 months. The cited paper contains data (not shown here) on language usage in each of nine major industrial categories.

The data from the original table is that shown in the columns labelled "number of sites" (the number of users replying that they did indeed make some use of the indicated language) and "average percent use" (the average percentage of the total programming man-hours that the using sites spent on the indicated language). The columns labelled "total hours per language" are the products of the "number of sites" and "average use" columns, and represent the total number of hours spent on each language, assuming each site was spending a total of one hour. The sum of all entries in these columns should thus be equal to the number of sites reporting, and agree closely with the 164 sites mentioned in the referenced paper. The columns entitled "percent of total hours" represent the proportion each entry in the "total hours per language" columns are to the grand total hours for all languages. For example, in 1969 through 1971, 162.2 users each reporting on how he spent an average man-hour of programming, reported they used a total of 86.9 man-hours on COBOL; and 86.9 is 53.6% of the total 162.2 hours.

"Language per site" is the quotient of the column entitled "number of sites" and the total number of sites reporting which I interpret to be the sum at the bottom of the "total hours per language" column. It states that, for example, in 1969 to 1971, about 85% of the sites used COBOL, 81% used assembly language, and that there were an average of 3.01 languages in use per site (assuming the category entitled "other" is treated as a single language).

The 1974 data, in the same format, is from MacdN75, which reported the results of a survey of 200 large organizations, 57 of which replied. The paper is useful in that it gives the programming-usage replies of each of the 57 respondents. It is disappointing in that it did not define what was meant by "using" a language— i.e. use by programmers, or by machine time? By time spent programming (my assumption), or by number of programs or number of lines of code produced?

## TABLE II.2.15.2 A COMPARISON OF SOME COMPILERS—NOTES

The comparison described by this table was carried for the Air Force, and a summary of the results was published in *Datamation* magazine (RubeR68). The first portion of the table summarizes the characteristics of 14 programs written by seven programmers. The last eight lines of the table compare the 14 programs in four different ways.

In the first half of the table, the first column describes the application area of the program in general terms. Herewith is a little more detail: one business problem was a payroll calculation, the other a file editing and updating operation. The interactive job involved the development of an on-line system permitting a user to enter equation statements and request their evaluation; the simulation task had to do with a mixture of input and execution queues; the scientific calculation used matrix and vector operations, the standard trigonometric functions, and various limiting and quantizing operations; and the two data management applications were actually one problem requiring that data be extracted from a file, formated, and printed. This last job was programmed by two different programmers, each using two different languages.

In the second half of the table, the first column indicates which languages are being compared. PL-I is compared with each of the other three, and then all PL-I programs are compared to all others.

The second column of the table specifies the languages used to implement the various applications. The third column specifies the programmers' years of experience. The seven programmers all were professionals and college graduates.

The fourth column specifies the number of statements which were required in each language for each application. The fifth, sixth, and seventh column give the coding, debugging, and total programmer time for each problem; and the last column converts total hours and number of statements into statements per man-month, assuming a 40-hour week and a 52-week year.

In the second half of the table, columns three through seven are averages of the appropriate lines from the first half of the table. For example, the two years experience shown in the PL-I/COBOL comparison represents an average of the years experience of the two programmers who handled business applications. The last column in the second half of the table, however, was computed from other columns, and is not an average of the first half. For example, the 681 statements per man-month shown for the PL-I/COBOL comparison is *not* an average of the 599 statements per man-month and 977 statements per man-month for the two PL-I business applications. Instead, it was computed by dividing the average 334 PL-I statements by the average 85 programmer hours, and multiplying the result by 173.3 (hours per month).

**TABLE II.2.15.1 THE USE OF VARIOUS PROGRAMMING AIDS I ●**
**(Percentage "Usage" of Aids)**

| Year: | 1964 | | | 1968 | 1970 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample: | 5265 US Govt. | 500 US | 425 Int'l. | 150 360/50 | 128 State of California Installations | | | | |
| Basis: | Appl. Primary Lang. | Instal. Princ. Compiler | Instal. Princ. Compiler | Instal. Machine Time | 57 360's | 25 1401's | 94 IBM | 34 Other | 128 Total |
| Assembly Lang. | 73.0 | | | | 8.3 | .4 | 6.1 | 12.5 | 7.8 |
| Autocoder | | | | | 3.1 | 81.0 | 23.9 | 0 | 17.4 |
| FORTRAN | 19.6 | 32.2 | 40.0 | 7 | 3.9 | 3.5 | 7.7 | 7.0 | 7.6 |
| COBOL | 3.7 | 13.0 | 7.4 | 41 | 40.9 | 6.1 | 28.7 | 51.5 | 34.8 |
| RPG | | | | | 33.5 | 0.9 | 22.1 | 14.5 | 19.9 |
| PL-I | | | | 4 | 2.1 | 0 | 1.3 | 0 | 0.9 |
| Emulation | | | | 21 | | | | | |
| ALGOL | 2.2 | 3.9 | 19.5 | | | | | | |
| Other Compilers | 1.5 | | 5.6 | | 8.2 | 8.2 | 10.2 | 14.5 | 11.6 |
| Total | 100.0 | 49.1 | 72.5 | 73 | 100.0 | 100.1 | 100.0 | 100.0 | 100.0 |

**TABLE II.2.15.1 THE USE OF VARIOUS PROGRAMMING AIDS II ●**

| | 1969-1971 | | | | | 1971-1972 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Sites | Lang. per Site | Average % Use | Total Hours per Lang. | Percent of Total Hours | No. of Sites | Lang. per Site | Average % Use | Total Hours per Lang. | Percent of Total Hours |
| COBOL | 138 | .85 | 63 | 86.9 | 53.6 | 138 | .85 | 70 | 96.6 | 59.2 |
| FORTRAN | 78 | .48 | 13 | 10.1 | 6.2 | 79 | .48 | 11 | 8.7 | 5.3 |
| Assembler | 131 | .81 | 30 | 39.3 | 24.2 | 124 | .76 | 27 | 33.5 | 20.5 |
| PL-I | 29 | .18 | 16 | 4.6 | 2.8 | 26 | .16 | 28 | 7.3 | 4.5 |
| RPG | 66 | .41 | 20 | 13.2 | 8.1 | 49 | .30 | 20 | 9.8 | 6.0 |
| Basic | 9 | .06 | 18 | 1.6 | 1.0 | 14 | .09 | 13 | 1.8 | 1.1 |
| APL | 2 | .01 | 25 | 0.5 | 0.3 | 1 | .01 | 1 | | |
| Other | 35 | .22 | 17 | 6.0 | 3.7 | 33 | .20 | 17 | 5.6 | 3.4 |
| Total | 488 | 3.01 | | 162.2 | 99.9 | 464 | 2.84 | | 163.3 | 100.0 |

**TABLE II.2.15.1 THE USE OF VARIOUS PROGRAMMING AIDS III ●**

| | 1974 | | | | |
|---|---|---|---|---|---|
| | No. of Sites | Lang. per Site | Average % Use | Total Hours per Lang. | Percent of Total Hours |
| COBOL | 45 | .79 | 69.6 | 31.3 | 55.0 |
| FORTRAN | 27 | .47 | 7.0 | 1.9 | 3.3 |
| Assembler | 18 | .32 | 14.3 | 2.6 | 4.6 |
| PL–I | 11 | .19 | 36.7 | 4.0 | 7.0 |
| RPG | 19 | .33 | 25.6 | 4.9 | 8.6 |
| Basic | 11 | .19 | 9.5 | 1.0 | 1.8 |
| BAL | 12 | .21 | 46.9 | 5.6 | 9.8 |
| Other | 15 | .26 | 37.3 | 5.6 | 9.8 |
| Total | 158 | 2.77 | | 56.9 | 99.9 |

## TABLE II.2.15.3 COMPILER PERFORMANCE

The data in this table came from a report (CowaR64) on a series of COBOL tests carried out by Westinghouse Electric Corporation, an early advocate of the use of COBOL.

For the most part, the columns are self-explanatory. Compiler date is the date at which the compiler was released by the manufacturer. Compiling speed came from two sources: from the computer manufacturer, if he was willing contractually to guarantee the speeds shown; and from experience at Westinghouse in other instances. The configuration given is the minimum configuration required for COBOL compilation. Three measures of system speed are given: the first two are Ken Knight's measures (KnigK66,68), which were discussed in the notes to Figure II.2.11. The last is an addition rate, in thousands of additions per second, found by taking the reciprocal of the computer's add time, as given in Adams Associates *Computer Characteristics Quarterly.* (AdamA)

The monthly cost is the typical, prime shift monthly rental for the system shown. (Asterisks identify systems whose costs are based on a 200 hour per month prime shift.) The cost per 100 statements, in the last column, is found by converting monthly cost to cost per minute (using either 200 or 176 hours per month), dividing the result by the compiling speed from the third column, and multiplying that quotient by 100.

## TABLE II.2.16.1 PRICE AND CAPACITY OF VARIOUS MEDIA—NOTES

The pricing history on punched cards, magnetic tape, and disk packs comes from Table II.1.27. Magnetic tape unit reel capacity comes from Table II.2.12.3: 2400-foot reels recorded at one-thousand characters per block are assumed, and the 1955, 1960, 1965, and 1970 figures presume recording densities of 200, 556, 1600, and 1600 bytes per inch.

The data on continuous forms comes from Table II.2.16.2—I have not yet been able to establish a price history for such forms. The microfilm data is from HarmG69. Once again, I have not yet found a record of the price history of microfilm supplies.

## TABLE II.2.16.2 PRICES FOR STANDARD CONTINUOUS FORMS—NOTES

This table is a copy of the price sheet for a forms supplier in the Los Angeles area in 1972. It was given to me by a supplier who stated that prices generally at that time were about 25% lower than those shown. As a rule of thumb, my informant suggested that one should figure a one-page form at $3.00 per thousand sheets, with another $4.00 added for each carbon copy required.

### TABLE II.2.15.2 A COMPARISON OF SOME COMPILERS

| | Language | Programmer Exper. (yrs.) | Number of Statements | Programmer Time (hrs.) Coding | Debugging | Total | Statements Per Man-Month |
|---|---|---|---|---|---|---|---|
| **Application Area** | | | | | | | |
| Business | PL-I | 3 | 453 | 13 | 118 | 131 | 599 |
| | COBOL | 3 | 502 | 14 | 60 | 74 | 1176 |
| Business | PL-I | 1 | 214 | 10 | 28 | 38 | 977 |
| | COBOL | 1 | 355 | 16 | 74 | 90 | 684 |
| Interactive | PL-I | 9 | 690 | 22 | 70 | 92 | 1299 |
| | FORTRAN | 9 | 1032 | 33 | 60 | 93 | 1922 |
| Simulation | PL-I | 10 | 703 | 46 | 44 | 90 | 1355 |
| | FORTRAN | 10 | 846 | 54 | 33 | 87 | 1685 |
| Scientific | PL-I | 4 | 324 | 10 | 14 | 24 | 2348 |
| | FORTRAN | 4 | 295 | 6 | 10 | 16 | 3196 |
| Data Mgmnt. | PL-I | 6 | 437 | 35 | 75 | 110 | 688 |
| | Jovial | 6 | 594 | 42 | 120 | 162 | 635 |
| Data Mgmnt. | PL-I | 6 | 456 | 36 | 165 | 201 | 393 |
| | Jovial | 6 | 726 | 26 | 120 | 146 | 862 |
| **Comparisons (Averages)** | | | | | | | |
| PL-I/COB. | PL-I | 2 | 334 | 12 | 73 | 85 | 681 |
| | COBOL | 2 | 429 | 15 | 67 | 82 | 907 |
| PL-I/FOR. | PL-I | 7.7 | 572 | 26 | 43 | 69 | 1437 |
| | FORTRAN | 7.7 | 724 | 31 | 34 | 65 | 1931 |
| PL-I/Jov. | PL-I | 6 | 447 | 35 | 120 | 155 | 500 |
| | Jovial | 6 | 660 | 34 | 120 | 154 | 743 |
| All | PL-I | 5.6 | 468 | 25 | 73 | 98 | 828 |
| | Others | 5.6 | 621 | 27 | 68 | 95 | 1133 |

## TABLE II.2.15.3 COBOL COMPILER PERFORMANCE

| Computer | Compiler Date | Compiling Speed (state/min) | Configuration<br>Memory Size (k bytes) | No. of Tapes | Tape Speed (kby/sec) | System Speed<br>Knight Commer. (kops) | Knight Scient. (kops) | Add Rate (kops) | Costs<br>Per Month ($k) | Per 100 Statmnts. ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| CDC 3600 | 4/64 | 1000 | 196.6 | 6 | 120 | 74.9 | 315.9 | 483.1 | *55.80 | *.47 |
| IBM 7094 | | 1000 | 147.5 | 7 | 60 | 95.9 | 175.9 | 250.0 | 61.25 | .58 |
| IBM 7090 | 12/62 | 1000 | 147.5 | 7 | 60 | 45.47 | 97.35 | 227.3 | 55.25 | .52 |
| IBM 7080 | 5/62 | 29 | 60.0 | 10 | 60 | 30.9 | 27.1 | 90.9 | 53.02 | 17.31 |
| CDC 1604A | 5/63 | 650 | 196.6 | 4 | 83.4 | 20.4 | 58.3 | 208.3 | *40.50 | *.52 |
| Uni 1107 | 1/63 | 700 | 147.5 | (drum) | N.A. | 76.05 | 138.7 | 250.0 | 36.94 | .50 |
| IBM 7074 | 3/62 | 30 | 50.0 | 7 | 60 | 31.65 | 41.99 | 100.0 | 28.10 | 8.87 |
| IBM 7044 | 9/63 | 600 | 73.7 | 5 | 60 | 23.4 | 67.7 | 200.0 | 26.36 | .42 |
| Uni 490 | 7/63 | 44 | 61.4 | 5 | 125 | 15.1 | 17.8 | 104.2 | 25.42 | 5.48 |
| Hon 1800 | 10/63 | 1000 | 49.1 | 6 | 48 | 57.75 | 110.6 | 125.0 | 24.41 | .23 |
| Uni III | 12/62 | 60 | 98.3 | 7 | 133 | 2.36 | 1.16 | 1.90 | 22.93 | 3.61 |
| BGH 5000 | 9/63 | 450 | 142.5 | 2+drums | 66 | 15.91 | 43.00 | | 22.75 | .48 |
| IBM 7070 | | 11 | 50.0 | 7 | 60 | 5.14 | 2.81 | 16.7 | 22.00 | 18.91 |
| BGH 5000 | 9/63 | 250 | 122.9 | 2+drums | 66 | 15.91 | 43.00 | | 21.50 | .82 |
| Uni III | | 47 | 49.2 | 7 | 133 | 2.36 | 1.16 | 1.90 | 20.30 | 4.09 |
| BGH 5000 | 9/63 | 80 | 98.3 | 2+drums | 66 | 15.91 | 43.00 | | 20.25 | 2.40 |
| IBM 7010 | 12/63 | 550 | 45.0 | 6 | 60 | 11.54 | 5.73 | 30.3 | 19.90 | .34 |
| BGH 5000 | 9/63 | 20 | 73.7 | 2+drums | 66 | 15.91 | 43.00 | | 19.00 | 9.00 |
| Hon 800 | | 600 | 49.1 | 6 | 48 | 23.8 | 28.8 | 41.7 | 18.51 | .29 |
| IBM 7040 | | 202 | 73.7 | 5 | 60 | 9.08 | 21.42 | 62.5 | 17.76 | .83 |
| IBM 1410 | 12/63 | 250 | 30.0 | 4 | 20 | 4.64 | 1.67 | 11.4 | 10.78 | .40 |
| Hon 1400 | 4/63 | 31 | 24.6 | 4 | 48 | 6.82 | 1.77 | 12.8 | 10.76 | 3.29 |
| Hon 400 | | 22 | 12.3 | 4 | 48 | 2.75 | 1.35 | 9.01 | 8.28 | 3.55 |
| RCA 301 | 7/62 | 10 | 15.0 | 6 | 10 | 1.06 | .32 | 10.2 | *6.42 | *4.50 |
| NCR 315 | 5/62 | 16 | 15.0 | 2 CRAM | N.A. | | | 20.8 | 6.35 | 3.75 |
| IBM 1401 | 12/62 | 10 | 3.0 | 4 | 20 | 1.63 | .50 | 4.35 | 5.46 | 5.20 |
| NCR 315 | 3/62 | 10 | 15.0 | 5 | 12 | 11.5 | 3.41 | 20.8 | 4.53 | 4.30 |

## TABLE II.2.16.1 PRICE AND CAPACITY OF VARIOUS MEDIA ●

| | | 1955 | 1960 | 1965 | 1970 | 1974 |
|---|---|---|---|---|---|---|
| **Punched Cards** | | | | | | |
| Price Per Million Cards | $k/M | 1.28 | 1.06 | 0.87 | 0.80 | 2.00 |
| Card Capacity | Bytes | 80 | 80 | 80 | 80 | 80 |
| Price Per Million Bytes | $/MBytes | 16.0 | 13.3 | 10.9 | 10.0 | 25.0 |
| Price Per Million Cards | $k/M | | | | 0.60 | |
| Card Capacity | bytes | | | | 96 | |
| Price Per Million Bytes | $/MBytes | | | | 6.2 | |
| **Magnetic Tape** | | | | | | |
| Price Per Reel | $ | 50.00 | 50.00 | 32.00 | 11.00 | 9.00 |
| Reel Capacity | MBy | 5.0 | 11.3 | 23.5 | 23.5 | 62.6 |
| Price Per Million Bytes | $/MBytes | 10.00 | 4.42 | 1.36 | 0.47 | 0.14 |
| **Disk Pack** | | | | | | |
| IBM Model Number | | | | 1316 | 2316 | 3336-11 |
| Price Per Pack | $ | | | 490 | 400 | 1000 |
| Pack Capacity | MBy | | | 7.25 | 29.2 | 200.0 |
| Price Per Million Bytes | $/MBytes | | | 67.58 | 13.7 | 5.00 |
| **Continuous Forms** | | | | | | |
| Price Per 1000 Sheets | $ | | | | 4.62 | 5.50 |
| Bytes Per Sheet | kby | | | | 7.80 | 7.80 |
| Price Per Million Bytes | $/MBytes | | | | .592 | .705 |
| **Microfilm** | | | | | | |
| Price Per 100-ft. roll, 16mm. | $ | | | | 6.00 | |
| Pages Per Roll | k | | | | 3 | |
| Bytes Per Page | k | | | | 6.5 | |
| Price Per Million Bytes | $/MBytes | | | | .31 | |
| **Diskette** | | | | | | |
| Price per Diskette | $ | | | | | 8.00 |
| Bytes per Diskette | k | | | | | 243 |
| Price per Million Bytes | $/MBytes | | | | | 32.92 |

TABLE II.2.16.2 PRICES FOR STANDARD CONTINUOUS FORMS (1972)
(Prices in Dollars per 1000 Sheets)

| Fold-to-Fold Length (inches) | Width (inches) | Number of Parts to Form 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 8 1/2 | 8 1/2 | 3.67 | 8.49 | 13.47 | 17.61 | 24.77 | 29.26 |
| | 9 7/8 | 3.86 | 8.78 | 13.93 | 18.18 | 25.26 | 29.82 |
| | 10 5/8 | 4.01 | 9.26 | 14.46 | 19.09 | 25.75 | 30.60 |
| | 11 3/4 | 4.12 | 9.68 | 15.29 | 20.91 | 28.14 | 32.14 |
| | 13 5/8 | 4.31 | 10.70 | 16.77 | 22.60 | 31.51 | 37.54 |
| | 14 7/8 | 4.56 | 11.37 | 18.10 | 24.98 | 32.63 | 40.35 |
| 11 | 8 1/2 | 3.70 | 9.30 | 13.82 | 19.16 | 26.67 | 32.35 |
| | 9 7/8 | 3.92 | 9.96 | 15.72 | 20.70 | 28.63 | 35.43 |
| | 10 5/8 | 4.05 | 10.80 | 16.50 | 22.25 | 30.53 | 37.40 |
| | 11 3/4 | 4.12 | 11.72 | 17.69 | 24.77 | 33.61 | 41.43 |
| | 13 5/8 | 4.38 | 13.45 | 20.84 | 28.14 | 36.42 | 43.23 |
| | 14 7/8 | 4.62 | 13.90 | 21.12 | 29.40 | 37.05 | 45.61 |

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS—NOTES

The data in this table is derived from Department of the Army Technical Bulletin TB18-19-2, "Management Information Systems—Catalogue of ADP Systems Development and Use Experience". It was published by Headquarters, Department of the Army in Washington on August 24, 1971. It was intended to help system designers in planning new management information systems for various military applications, and contains data, in a standardized format, on 18 Air Force computer systems and 20 Army systems. In addition to the data summarized in the accompanying table, the report contains detailed information on project history and schedule, hardware configurations, program development, personnel, application program maintenance, system benefits, and future plans.

Most of the systems were designed in the mid-Sixties, and their present status is generally not specified. I will describe them as if they were in operation today.

I will begin by briefly reporting the nature and function of each of the 38 systems (which are identified by the column headings), and will then discuss the material covered in the body of the table.

**AF1. ADOBE.** This system takes data recorded in real time at a rocket test site, converts it via semi-automatic keypunching into punched card input, and prepares reports which help users evaluate rocket test results.

**AF2. AMPS.** One-hundred twenty-five of these military pay systems prepare paychecks twice a month for Air Force personnel around the world. They also prepare accrual and withholding tax reports which are forwarded to a central system for further analysis.

**AF3. DSWC.** Eight of these systems plan and analyze the workloads of automatic data processing equipment and personnel for various Air Force operations.

**AF4. GE/BSS.** Seven of these systems provide management information to help control the distribution, ordering, and inventory levels of aircraft replacement parts.

**AF5. GWC.** This system prepares weather analyses, prognoses, and forecasts based on observations of weather conditions at the earth's surface and at various altitudes.

**AF6. MAFR.** This accountability and fund reporting system keeps track of cash expenditures and of the status of funds allocated for various specific tasks.

**AF7. MILSTAMP.** The Air Force uses this system to monitor and report on materiel shipments by military and civilian carriers.

**AF8. MISSIM.** This system is a research tool which simulates the firing of ground-to-air missiles at an aircraft target. One input to the system is real-time data from radar tracking an actual aircraft which will be the target of the simulated attack.

**AF9. ORBIT.** This system accurately determines the orbits of earth satellites from satellite observation data.

**AF10. PDS.** Seven of these installations, which are part of a larger inventory management system, help expedite high priority requisitions from various government sources and from Air Force contractors.

**AF11. PDSO/MAC.** Eight of these installations provide management information on Air Force officers, as part of a personnel data system.

**AF12. PDSO/MPC.** This system maintains a central file of personnel data on all active Air Force officers.

**AF13. RAFT.** This pilot project was a regional accounting and finance system designed to handle civilian payrolls and other financial data at the Air Force base level.

**AF14. RRC.** Seven of these systems support the Air Force equipment repair activity. They identify material items and quantities needed, and help establish priorities for expediting.

**AF15. SC/ACCT.** Ten of these systems keep track of financial and accounting data for ten Air Force Divisions.

**AF16. SPCTRK.** This system detects, tracks, and catalogues all manmade objects in space. It also backs up an independent ballistic missile early warning system.

**AF17. TCC.** This system provides data on the operational status of the Tactical Air Command, to help that Command plan, manage, and control its resources during normal and emergency conditions.

**AF18. 1050/BSS.** Seventy-five of these systems serve as management support for the supply offices at 75 Air Force bases. They implement a standard automatic inventory control system, processing requisitions, receipts, issues, etc., for material at the bases.

**AR1. ACT I.** This system helps monitor and control enlisted trainees during their basic and advanced Army training.

**AR2. ADMSS.** This system reports on the status of administrative (office) space occupied by the Army in the National Capital Region.

**AR3. ARS.** This system establishes and maintains a data base handling information on all non-combat accidents involving Army military and civilian personnel, worldwide.

**AR4. CRFS.** This system stores, processes, and retrieves selected information from intelligence documents in the fields of security and counterintelligence.

**AR5. DIS.** This system records, classifies and displays information on monetary and manpower deficiencies as extracted from inspection and audit reports pertaining to Army agencies.

**AR6. ECD.** This system includes a personnel file for the top six enlisted ranks. Its purpose is to assist in the development of goals and objectives on career progression and promotion opportunity for these noncommissioned officers.

**AR7. FPS.** Ten of these Freight Planning Systems provide shipment planning and status data to various Army depots, and also automate the preparation of government bills of lading.

**AR8. FSFA.** This system mechanizes the accounting of certain Army depot inventories.

**AR9. ISAS.** This system helps account for the use of operating supplies and equipment, including repair parts, for the depot maintenance and repair activity.

**AR10. MACE.** This system helps automate the control of military air cargo from receipt of a shipping request to delivery to the airlift command.

**AR11. MPAS.** This prototype system provides personnel management and accounting data and information to link Army field offices with the central Army personnel reporting system.

**AR12. PERMACAP.** Thirty-seven of these systems provide personnel management and accounting data and information to link Army divisions with the central Army personnel reporting system.

**AR13. PHS.** This system accumulates and stores procurement history and contract performance data, and determines the sufficiency and commitment of funds, for the Army Materiel Command.

**AR14. PMS.** This system helps maintain an adequate level of repair parts for depot maintenance activities.

**AR15. SAMS.** This system helps provide Army Headquarters with manpower data pertinent to long range planning.

**AR16. SCS.** This system contains data relating to forces, facilities, and stations which are used to produce tentative stationing assignment plans for various Army units and groups.

**AR17. SDB.** This system produces reports on qualified, active enlisted personnel involved in specialized training programs.

**AR18. SSS.** This system prepares reports on personnel surveys periodically conducted worldwide by the Army Command.

**AR19. STATEM.** This system maintains the current status of all shipments of critical commodities being transported by or for the Army, and provides answers for questions on the shipment status of individual items.

**AR20. TAADS.** This system maintains basic data for the computation and management of personnel and equipment resource requirements for all Army units. **ARTo.** This column provides a composite profile of 19 of the 20 Army systems.

**ARLo.** This column contains a profile of six Army logistic systems: FPS, ISAS, MACE, PMS, PHS, and STATEM.

**ARPe.** This column supplies a profile of six Army personnel systems: PERMACAP, MPAS, ARS, ECD, ACT I, and SDB.

**ARFi.** This column provides a profile of the finance system FSFA.

**ARAd.** This column supplies a profile of six administrative Army systems: ADMSS, CRFS, DIS, SCS, SAMS, and TAADS.

**ARCo.** This column supplies a profile of the 11 systems programmed principally in the COBOL language.

**ARAt.** This column supplies a profile of the six systems coded primarily in the Autocoder Language.

**Avg.-Med.** These two columns contain the arithmetic average and the median of the data from the 20 Army sytems and the 18 Air Force systems.

**Development.** 1. This line specifies the date the development stage was complete and the operational stage began. If a system is installed at many locations, it is the date the first installation became operational.

2-4. The months of elapsed development time and the man-months of development effort are explicitly called out for each system. The elapsed time begins when system design begins, and ends when the system is operational. The development effort includes time expended by managers, analysts, programmers, and operators during the development phase. Line 4, the average manpower used, is found by dividing development effort by development time.

5-5a. The number of source and object instructions written per man-month of development effort was found by dividing lines 22 and 23, respectively, by line 3.

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS

| Line | Item | Units | AF1 | AF2 | AF3 | AF4 | AF5 | AF6 | AF7 | AF8 | AF9 | AF10 | AF11 | AF12 | AF13 | AF14 | AF15 | AF16 | AF17 | AF18 | AR1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Development** | | | | | | | | | | | | | | | | | | | | |
| 1. | Date Operational | | 1965 | 1964 | 1964 | 1962 | 1961 | 1963 | 1964 | 1964 | 1966 | 1964 | 1966 | 1965 | 1964 | 1965 | 1964 | 1964 | 1965 | 1965 | 1966 |
| 2. | Development Time | mo. | 25 | 18 | 12 | 10 | 21 | 7 | 11 | 38 | 24 | 18 | 22 | 20 | 23 | 4 | 12 | 45 | 25 | 18 | 18 |
| 3. | Development Effort | mm. | 21 | 704 | 86 | 375 | 4404 | 392 | 61 | 66 | 49 | 267 | 489 | 1443 | 381 | 118 | 226 | 2424 | 748 | 1400 | 105.8 |
| 4. | Average Manpower | | .84 | 39.11 | 7.16 | 23.44 | 209.7 | 56.0 | 5.55 | 1.74 | 2.04 | 14.8 | 22.2 | 72.2 | 16.6 | 29.5 | 18.8 | 53.9 | 29.9 | 77.8 | 5.88 |
| 5. | Source Instr./Man-mo. | k | .216 | .020 | 2.42 | .400 | .023 | .064 | .399 | .324 | .093 | .053 | .010 | .135 | .091 | .164 | .174 | .175 | .201 | - | .010 |
| 5a. | Object Instr./Man-mo. | k | 1.07 | .202 | 2.42 | .400 | .028 | .256 | 1.59 | 1.27 | .327 | .053 | .448 | .541 | .091 | .164 | .292 | .200 | .201 | .243 | .181 |
| | **Input** | | | | | | | | | | | | | | | | | | | | |
| 6. | Volume | mbpm. | .626 | .941 | 1.836 | 4.000 | 715.4 | 18.88 | 57.88 | 77.54 | .480 | 4.39 | 11.40 | 46.46 | 6.402 | 79.57 | .576 | 26.56 | 24.65 | 7.40 | 19.5 |
| 7. | Transaction Types | | 5 | 14 | 38 | 42 | 24 | 65 | 3 | 7 | 20 | 11 | 209 | 122 | 48 | 10 | 334 | 41 | 58 | 229 | 14 |
| 8. | Av. Volume/Trans. | mbpm. | .125 | .067 | .048 | .095 | 29.81 | .290 | 19.29 | 11.08 | .024 | .399 | .055 | .381 | .133 | 7.96 | .002 | .648 | .425 | .032 | 1.39 |
| 8a. | Transactions | ktpm. | | | | | | | | | | | | | | | | | | | |
| 8b. | Av. Size | kby. | | | | | | | | | | | | | | | | | | | |
| | **Output** | | | | | | | | | | | | | | | | | | | | |
| 9. | Volume | mbpm. | 1.094 | 1.007 | 13.07 | 40.31 | 598.0 | 401.6 | 11.95 | 47.13 | 3.600 | 9.59 | 69.21 | 81.60 | 26.07 | 10.31 | .796 | 1240. | 5.007 | 7.40 | 34.5 |
| 10. | Format Types | | 11 | 11 | 33 | 43 | 121 | 156 | 21 | 39 | 2 | 20 | 21 | 141 | 57 | 11 | 27 | 70 | 31 | 339 | 16 |
| 11. | Av. Volume/Format | mbpm. | .099 | .092 | .396 | .937 | 4.942 | 2.574 | .569 | 1.208 | 1.80 | .480 | 3.30 | .579 | .457 | .937 | .029 | 17.7 | .162 | .022 | 2.16 |
| | **Data Base** | | | | | | | | | | | | | | | | | | | | |
| 12. | Total Characters | mby. | 0 | 13.21 | 17.27 | 27.00 | 3.79 | 28.55 | 28.68 | 0 | 0 | 116.4. | 11.57 | 276.7 | 17.51 | .628 | 3.00 | 44.42 | 90.29 | 3.981 | 189 |
| 13. | Percent on Disk | % | | 0 | 0 | 100 | 0 | 0 | 0 | | | 100 | 0 | 86 | 0 | 0 | 100 | 0 | 9 | 100 | 0 |
| 14. | No. of Record Types | | | 3 | 3 | 11 | 7 | 11 | 3 | | | 8 | 5 | 6 | 8 | 2 | 6 | 6 | 33 | 115 | 6 |
| 15. | No. of Records | k | | 5.0 | 203.5 | 180 | unk | 265.0 | 399.9 | | | 369.3 | 17.81 | 544.5 | 135.5 | 7.0 | unk | 553.3 | unk | unk | 836 |
| 16. | Av. Record/Type | k | | 1.67 | 67.83 | 16.36 | | 24.09 | 133.3 | | | 46.16 | 3.56 | 107.4 | 16.9 | 3.50 | - | 92.2 | - | - | 139.3 |
| 17. | Av. Bytes/Record | kby. | | 2.64 | .085 | .150 | | .108 | .072 | | | .294 | .650 | .514 | .129 | .090 | - | .080 | - | - | .226 |
| 18. | Data Base Growth Rate | %/mo. | | unk | 0.2 | unk | unk | unk | unk | | | unk | unk | 1.1 | unk | 0.1 | unk | 7 | unk | unk | var. |
| 19. | Update Input Volume | mbpm. | | .941 | 1.836 | 4.000 | unk | 18.88 | 57.88 | | | 4.39 | 11.40 | 45.85 | 6.402 | .052 | .530 | 26.56 | unk | 7.40 | |
| 20. | Percent of Tot. | % | | 7.1 | .106 | .148 | | .661 | 1.496 | | | .038 | .985 | .166 | .366 | .083 | .177 | .598 | - | 1.86 | |
| | **Programs** | | | | | | | | | | | | | | | | | | | | |
| 21. | Language | | FOR | M.L. | Atcd. | A.L. | FOR | COB | COB | FOR | FOR | A.L. | COB | COB | A.L. | Atcd. | Atcd. | Var. | Atcd. | A.L. | Atcd. |
| 22. | No. of Source State. | k | 4.532 | 14.14 | 208.1 | 150.0 | 99.79 | 25.0 | 24.31 | 21.38 | 4.58 | 14.2 | 48.66 | 195.1 | 34.62 | 19.3 | 39.36 | 432.3 | 150 | unk | 10.54 |
| 23. | No. of Object Instr. | k | 22.50 | 14.14 | 208.1 | 150.0 | 124.2 | 100.2 | 97.25 | 84.00 | 16.02 | 14.2 | 219.0 | 780.5 | 34.62 | 19.3 | 66.00 | 485.2 | 150 | 340 | 19.12 |
| 24. | Object/Source | | 4.96 | 1.00 | 1.00 | 1.00 | 1.251 | 4.008 | 4.00 | 3.93 | 3.497 | 1.00 | 4.50 | 4.00 | 1.00 | 1.00 | 1.677 | 1.146 | 1.00 | - | 1.81 |
| | Percent of Instructions | | | | | | | | | | | | | | | | | | | | |
| 25. | Input Edit | % | 40 | 13 | | | 9 | 9 | 16 | 66 | 17 | 12 | 16 | 8 | 6 | 9 | 3 | 8 | 17 | 4 | 20 |
| 26. | File Maintenance | % | | 62 | 34 | 60 | | 15 | 27 | | | 68 | 35 | 27 | 30 | 2 | 41 | 12 | 8 | 63 | 32 |
| 27. | Query | % | | | | | | | | | | | 5 | 35 | 5 | 8 | 6 | 3 | 4 | 4 | |
| 28. | Sort | % | | 2 | | 10 | | 8 | | | | 2 | 4 | 4 | 3 | | 3 | 5 | | 3 | 2 |
| 29. | Merge | % | | | | 10 | | 2 | | | | | 1 | 1 | 3 | | | 1 | 2 | 1 | 1 |
| 30. | Compute | % | 45 | | | | 44 | 38 | 3 | 21 | 53 | | | | 27 | 27 | | 51 | 35 | 7 | 8 |
| 31. | Report Generation | % | 15 | 22 | 66 | 20 | 42 | 28 | 54 | 13 | 26 | 16 | 38 | 25 | 26 | 54 | 42 | 14 | 16 | 18 | 38 |
| 32. | Control | % | | 1 | | | 5 | | | | 4 | 2 | | | | | 5 | 6 | 18 | | |

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS

| Line | Item | Units | AF1 | AF2 | AF3 | AF4 | AF5 | AF6 | AF7 | AF8 | AF9 | AF10 | AF11 | AF12 | AF13 | AF14 | AF15 | AF16 | AF17 | AF18 | AR1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Operations** | | | | | | | | | | | | | | | | | | | | |
| | Computers | | | | | | | | | | | | | | | | | | | | |
| 33. | Base Computer–Mfg. | | IBM | NCR | IBM | GE | IBM | RCA | Uni | IBM | IBM | RCA | HIS | BGH | RCA | IBM | IBM | Phil. | IBM | Uni | IBM |
| 34. | Type | | 7040 | 390 | 7080 | 225 | 7094 | 501 | 1107 | 7094II | 7044 | 301 | 800 | 5500 | 301 | 7080 | 1410 | 212 | 1410 | 1050 | 7080 |
| 35. | Speed | kops | 62.5 | .089 | 90.9 | 27.8 | 250.0 | 2.78 | 250.0 | 714.3 | 200.0 | 14.9 | 41.7 | 500.0 | 10.1 | 90.9 | 11.36 | 1667. | 11.36 | 8.55 | 90.9 |
| 36. | Number in Use | | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| 37. | Total Usage/Mo. | hrs. | 12 | 277 | 14 | 176 | 500 | 146 | 41 | 67 | 1 | 270 | 89 | 376 | 126 | 4 | 165 | 569 | 220 | 504 | 43.7 |
| 38. | Total Operations/mo. | Bop | 2.70 | .089 | 4.58 | 17.61 | 450.0 | 1.46 | 36.9 | 172.3 | .720 | 14.5 | 13.4 | 676.8 | 4.58 | 1.31 | 6.45 | 3,415 | 9.00 | 15.5 | 14.3 |
| 38a. | Rental (each) | $k/mo | 18.295 | 6.421 | 69.945 | 9.400 | 72.43 | 16.151 | 60.390 | 85.825 | 31.315 | 7.660 | 13.033 | 48.065 | 11.422 | 69.945 | 14.345 | 75.390 | 17.640 | 9.284 | 61.800 |
| 39. | Peripheral Computer–Mfg. | | IBM | | IBM | | IBM | RCA | Uni | IBM | IBM | | HIS | | | IBM | | Phil. | | | IBM |
| 40. | Type | | 1401 | | 1401 | | 1401 | 301 | 1050 | 1401 | 1460 | | 200 | | | 1401 | | 1000 | | | 1460 |
| 41. | Speed | kops | 4.35 | | 4.35 | | 4.35 | 14.9 | 8.55 | 4.35 | 9.26 | | 22.7 | | | 4.35 | | 25.6 | | | 9.26 |
| 42. | Number in Use | | 1 | | 5 | | 2 | 1 | 1 | 2 | 1 | | 1 | | | 5 | | 1 | | | 1 |
| 43. | Total Usage/Mo. | hrs. | 10 | | 67 | | 1040 | 84 | 29 | 63 | 1 | | | | | 15 | | unk | | | 53.4 |
| 44. | Total Operations/Mo | Bop | .157 | | 1.05 | | 16.3 | 4.51 | .893 | .987 | .033 | | | | | .235 | | | | | 1.78 |
| 44a. | Rental (each) | $k/mo | 8.94 | | 6.421 | | 19.633 | 8.364 | 7.61 | 7.33 | 7.490 | | 6.590 | | | 6.421 | | 17.060 | | | 13.533 |
| 45. | Peripheral Computer–Mfg. | | | | | | | IBM | | | | | | | | | | IBM | | | |
| 46. | Type | | | | | | | 1401 | | | | | | | | | | 1620 | | | |
| 47. | Speed | kops | | | | | | 4.35 | | | | | | | | | | 7.14 | | | |
| 48. | Number in Use | | | | | | | 1 | | | | | | | | | | 1 | | | |
| 49. | Total Usage/Mo. | hrs. | | | | | | 37 | | | | | | | | | | unk | | | |
| 50. | Total Operations/Mo. | | | | | | | .579 | | | | | | | | | | | | | |
| 50a. | Rental (each) | $k/mo | | | | | | 8.130 | | | | | | | | | | 6.421 | | | |
| | Usage | | | | | | | | | | | | | | | | | | | | |
| 51. | Grand Tot. Operations/mo. | Bop | 2.86 | .089 | 5.63 | 17.61 | 466.3 | 6.55 | 37.8 | 173.3 | .753 | 14.5 | 13.4 | 676.8 | 4.58 | 1.55 | 6.45 | 3415 | 9.00 | 15.5 | 16.1 |
| 52. | Card Read Speed | cpm | 800 | 15 | 800 | 400 | 250 | 800 | 900 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 2000 | 800 | 400 | 800 |
| 53. | Total Usage/mo. | hrs. | 10 | 277 | 67 | 176 | 1040 | 84 | 29 | 63 | 1 | 135 | unk | 376 | 126 | 15 | 165 | unk | 220 | 504 | 53.4 |
| 54. | Total Capacity | mbpm. | 38.4 | 19.94 | 257.3 | 337.9 | 1,248 | 322.6 | 125.3 | 241.9 | 3.84 | 518.4 | | 1,444 | 483.8 | 57.6 | 633.6 | | 844.8 | 967.7 | 205.1 |
| 55. | Percent Used | % | 1.63 | 4.72 | .713 | 1.18 | 57.3 | 5.9 | 46.2 | 32.1 | 12.5 | .846 | | 3.22 | 1.32 | 1.38 | .090 | | 2.92 | .764 | 9.51 |
| 56. | Line Print Speed | lpm | 600 | na | 600 | 900 | 600 | 1000 | 900 | 600 | 1100 | 1000 | 900 | 650 | 1000 | 600 | 600 | 900 | 600 | 900 | 1100 |
| 57. | Total Usage/mo. | hrs. | 10 | na | 67 | 176 | 1040 | 84 | 29 | 100 | 1 | 135 | unk | 376 | 126 | 15 | 165 | unk | 220 | 504 | 53.4 |
| 58. | Total Capacity | mbpm. | 47.52 | | 318.4 | 1,254 | 4,492 | 665.3 | 187.9 | 475.2 | 8.71 | 1,069 | | 1,936 | 997.9 | 71.3 | 784.1 | | 1,045 | 3,593 | 465.2 |
| 59. | Percent Used | % | 2.3 | | 4.10 | 3.21 | 13.3 | 60.4 | 6.35 | 9.91 | 41.3 | .897 | | 4.21 | 2.61 | 14.5 | .101 | | .479 | .205 | 7.41 |
| 60. | Total I/O Characters | mbpm. | 1.720 | 1.948 | 14.91 | 44.31 | 1313.4 | 420.5 | 69.8 | 124.7 | 4.08 | 13.98 | 80.6 | 128.1 | 32.5 | 89.9 | 1.37 | 1,267 | 29.7 | 14.8 | 54.0 |
| 61. | Operations/Char. | | 1663 | 45.7 | 377.6 | 397.4 | 355.0 | 15.57 | 541.5 | 1390. | 184.6 | 1037 | 166.3 | 5283 | 140.9 | 17.2 | 4708 | 2695 | 303.0 | 1047 | 298.1 |
| 62. | Output Ch./Input Ch. | | 1.75 | 1.07 | 7.12 | 10.08 | .836 | 21.3 | .206 | .608 | 7.50 | 2.18 | 6.07 | 1.76 | 4.07 | .130 | 1.38 | 46.7 | .203 | 1.00 | 1.77 |
| 62a. | I/O Char./Object Instr. | | 76.44 | 137.8 | 71.64 | 295.4 | 10575 | 4196 | 717.7 | 1485 | 254.7 | 984.5 | 368.0 | 164.1 | 938.8 | 4658 | 20.75 | 2612 | 198.0 | 43.5 | 2824 |
| 62b. | Object Instr./Op./Ch. | k | .014 | .309 | .551 | .377 | .350 | 6.435 | .180 | .060 | .087 | .014 | 1.317 | .148 | .246 | 1.122 | .014 | .180 | .495 | .325 | .064 |
| | Program Maintenance | | | | | | | | | | | | | | | | | | | | |
| 63. | Programmers Assigned | | 1.2 | 8 | 5 | 4 | 59 | 11 | 2 | 1.2 | 0 | 8 | 9 | 50 | 4 | 6 | 2 | 20 | 30 | 68 | 4.7 |
| 64. | Source Instr./Prog. | k | 3.78 | 1.77 | 41.6 | 37.5 | 1.69 | 2.72 | 12.2 | 17.8 | - | 1.78 | 5.41 | 3.90 | 8.67 | 3.22 | 19.7 | 22.7 | 5.00 | | 2.24 |
| 65. | Hardware Time | hr/mo | 17 | 176 | 23 | 75 | 177 | 59 | 10 | 4 | 0 | 6 | 14 | 68 | unk | 7 | 28 | 180 | 148 | unk | 1.7 |
| 66. | Source Instr./Hour | k | .267 | .083 | 9.05 | 2.0 | .564 | .157 | 2.43 | 5.35 | - | 2.36 | 3.48 | 2.87 | | 2.76 | 1.41 | 2.35 | 1.01 | | 6.20 |

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS

| Line | Item | Units | AR2 | AR3 | AR4 | AR5 | AR6 | AR7 | AR8 | AR9 | AR10 | AR11 | AR12 | AR13 | AR14 | AR15 | AR16 | AR17 | AR18 | AR19 | AR20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Development** | | | | | | | | | | | | | | | | | | | | |
| 1. | Date Operational | | 1967 | 1969 | 1968 | 1968 | 1969 | 1967 | 1968 | 1968 | 1969 | 1970 | 1967 | 1968 | 1968 | 1970 | 1968 | 1970 | 1969 | 1969 | 1969 |
| 2. | Development Time | mo. | 13 | 32 | 13 | 9 | 23 | 6 | 11 | 15 | 21 | 25 | 15 | 15 | 15 | 14 | 13.2 | 12 | unk | 22 | 8 |
| 3. | Development Effort | mm. | 21 | 20.5 | 22.3 | 21 | 42.2 | 39.5 | 79 | 167 | 246 | 399 | 451 | 47 | 49 | 42.7 | 162.8 | 16.6 | unk | 141 | 43.5 |
| 4. | Average Manpower | | 1.62 | .641 | 1.72 | 2.33 | 1.83 | 6.58 | 7.18 | 11.13 | 9.81 | 15.96 | 30.1 | 3.13 | 3.27 | 3.05 | 12.3 | 1.38 | - | 6.41 | 5.44 |
| 5. | Source Instr./Man-mo. | k | .543 | .539 | .237 | .170 | .091 | .651 | .221 | .202 | .086 | .074 | .038 | .107 | .146 | .250 | .144 | 1.61 | - | .068 | .356 |
| 5a. | Object Instr./Man-mo. | k | .939 | 2.62 | .391 | .268 | .391 | .578 | .253 | .230 | .302 | .213 | | .142 | .182 | .876 | .503 | 5.94 | | .238 | 1.51 |
| | **Input** | | | | | | | | | | | | | | | | | | | | |
| 6. | Volume | mbpm. | .086 | .281 | 1.92 | .059 | 159 | 5.57 | 7.93 | 7.20 | 2.38 | 5.00 | 3.00 | 6.48 | 3.40 | .465 | .524 | .676 | 27.12 | 5.06 | 151.1 |
| 7. | Transaction Types | | 7 | 2 | 5 | 5 | 14 | 33 | 22 | 56 | 23 | 217 | 167 | 11 | 39 | 4 | 10 | 4 | 3 | 18 | 20 |
| 8. | Av. Volume/Trans. | mbpm. | .012 | .141 | .384 | .012 | 11.4 | .168 | .360 | .129 | .103 | .023 | .018 | .589 | .087 | .116 | .053 | .169 | 9.04 | .281 | 7.56 |
| 8a. | Transactions | ktpm. | | | | | | | | | | | | | | | | | | | |
| 8b. | Av. Size | kby. | | | | | | | | | | | | | | | | | | | |
| | **Output** | | | | | | | | | | | | | | | | | | | | |
| 9. | Volume | mbpm. | .295 | .631 | 17.39 | .403 | .564 | 24.36 | 18.73 | 21.86 | 28.22 | 5.06 | 13.15 | 13.21 | 15.85 | 7.84 | 2.70 | .140 | .111 | 3.80 | 894.2 |
| 10. | Format Types | | 20 | 10 | 10 | 8 | 10 | 37 | 30 | 79 | 49 | 85 | 119 | 29 | 52 | 8 | 11 | 5 | 4 | 18 | 35 |
| 11. | Av. Volume/Format | mbpm. | .015 | .063 | 1.74 | .050 | .056 | .658 | .624 | .277 | 4.66 | .060 | .111 | .456 | .305 | .980 | .245 | .028 | .028 | .211 | 25.6 |
| | **Data Base** | | | | | | | | | | | | | | | | | | | | |
| 12. | Total Characters | mby. | .218 | 11.48 | 117.9 | 1.957 | 414 | 83.93 | 10.44 | 28.08 | 172.7 | 5.46 | 6.75 | 9.11 | 37.18 | 25.04 | 10.50 | 12.78 | 2.38 | 82.0 | 394.5 |
| 13. | Percent on Disk | % | 0 | 0 | 0 | 0 | 0 | 99 | 38.1 | 64 | 100 | 98 | 0 | 0 | 49 | 3 | 93 | 0 | 0 | 99 | 7.6 |
| 14. | No. of Record Types | | 3 | 2 | 5 | 2 | 9 | 13 | 10 | 5 | 18 | 16 | 11 | 4 | 8 | 5 | 25 | 1 | 1 | 19 | 14 |
| 15. | No. of Records | k | 1.44 | 140 | 662 | 36.17 | 8360 | 214.4 | 26.48 | 183.9 | 524.5 | 66.0 | 84.5 | 60.7 | 247.6 | 233.0 | 50.4 | 32.6 | 28.0 | 246.0 | 6502 |
| 16. | Av. Record/Type | k | .480 | 70.0 | 132.4 | 18.1 | 928.9 | 16.5 | 2.65 | 36.8 | 29.1 | 4.13 | 7.68 | 15.2 | 31.0 | 46.6 | 2.02 | 32.6 | 28.0 | 12.9 | 464.4 |
| 17. | Av. Bytes/Record | kby. | .151 | .082 | .178 | .054 | .050 | .391 | .394 | .153 | .329 | .083 | .080 | .150 | .150 | .107 | .208 | .392 | .085 | .333 | .061 |
| 18. | Data Base Growth Rate | %/mo. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 2 | 0.7 | 0.7 | 0.3 | 0.01 | 0 | 0 | 0 |
| 19. | Update Input Volume | mbpm. | | | | | | | | | | | 3.0 | | | | | | | | |
| 20. | Percent of Tot. | % | | | | | | | | | | | .444 | | | | | | | | |
| | **Programs** | | | | | | | | | | | | | | | | | | | | |
| 21. | Language | | COB | COB | COB | COB | COB | Atcd. | Atcd. | Atcd. | COB | COB | M.L. | Atcd. | Atcd. | COB | COB | COB | Atcd. | COB | COB |
| 22. | No. of Source State. | k | 11.41 | 11.04 | 5.29 | 3.57 | 3.82 | 19.26 | 17.48 | 33.76 | 17.79 | 29.63 | 17.24 | 5.01 | 7.14 | 10.69 | 23.40 | 26.69 | 2.63 | 9.58 | 15.47 |
| 23. | No. of Object Instr. | k | 19.72 | 53.68 | 8.73 | 5.36 | 16.48 | 22.82 | 19.99 | 38.46 | 62.27 | 85.15 | 17.24 | 6.68 | 8.91 | 37.40 | 81.88 | 98.64 | 3.79 | 33.52 | 65.78 |
| 24. | Object/Source | | 1.73 | 4.86 | 1.65 | 1.50 | 4.31 | 1.18 | 1.14 | 1.14 | 3.50 | 2.87 | - | 1.33 | 1.25 | 3.50 | 3.50 | 3.70 | 1.44 | 3.50 | 4.25 |
| | Percent of Instructions | | | | | | | | | | | | | | | | | | | | |
| 25. | Input Edit | % | 26.5 | 7 | 23.5 | 30.0 | 22 | 6 | 11 | 5 | 14.0 | 19 | 24 | 13 | 10 | 32 | 13 | 25 | 72 | 7 | 8 |
| 26. | File Maintenance | % | 13.9 | 36 | 26.2 | 25.4 | 25 | 40 | 29 | 64 | 21.0 | 35 | 21 | 35 | 66 | 22 | 37 | 72 | 8 | 51 | 13 |
| 27. | Query | % | | | | | | | | | 4.0 | | | | | | | | | 39 | |
| 28. | Sort | % | 1.1 | 1 | 0.7 | 1.0 | 3 | | 1 | 1 | 0.4 | 1 | | 1 | 1 | 3 | 8 | | 1 | | .2 |
| 29. | Merge | % | | | | | | | | | | | | 2 | | | 4 | | | | .2 |
| 30. | Compute | % | | 18 | | | 5 | 4 | 8 | 6 | | 4 | 13 | | | 1 | 11 | 1 | 1 | | |
| 31. | Report Generation | % | 54.7 | 38 | 46.6 | 39.6 | 45 | 50 | 51 | 24 | 60.0 | 41 | 43 | 49 | 23 | 42 | 27 | 2 | 18 | 3 | 75 |
| 32. | Control | % | 3.8 | | 3.0 | 4.0 | | | | | 0.6 | | | | | | | | | | |

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS

| Line | Item | Units | AR2 | AR3 | AR4 | AR5 | AR6 | AR7 | AR8 | AR9 | AR10 | AR11 | AR12 | AR13 | AR14 | AR15 | AR16 | AR17 | AR18 | AR19 | AR20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Operations** | | | | | | | | | | | | | | | | | | | | |
| | Computers | | | | | | | | | | | | | | | | | | | | |
| 33. | Base Computer–Mfg. | | CDC | IBM | CDC | CDC | IBM | IBM | IBM | IBM | BGH | IBM | Uni | IBM | IBM | IBM | IBM | IBM | IBM | BGH | IBM |
| 34. | Type | | 3304 | 7080 | 3304 | 3304 | 7080 | 1410 | 1410 | 1410 | 5500 | 360/30 | 1005 | 1410 | 1410 | 360/65 | 360/50 | 7080 | 7080 | 5500 | 360/65 |
| 35. | Speed | kops | 363.6 | 90.9 | 363.6 | 363.6 | 90.9 | 11.36 | 11.36 | 11.36 | 500 | 25.0 | 3.91 | 11.36 | 11.36 | 769.2 | 250.0 | 90.9 | 90.9 | 500.0 | 769.2 |
| 36. | Number in Use | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 37. | Total Usage/Mo. | hrs. | .117 | 5.8 | 6.53 | .0444 | 12 | 69.0 | 27.7 | 63.1 | 253 | 112 | 176 | 7.3 | 56.8 | 2 | 11.5 | 19.1 | 0.8 | 18.6 | 20.1 |
| 38. | Total Operations/mo. | Bop | .153 | 1.90 | 8.55 | .057 | 3.93 | 2.82 | 1.13 | 2.58 | 455.4 | 10.1 | 2.48 | .299 | 2.32 | 5.54 | 10.4 | 6.25 | .262 | 33.5 | 55.7 |
| 38a. | Rental (each) | $k/mo | 33.815 | 61.800 | 33.815 | 33.815 | 61.800 | 30.208 | 30.208 | 30.208 | 75.047 | 19.019 | 4.407 | 30.208 | 30.208 | 107.36 | | 61.800 | 61.800 | 83.653 | 107.36 |
| 39. | Peripheral Computer–Mfg. | | | IBM | | | IBM | IBM | IBM | IBM | | | | IBM | IBM | | | IBM | IBM | | |
| 40. | Type | | | 1460 | | | 1460 | 1401 | 1401 | 1401 | | | | 1401 | 1401 | | | 1460 | 1460 | | |
| 41. | Speed | kops | | 9.26 | | | 9.26 | 4.35 | 4.35 | 4.35 | | | | 4.35 | 4.35 | | | 9.26 | 9.26 | | |
| 42. | Number in Use | | | 1 | | | 1 | 1 | 1 | 1 | | | | 1 | 1 | | | 1 | 1 | | |
| 43. | Total Usage/Mo. | hrs. | | 1.0 | | | 0.8 | 59.4 | 16.5 | 60.3 | | | | 9.2 | 37.1 | | | 2.7 | 18.6 | | |
| 44. | Total Operations/Mo | Bop | | .033 | | | .028 | .930 | .258 | .944 | | | | .144 | .581 | | | .090 | .620 | | |
| 44a. | Rental (each) | $k/mo | | 13.533 | | | 13.533 | 6.475 | 6.475 | 6.475 | | | | 6.475 | 6.475 | | | 13.533 | 13.533 | | |
| 45. | Peripheral Computer–Mfg. | | | | | | | | | | | | | | | | | | | | |
| 46. | Type | | | | | | | | | | | | | | | | | | | | |
| 47. | Speed | kops | | | | | | | | | | | | | | | | | | | |
| 48. | Number in Use | | | | | | | | | | | | | | | | | | | | |
| 49. | Total Usage/Mo. | hrs. | | | | | | | | | | | | | | | | | | | |
| 50. | Total Operations/Mo. | | | | | | | | | | | | | | | | | | | | |
| 50a. | Rental (each) | $k/mo | | | | | | | | | | | | | | | | | | | |
| | Usage | | | | | | | | | | | | | | | | | | | | |
| 51. | Grand Tot. Operations/mo. | Bop | .153 | 1.93 | 8.55 | .057 | 3.96 | 3.75 | 1.39 | 3.52 | 455.4 | 10.1 | 2.48 | .443 | 2.90 | 5.54 | 10.4 | 6.34 | .882 | 33.5 | 55.7 |
| 52. | Card Read Speed | cpm | 1200 | 800 | 1200 | 1200 | 800 | 800 | 800 | 800 | 1400 | 1000 | 500 | 800 | 800 | 1000 | 1000 | 800 | 800 | 300 | na |
| 53. | Total Usage/mo. | hrs. | .117 | 1.0 | 6.53 | .0444 | 0.8 | 128.4 | 44.2 | 123.4 | 253 | 112 | 352 | 16.5 | 93.9 | 2 | 11.5 | 2.7 | 18.6 | 18.6 | |
| 54. | Total Capacity | mbpm. | .674 | 3.84 | 37.6 | .256 | 3.07 | 493.1 | 169.7 | 473.9 | 1,700 | 537.6 | 844.8 | 63.4 | 360.6 | 9.60 | 55.2 | 10.4 | 71.4 | 26.8 | |
| 55. | Percent Used | % | 12.8 | 7.32 | 5.11 | 23.0 | 5179 | 1.13 | 4.67 | 1.52 | .140 | .930 | .355 | 10.2 | .943 | 4.84 | .949 | 6.50 | 38.0 | 18.9 | |
| 56. | Line Print Speed | lpm | 1000 | 1100 | 1000 | 1000 | 1100 | 600 | 600 | 600 | 1040 | 1100 | 600 | 600 | 600 | 1100 | 1100 | 1100 | 1100 | 850 | na |
| 57. | Total Usage/mo. | hrs. | .158 | 1.0 | 6.53 | .25 | 0.8 | 128.4 | 44.2 | 123.4 | 506 | 112 | 176 | 16.5 | 93.9 | 5.57 | 11.5 | 2.7 | 18.6 | 37.2 | |
| 58. | Total Capacity | mbpm. | 1.25 | 8.71 | 51.7 | 1.98 | 6.97 | 610.1 | 210.0 | 586.4 | 4,168 | 975.7 | 836.4 | 78.4 | 446.2 | 48.5 | 100.2 | 23.5 | 162.0 | 250.4 | |
| 59. | Percent Used | % | 23.6 | 7.24 | 33.6 | 20.4 | 8.09 | 3.99 | 8.92 | 3.73 | .677 | 0.5 | 1.6 | 16.8 | 3.6 | 16.2 | 2.7 | 0.6 | 0.1 | 1.5 | |
| 60. | Total I/O Characters | mbpm. | .381 | .912 | 19.31 | .462 | 159.6 | 29.9 | 26.7 | 29.1 | 30.6 | 10.1 | 16.2 | 19.7 | 19.3 | 8.31 | 3.22 | .816 | 27.2 | 8.86 | 1045 |
| 61. | Operations/Char. | | 401.6 | 2116 | 442.8 | 123.4 | 24.8 | 125.4 | 52.1 | 121.0 | 14,882 | 1000 | 153.1 | 22.5 | 150.3 | 666.7 | 3230 | 7770 | 32.4 | 3781 | 53.3 |
| 62. | Output Ch./Input Ch. | | 3.43 | 2.25 | 9.06 | 6.83 | .004 | 4.37 | 2.36 | 3.04 | 11.9 | 1.01 | 4.38 | 2.04 | 4.66 | 16.7 | 5.15 | .207 | .004 | .553 | 5.92 |
| 62a. | I/O Char./Object Instr. | | 19.3 | 17.0 | 2212 | 86.2 | 9684 | 1310 | 1336 | 756.6 | 491.4 | 118.6 | 939.7 | 2949 | 2166 | 222.2 | 39.3 | 8.3 | 7177 | 264.3 | 15886 |
| 62b. | Object Instr./Op./Ch. | k | .049 | .025 | .020 | .062 | .665 | .182 | .384 | .318 | .004 | .085 | .113 | .297 | .059 | .056 | .025 | .013 | .117 | .009 | 1.234 |
| | Program Maintenance | | | | | | | | | | | | | | | | | | | | |
| 63. | Programmers Assigned | | - | 1.3 | - | - | 2.2 | 4 | 3 | 9 | 2 | 31 | 10 | 2 | 4 | 4 | 2 | 2 | 1.15 | 2 | 8 |
| 64. | Source Instr./Prog. | k | | 8.49 | | | 1.74 | 4.82 | 5.83 | 3.75 | 8.90 | .956 | 1.22 | 2.51 | 1.79 | 2.67 | 11.7 | 13.3 | 2.29 | 4.79 | 1.93 |
| 65. | Hardware Time | hr/mo | - | 4.3 | - | - | 6.45 | 4.9 | 3.1 | 8.8 | 33 | 5.8 | 63 | 1.3 | 3.9 | 2 | unk | 1.3 | 9.7 | 1.4 | unk |
| 66. | Source Instr./Hour | k | | 2.57 | | | .592 | 13.93 | 5.64 | 3.84 | .539 | 5.11 | .274 | 3.85 | 1.83 | 5.35 | - | 20.5 | .271 | 6.84 | - |

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS

| Line | Item | Units | ARTo | ARLo | ARPe | ARFi | ARAd | ARCo | ARAt | Avg | Med |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Development** | | | | | | | | | | |
| 1. | Date Operational | | | | | | | | | | |
| 2. | Development Time | mo. | 15.7 | 15.7 | 20.8 | 11 | 11.3 | 16 | 13 | | |
| 3. | Development Effort | mm. | 105.9 | 114.9 | 154.0 | 79 | 50.9 | 100.4 | 83.2 | 425.2 | 118 |
| 4. | Average Manpower | | 6.75 | 7.32 | 7.40 | 7.18 | 4.50 | 6.28 | 6.40 | 21.9 | 7.18 |
| 5. | Source Instr./Man-mo. | k | .126 | .134 | .079 | .221 | .228 | .126 | .187 | | |
| 5a. | Object Instr./Man-mo. | k | | | | | | .421 | .212 | .710 | .297 |
| | **Input** | | | | | | | | | | |
| 6. | Volume | mbpm. | 21.04 | 5.01 | 31.08 | 7.93 | 25.71 | 15.24 | 8.35 | 39.3 | 5.99 |
| 7. | Transaction Types | | 35 | 30 | 167 | 22 | 18 | 31 | 29 | 51.4 | 19.0 |
| 8. | Av. Volume/Trans. | mbpm. | .601 | .276 | .186 | .360 | 1.43 | .492 | .288 | 2.68 | .155 |
| 8a. | Transactions | ktpm. | 268.6 | 82.77 | 573.5 | 50.28 | 185.9 | 141.0 | 81.20 | | |
| 8b. | Av. Size | kby. | .078 | .100 | .054 | .158 | .138 | .108 | .103 | | |
| | **Output** | | | | | | | | | | |
| 9. | Volume | mbpm. | 58.04 | 17.88 | 9.01 | 18.73 | 153.8 | 87.32 | 18.79 | 96.6 | 12.5 |
| 10. | Format Types | | 33 | 49 | 119 | 33 | 15 | 46 | 44 | 47.1 | 28.0 |
| 11. | Av. Volume/Format | mbpm. | 1.76 | .367 | .076 | .568 | 10.25 | 1.90 | .427 | 1.96 | .426 |
| | **Data Base** | | | | | | | | | | |
| 12. | Total Characters | mby. | 85.62 | 60.49 | 106.6 | 10.44 | 93.98 | 75.30 | 41.62 | 60.47 | 13.24 |
| 13. | Percent on Disk | % | 22.6 | 89.0 | 5 | 38.1 | 1.3 | 36.7 | 41.7 | | |
| 14. | No. of Record Types | | 9 | 11 | 11 | 10 | 9 | 10 | 8 | 11.5 | 6 |
| 15. | No. of Records | k | 974.5 | 214.8 | 1586 | 26.48 | 1250 | 773.7 | 261.5 | 606 | 184 |
| 16. | Av. Record/Type | k | 108.3 | 19.5 | 144.2 | 2.65 | 138.9 | 77.4 | 32.7 | 64.1 | 28.0 |
| 17. | Av. Bytes/Record | kby. | .088 | .282 | .067 | .394 | .075 | .097 | .159 | .273 | .156 |
| 18. | Data Base Growth Rate | %/mo. | 1 | 1 | 0 | 0 | 0.03 | 1 | 1 | | |
| 19. | Update Input Volume | mbpm. | | | | | | | | | |
| 20. | Percent of Tot. | % | | | | | | | | | |
| | **Programs** | | | | | | | | | | |
| 21. | Language | | | | | | | COB | Atcd. | | |
| 22. | No. of Source State. | k | 13.32 | 15.43 | 12.21 | 17.48 | 11.63 | 12.62 | 15.53 | | |
| 23. | No. of Object Instr. | k | 31.88 | 27.51 | 32.37 | 19.99 | 34.48 | 42.25 | 17.65 | 97.7 | 36.5 |
| 24. | Object/Source | | 2.39 | 1.78 | 2.65 | 1.14 | 2.96 | 3.35 | 1.14 | | |
| | Percent of Instructions | | | | | | | | | | |
| 25. | Input Edit | % | 14.2 | 7.8 | 18.6 | 11 | 18.3 | 17.7 | 8.8 | 16.9 | 13.0 |
| 26. | File Maintenance | % | 35.3 | 48.0 | 31.0 | 29 | 24.2 | 27.7 | 47.0 | 30.4 | 28.0 |
| 27. | Query | % | 1.5 | 4.0 | 0 | 0 | 0 | 4.5 | 0 | 2.97 | 0 |
| 28. | Sort | % | 1.5 | 0.5 | 0.7 | 1 | 4.5 | 2.0 | 1.0 | 1.85 | 0 |
| 29. | Merge | % | 0.5 | 0.3 | 0 | 0 | 1.0 | 0.6 | 1.0 | .74 | 0 |
| 30. | Compute | % | 5.3 | 2.9 | 9.1 | 8 | 4.0 | 4.6 | 5.3 | 11.3 | 3.5 |
| 31. | Report Generation | % | 41.2 | 35.6 | 40.6 | 51 | 46.5 | 42.7 | 37.0 | 34.3 | 38.0 |
| 32. | Control | % | 0.5 | 0.9 | 0 | 0 | 1.1 | 0.2 | 0 | 1.38 | 0 |

## TABLE II.2.21.1 ARMY AND AIR FORCE MANAGEMENT INFORMATION SYSTEMS

| Line | Item | Units | ARTo | ARLo | ARPe | ARFi | ARAd | ARCo | ARAt | Avg | Med |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Operations** | | | | | | | | | | |
| | Computers | | | | | | | | | | |
| 33. | Base Computer–Mfg. | | | | | | | | | | |
| 34. | Type | | | | | | | | | | |
| 35. | Speed | kops | | | | | | | | | |
| 36. | Number in Use | | | | | | | | | | |
| 37. | Total Usage/Mo. | hrs. | | | | | | | | | |
| 38. | Total Operations/mo. | Bop | | | | | | | | | |
| 38a. | Rental (each) | $k/mo | | | | | | | | | |
| 39. | Peripheral Computer–Mfg. | | | | | | | | | | |
| 40. | Type | | | | | | | | | | |
| 41. | Speed | kops | | | | | | | | | |
| 42. | Number in Use | | | | | | | | | | |
| 43. | Total Usage/Mo. | hrs. | | | | | | | | | |
| 44. | Total Operations/Mo | Bop | | | | | | | | | |
| 44a. | Rental (each) | $k/mo | | | | | | | | | |
| 45. | Peripheral Computer–Mfg. | | | | | | | | | | |
| 46. | Type | | | | | | | | | | |
| 47. | Speed | kops | | | | | | | | | |
| 48. | Number in Use | | | | | | | | | | |
| 49. | Total Usage/Mo. | hrs. | | | | | | | | | |
| 50. | Total Operations/Mo. | | | | | | | | | | |
| 50a. | Rental (each) | $k/mo | | | | | | | | | |
| | Usage | | | | | | | | | | |
| 51. | Grand Tot. Operations/mo. | Bop | | 83.25 | 7.45 | 1.39 | | | | 144.7 | 6.5 |
| 52. | Card Read Speed | cpm | | | | | | | | | |
| 53. | Total Usage/mo. | hrs. | | | | | | | | | |
| 54. | Total Capacity | mbpm. | | | | | | | | | |
| 55. | Percent Used | % | | | | | | | | 9.4 | 4.0 |
| 56. | Line Print Speed | lpm | | | | | | | | | |
| 57. | Total Usage/mo. | hrs. | | | | | | | | | |
| 58. | Total Capacity | mbpm. | | | | | | | | | |
| 59. | Percent Used | % | | | | | | | | 8.3 | 3.5 |
| 60. | Total I/O Characters | mbpm. | | 22.89 | 40.09 | 26.66 | | | | | |
| 61. | Operations/Char. | | | | | | | | | 1468 | 300 |
| 62. | Output Ch./Input Ch. | | | | | | | | | 5.25 | 2.31 |
| 62a. | I/O Char./Object Instr. | | | | | | | | | 2008 | 604.0 |
| 62b. | Object Instr./Op./Ch. | k | | | | | | | | .421 | .133 |
| | Program Maintenance | | | | | | | | | | |
| 63. | Programmers Assigned | | | | | | | | | | |
| 64. | Source Instr./Prog. | k | | | | | | | | 8.13 | 3.9 |
| 65. | Hardware Time | hr/mo | 5.8 | | | | | | | | |
| 66. | Source Instr./Hour | k | | | | | | | | 3.45 | 2.5 |

**Inputs.** 6. Input volume is the expected amount of input characters originating outside the data processing system, measured in millions of bytes (characters) per month. On punched card inputs, only character positions used for data are counted.

7-8. Input characters describe transactions, and line 7 counts the number of different transaction types for each system. A transaction type is generally identified by a unique transaction code and/or a unique input format. The average number of characters per transaction type, on line 8, is found by dividing line 6 by line 7.

8a-8b. The number of transactions occurring per month (in thousands of transactions per month) was given in the summary information on Army systems only. The average size of a transaction, in thousands of bytes, was found by dividing line 6 by line 8a.

**Output.** 9. The output volume is the expected number of characters output to system users, in millions of bytes per month. Only non-blank characters are counted.

10-11. Output format types is basically the number of different kinds of reports produced by the system. And the average number of output characters per format type, in millions of bytes per month, is shown on line 11 and was computed by dividing line 9 by line 10.

**Data Base.** 12. The data base is a collection of files containing unique information, accessible to the system, and normally referred to or updated relatively frequently. Intermediate files are not counted. The total characters in the data base, in millions of bytes, is shown on this line. Note that a few applications involve no data base at all.

13. For some applications, the data base is stored on magnetic tape or even on punched cards. Where the information is available on direct access storage devices (disks), the percentage so stored is given on this line.

14-17. The number of kinds of records are shown on line 14, and the total number of records in the data base, in thousands, on line 15. Line 16 was computed by dividing line 15 by line 14. The average number of characters per record, in thousands of bytes, is shown in line 17 and was computed by dividing line 12 by line 15.

18. The growth rate of the data base, expressed as a percent of total characters per month, is shown on this line. Note that, for many systems, the growth rate is unknown.

19-20. The number of input charcters per month used to update the data base is shown on line 19, in millions of bytes per month. It is expressed as a percentage of the total characters in the data base on line 20.

**Programs.** 21. This line names the programming language which was used for the application programs. Where more than one language was used, the predominant one is shown. The abbreviations used are as follows: FOR is FORTRAN; M.L. is Machine Language; Atcd. is Autocoder; A.L. is Assembly Language; COB is COBOL; Var is "various", and indicates that there was no predominant language.

22-24. Line 22 shows the number of lines of code, in thousands, written by the programmers in the language shown on line 21. The number of object instructions, shown in thousands on line 23, is the number of machine-format instructions, generated by the compiler or assembler, appearing in an object programmed deck which can be directly processed by the computer. Line 24 is the ratio of line 23 to line 22.

25-32. These lines show the proportion of *source* statements attributable to each of eight functions. No specific definition of the functions was given, and the report doesn't describe how the percentages were determined.

**Operations.** 33-50a. Each data processing system included one or more CPU's, and this portion of the table identifies the CPU's involved. It is divided into three identical parts, making it possible to describe three different kinds of processor. The first, described on lines 33 to 38a, is called the Base Computer; the other two, described on lines 39 to 44a and 45 to 50a, are called Peripheral Computers and apparently are generally assigned to input/output operations. The computer manufacturer, type, and number in use (per site) are self-explanatory. Computer speed, in thousands of operations per second, is basically the raw rate at which additions can be carried out by the CPU. (It is the "Adams addition rate" from Table II.2.11.1.) Total usage per month, in hours, is the average time *all* computers of a given type were employed in processing this application. Total operations per month for each class of computer is found by multiplying speed by 3600, to get thousands of operations per hour, multiplying the result by total usage per month, and dividing that answer by one million to convert to billions of operations per month. Finally, the basic monthly rental of each computer system is given, in thousands of dollars per month. These figures are for single systems, and must be multiplied by the number of systems in use if we want to compute total rental figures. Furthermore, they are basic rental figures, and neither include overtime charges, nor are factored to take into account the actual hours per month each system is used in the given application.

51. This line is the sum of lines 38, 44, and 50. It shows the total number of operations per month carried out by all computers on the given application.

52-55. Each system has at least one card reader, and card reading speeds in cards per minute are shown on line 52. The figure for card reader usage per month is based on the assumption that the card reader(s) is available for input anytime the peripheral processor(s) is used. Card reader usage is thus peripheral computer usage multiplied by the number of card readers on the peripheral computer or computers. The total card reader capacity, in millions of bytes per month, assumes that the card readers are operated at full speed, and that each card contains a full 80 characters. It is computed by multiplying card reader speed on line 52 by 60 and then by 80 to get bytes per hour read, multiplying that result by total usage per month, and dividing the result by one million to convert it to millions of bytes per month. Line 55 shows the percentage of total usage time the card reader would be used if it read in all the input characters each month. It is the quotient of lines 6 and lines 54. In interpreting this figure, one must keep in mind the facts that some system inputs come via magnetic tape units and other devices besides card readers; and that most cards contain far less than their maximum capacity of 80 characters.

56-59. Just as each system has one or more card readers, it also has one or more line printers. Printer speed in lines per minute is given, and total line printer usage per month was computed in a fashion entirely equivalent to that used to compute card reader usage per month. Line printer output capacity was obtained by multiplying the printer speed by 132 to obtain characters per line, multiplying that result by 60 to obtain lines per hour and then multiplying by line 57 and dividing by one million to get capacity in millions of bytes. Line 59 shows what percentage of time the line printer would have to be used to handle system output, assuming that all output characters went out on the printer and that each line contained a full 132 characters. It was computed by dividing line 9 by line 58. In interpreting the results, one must keep in mind that some system outputs go to magnetic tape units and other devices, as well as to printers; and that many output lines printed contain far less than 132 characters.

60-62. The total input/output characters is the sum of lines 6 and 9. The operations carried out per character were computed by dividing the total number of operations carried out by all computers per month, from line 51, by the total number of input/output characters on line 60.

The ratio of output characters to input characters is simply the quotient of lines 9 and 6.

**Program Maintenance.** 63-66. The number of programmers assigned to program maintenance, and the amount of computer system time per month employed in maintenance, were both given in the report. Line 64 is the quotient of the number of source statements required by the application (line 22) and the number of maintenance programmers assigned on line 63. Line 66 is the quotient of lines 22 and 65.

### TABLE II.2.21.2 DISTRIBUTION OF ARMY/AF MIS DATA—NOTES

The data in this table was derived from that in Table II.2.21.1 by counting the number of Army and Air Force systems in each given range. The line numbers in this table are the same as the line numbers in the previous table. Note that most of the range ratios are logarithmic, with the starting point of each boundary either ten times or four times the magnitude of the starting point of the previous boundary.

### TABLE II.2.21.2 DISTRIBUTIONS OF ARMY/AF MIS DATA

| Line | Item | Figure | Units | Range, Number, or Percentage | | | | |
|---|---|---|---|---|---|---|---|---|
| 2. | Development Time | | | | | | | |
| | Range | | mos. | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 |
| | No. in Range | | | 5 | 18 | 11 | 2 | 1 |
| | Percent Distrib. | | % | 13.5 | 48.6 | 29.7 | 5.4 | 2.7 |
| 3. | Development Effort | | | | | | | |
| | Range | | mm. | 16-64 | 64-256 | 256-1k | 1k-4k | 4k-16k |
| | No. in Range | | | 14 | 10 | 9 | 3 | 1 |
| | Percent Distrib. | | % | 37.8 | 27.0 | 24.3 | 8.1 | 2.7 |
| 4. | Average Manpower | | | | | | | |
| | Range | | | .4-1.6 | 1.6-6.4 | 6.4-25 | 25-102 | 102-410 |
| | No. in Range | | | 3 | 12 | 13 | 8 | 1 |
| | Percent Distrib. | | % | 8.1 | 32.4 | 35.1 | 21.6 | 2.7 |
| 5a. | Object Instr./Man-mo. | | | | | | | |
| | Range | | | 10-40 | 40-160 | 160-640 | 640-2k | over 2k |
| | No. In Range | | | 1 | 4 | 23 | 6 | 2 |
| | Percent Distrib. | | % | 2.8 | 11.1 | 63.9 | 16.7 | 5.6 |
| 6. | Input Volume | 2.21.1 | | | | | | |
| | Range | | mbpm. | .01-.1 | .1-1 | 1-10 | 10-100 | 100-1k |
| | No. in Range | | | 2 | 8 | 15 | 10 | 3 |
| | Percent Distrib. | | % | 5.3 | 21.1 | 39.5 | 26.3 | 7.9 |
| 7. | Input Transaction Types | | | | | | | |
| | Range | | | 1-3 | 4-15 | 16-63 | 64-255 | 255-1k |
| | No. in Range | | | 3 | 14 | 14 | 6 | 1 |
| | Percent Distrib. | | % | 7.9 | 36.8 | 36.8 | 15.8 | 2.6 |
| 8. | Av. Vol./Trans | | | | | | | |
| | Range | | mbpm. | 0-.01 | .01-.1 | .1-1 | 1-10 | 10-100 |
| | No. in Range | | | 1 | 12 | 17 | 4 | 4 |
| | Percent Distrib. | | % | 2.6 | 31.6 | 44.7 | 10.5 | 10.5 |
| 9. | Output Volume | 2.21.2 | | | | | | |
| | Range | | mbpm. | .1-1 | 1-10 | 10-100 | 100-1k | 1k-10k |
| | No. in Range | | | 7 | 10 | 17 | 3 | 1 |
| | Percent Distrib. | | % | 18.4 | 26.3 | 44.7 | 7.9 | 2.6 |
| 10. | Output Format Types | | | | | | | |
| | Range | | | 1-3 | 4-15 | 16-63 | 64-255 | 256-1k |
| | No. in Range | | | 1 | 11 | 18 | 7 | 1 |
| | Percent Distrib. | | % | 2.6 | 28.9 | 47.4 | 18.4 | 2.6 |
| 11. | Output Vol. per Format | | | | | | | |
| | Range | | mbpm. | .01-.1 | .1-1 | 1-10 | 10-100 | 100-1k |
| | No. in Range | | | 11 | 17 | 8 | 2 | 0 |
| | Percent Distrib. | | % | 28.9 | 44.7 | 21.1 | 5.3 | 0 |

**TABLE II.2.21.2 DISTRIBUTIONS OF ARMY/AF MIS DATA (continued)**

| Line | Item | Figure | Units | Range, Number, or Percentage | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12. | Data Base Size | 2.21.4 | | | | | | | |
| | Range | | mby | 0 | .1-1 | 1-10 | 10-100 | 100-1k | |
| | No. in Range | | | 3 | 2 | 9 | 17 | 7 | |
| | Percent Distrib. | | % | 7.9 | 5.3 | 23.7 | 44.7 | 18.4 | |
| 14. | DB Record Types | | | | | | | | |
| | Range | | | 1-3 | 4-15 | 16-63 | 64-255 | 255-1k | |
| | No. in Range | | | 9 | 20 | 5 | 1 | 0 | |
| | Percent Distrib. | | % | 25.7 | 57.1 | 14.3 | 2.9 | 0 | |
| 15. | No. of Records | | | | | | | | |
| | Range | | k | 1-10 | 10-100 | 100-1k | 1k-10k | 10k-.1M | |
| | No. in Range | | | 3 | 9 | 17 | 2 | 0 | |
| | Percent Distrib. | | % | 9.7 | 29.0 | 54.8 | 6.5 | 0 | |
| 16. | Av. Records/Type | | | | | | | | |
| | Range | | k | .1-1 | 1-10 | 10-100 | 100-1k | 1k-10k | |
| | No. in Range | | | 1 | 7 | 17 | 6 | 0 | |
| | Percent Distrib. | | % | 3.2 | 22.5 | 54.8 | 19.4 | 0 | |
| 17. | Av. Record Size | 2.21.5 | | | | | | | |
| | Range | | kby. | 0-.1 | .1-.2 | .2-.3 | .3-.4 | over .4 | |
| | No. in Range | | | 11 | 9 | 3 | 5 | 3 | |
| | Percent Distrib. | | % | 35.5 | 29.0 | 9.7 | 16.1 | 9.7 | |
| 23. | Obj. Instr. in Prog. | 2.21.6 | | | | | | | |
| | Range | | k | 1-4 | 4-16 | 16-64 | 64-256 | 256-1k | |
| | No. in Range | | | 1 | 6 | 14 | 13 | 3 | |
| | Percent Distrib. | | % | 2.7 | 16.2 | 37.8 | 35.1 | 8.1 | |
| 25. | Input Edit | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 2 | 25 | 8 | 1 | 2 | 0 |
| | Percent Distrib. | | % | 5.3 | 65.8 | 21.1 | 2.6 | 5.3 | 0 |
| 26. | File Maintenance | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 4 | 7 | 17 | 3 | 7 | 0 |
| | Percent Distrib. | | % | 10.5 | 18.4 | 44.7 | 7.9 | 18.4 | 0 |
| 27. | Query | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 28 | 8 | 2 | 0 | 0 | 0 |
| | Percent Distrib. | | % | 73.7 | 21.1 | 5.3 | 0 | 0 | 0 |
| 28. | Sort | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 12 | 26 | 0 | 0 | 0 | 0 |
| | Percent Distrib. | | % | 31.6 | 68.4 | 0 | 0 | 0 | 0 |
| 29. | Merge | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 26 | 12 | 0 | 0 | 0 | 0 |
| | Percent Distrib. | | % | 68.4 | 31.6 | 0 | 0 | 0 | 0 |
| 30. | Compute | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 15 | 23 | 0 | 0 | 0 | 0 |
| | Percent Distrib. | | % | 39.5 | 60.5 | 0 | 0 | 0 | 0 |
| 31. | Report Base | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 0 | 9 | 13 | 13 | 3 | 0 |
| | Percent Distrib. | | % | 0 | 23.7 | 34.2 | 34.2 | 7.9 | 0 |
| 32. | Control | | | | | | | | |
| | Range | | % | 0 | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| | No. in Range | | | 27 | 11 | 0 | 0 | 0 | 0 |
| | Percent Distrib. | | % | 71.1 | 28.9 | 0 | 0 | 0 | 0 |

**TABLE II.2.21.2 DISTRIBUTIONS OF ARMY/AF MIS DATA (continued)**

| Line | Item | Figure | Units | Range, Number, or Percentage | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 51. | Operations/Mo. | | | | | | | | |
| | Range | | Bop. | .01-.1 | .1-1 | 1-10 | 10-100 | 100-1k | 1k-10k |
| | No. in Range | | | 2 | 4 | 17 | 10 | 4 | 1 |
| | Percent Distrib. | | % | 5.3 | 10.5 | 44.7 | 27.1 | 11.5 | 2.6 |
| 55. | Card Reader Usage | | | | | | | | |
| | Range | | % | 0-.4 | .4-1.6 | 1.6-6.4 | 6.4-25 | 25-100 | |
| | No. in Range | | | 3 | 11 | 8 | 8 | 4 | |
| | Percent Distrib. | | % | 8.8 | 32.4 | 23.5 | 23.5 | 11.8 | |
| 59. | Line Printer Usage | | | | | | | | |
| | Range | | % | 0-.4 | .4-1.6 | 1.6-6.4 | 6.4-25 | 25-100 | |
| | No. in Range | | | 11 | 3 | 8 | 9 | 3 | |
| | Percent Distrib. | | % | 32.4 | 8.8 | 23.5 | 26.5 | 8.8 | |
| 61. | Comp. Op/Character | 2.21.7 | | | | | | | |
| | Range | | | 1-10 | 10-100 | 100-1k | 1k-10k | 10k-100k | |
| | No. in Range | | | 0 | 8 | 18 | 11 | 1 | |
| | Percent Distrib. | | % | 0 | 21.1 | 47.4 | 28.9 | 2.6 | |
| 62. | Output Ch./Input Ch. | 2.21.3 | | | | | | | |
| | Range | | | 0-.01 | .01-.1 | .1-1 | 1-10 | 10-100 | |
| | No. in Range | | | 2 | 0 | 7 | 24 | 5 | |
| | Percent Distrib. | | % | 5.3 | 0 | 18.4 | 63.1 | 13.2 | |
| 62a. | I/O Ch./Obj. Instr. | | | | | | | | |
| | Range | | | 1-10 | 10-100 | 100-1k | 1k-10k | 10k-100k | |
| | No. in Range | | | 1 | 8 | 15 | 12 | 2 | |
| | Percent Distrib. | | % | 2.6 | 21.1 | 39.5 | 31.6 | 5.3 | |
| 62b. | Obj. Instr/Op/Char | | | | | | | | |
| | Range | | | 4-16 | 16-64 | 64-256 | 256-1k | 1k-4k | 4k-16k |
| | No. in Range | | | 6 | 8 | 10 | 10 | 3 | 1 |
| | Percent Distrib. | | % | 15.8 | 21.1 | 26.3 | 26.3 | 7.9 | 2.6 |
| 64. | Instr. Maint./Prog. | | | | | | | | |
| | Range | | k | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | |
| | No. in Range | | | 25 | 5 | 1 | 1 | 1 | |
| | Percent Distrib. | | % | 75.8 | 15.2 | 3.0 | 3.0 | 3.0 | |
| 66. | Instr. Maint./Comp. Hr. | | | | | | | | |
| | Range | | k | 0-5 | 5-10 | 10-15 | 15-20 | 20-25 | |
| | No. in Range | | | 22 | 7 | 0 | 0 | 1 | |
| | Percent Distrib. | | % | 73.3 | 23.3 | 0 | 0 | 3.3 | |

## TABLE II.2.21.3 WORKLOAD CHARACTERISTICS AT TWO UNIVERSITIES—NOTES

The first seven columns of this table present the results of two separate analyses of computer operations carried out at two different universities. The University of Washington study (HuntE71) describes jobs run on a CDC 6400 computer in about 1970. The University of Michigan operation used an IBM 7090 computer (with an IBM 1410 input/output processor), and the data was collected in 1964 (RosiR65,WaltE67). The last column presents more or less comparable data from the Army/Air Force management information systems. Averages and medians represent all 38 Army and Air Force systems, and are taken from Table II.2.21.1.

**University of Washington.** The source paper provided data on two types of jobs, and on both types combined. The types were described as "jobs associated with research projects and jobs associated with instruction."

**University of Michigan.** The two referenced papers present very detailed analyses of the same data. A total of 10,651 jobs were described, and were broken down in nine different ways. Three different classes of user were included. The "uncontrolled" users included faculty members doing unsponsored research, students working on doctoral theses, and people doing sponsored research. I assume this "uncontrolled" category is comparable to the University of Washington's "research" category, and thus put it in the column labelled research. A second category includes all users solving assigned problems from graduate and undergraduate programming courses and from other university courses. I include this category in the column labelled "instruction". Finally, a third category of users are the staff members of the computer center. Only about 2.5% of the total number of jobs were carried out by the staff, and the remaining jobs were about equally divided between research and instruction.

The program runs of each of these three categories of users are further subdivided into three parts—making the total nine subdivisions referred to above. These three categories are unsuccessful jobs (jobs for which post-mortem dumps, input/output errors, or other errors occur); successful jobs (jobs which are not unsuccessful); and no execution jobs (jobs containing errors which make loading impossible, or jobs for which execution was not requested). About 42% of all jobs were successfully executed, 30% were unsuccessful, and 28% were not executed. As a percent of total *time*, rather than total number of jobs, the successful jobs represented 41%, the unsuccessful ones 49%, and the non-executed jobs 10% of total time.

Although the unsuccessful and non-executed jobs thus represent a very substantial portion of the total load on the university computer center, I have not included them in the table—I include successful runs only. Statistics on the unsuccessful jobs are not too different from the successful ones, and I presume the success run data is most likely comparable to the Army/Air Force data in the last column.

Let me now describe the data on each of the lines of the table in turn.

1. This line shows the number of jobs run in each category. Note that a "job" in the university is an individual program run for some user. In the Army/Air Force environment, there was no identifiable "job". Each of those 38 systems performed a function of some kind, and the functions were carried out by a variety of programs written by many individuals and each presumably corresponding to one 'job". (See discussion in connection with Program Length on line 28 below.)

**Inputs Per Job.** 2-6. The only inputs mentioned for the university systems were punched cards. The average number of cards read per job is shown on line 2, the standard deviation from that average appears on line 3, and the median, or 50th percentile, on line 4. Lines 5 and 6 show the 10th and 90th percentiles, which were presented only for the University of Michigan data.

7. The average number of input characters per job, in thousands of bytes, was computed assuming that each card contained a full 80 characters. It thus substantially overstates the number of characters per job by some amount, probably a factor of about 2. The Army/Air Force data, on the other hand, was presented directly in characters. (Also note that it represents characters per month where the other columns show characters per job—a comment which applies to lines 20 and 33 below, as well as to line 7.)

**Outputs Per Job.** 8-12. The average number of lines printed per job is shown on line 8, and the standard deviations, medians, and percentiles, on lines 9 through 12.

13. The average number of characters printed per job is computed from line 8 under the assumption that each line printed contains a full 132 characters. Once again, this assumption results in an overstatement.

14-19. A portion of the University of Michigan output appeared in the form of punched cards, and the average number of cards punched appears in line 14 with associated data on lines 15 through 18. The average number of characters per job, on line 19, was computed once again assuming that each output card contains a full 80 characters.

20. Total output characters is the sum of lines 13 and 19. For the Army/Air Force systems, the total output characters are the average of all systems, given in characters per month. Generally speaking, though most of the output is printed, some of it recorded on magnetic tape and some is punched on cards.

**Processing Per Job.** 21-25. For the University of Washington, total time given is that required by the central processor only. A roughly equal amount of time per job is required for a peripheral processor, but I did not include that time because I had no measure of the peripheral processor's speed. For the University of Michigan system, the total time is the sum of processing time (spent for a job in system monitor activities), loading and translation time, and execution time (spent with the system under the control of user-supplied programs). (The reference paper breaks total time down into each of these categories for each of the nine job breakdowns.)

26-27. The CPU speed is the reciprocal of the Adams addition time, representing the maximum number of additions per second carried out by the CDC 6400 and the IBM 7090. Average CPU operation per job, on line 27, is the product of lines 21 and 26, divided by one thousand to convert the result to millions of operations.

28-32. For the University of Washington data, program length was not given. Instead, the amount of central memory used, as a percentage of 32 kwords was given and I assumed that corresponded to program length. The University of Michigan data, on the other hand, included the category "program length". For both Universities, the numbers are given in thousands of words of storage; and we must keep in mind that the CDC 6400 has 60-bit words while the IBM 7090 has only 36-bit words. For the Army/Air Force system, program length is given in number of object instructions, and once again is not directly comparable. The standard deviation, median, and percentiles for program length are given on lines 29 to 32.

33. Total input/output characters is the sum of input characters on line 7 and output characters on line 20.

**Ratios.** 34. For the first seven columns, this line is the ratio of line 20 to line 7. For the Army/Air Force systems in the last column, the entry is the average of ratios for the 38 systems in the study.

35. For the first seven columns, this line is the ratio of line 27 to line 33 (the result being multiplied by one thousand to adjust for the difference in units). For the last column, the entry is the average figure for the 38 Army/Air Force systems.

36. For the first seven columns, this line is the ratio of line 33 to line 28. For the last column, it is the average ratio for the 38 Army/Air Force systems.

**TABLE II.2.21.3 WORKLOAD CHARACTERISTICS AT TWO UNIVERSITIES, COMPARED WITH ARMY/AIR FORCE MIS**

| | | Units | Univ. of Wash. | | | Univ. of Mich. (Successful Runs Only) | | | | Army/AF MIS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Res. | Instr. | Total | Res. | Instr. | Staff | Total | (per mo.) |
| 1. | No. of Jobs Run | | 527 | 1061 | 1588 | 2014 | 2311 | 111 | 4436 | |
| | Inputs Per Job | | | | | | | | | |
| 2. | Cards Read—Av. | | 490 | 95 | 224 | 307 | 97 | 496 | 203 | |
| 3. | Std. Deviation | | | | 495 | 490 | 142 | 924 | 393 | |
| 4. | Median | | | | | 151 | 71 | 198 | 89 | |
| 5. | Percentiles—10th | | | | | 38 | 33 | 3 | 35 | |
| 6. | 90th | | | | | 708 | 62 | * | 435 | |
| 7. | Av. Number of Char. | kBy | 39.20 | 7.60 | 17.92 | 24.56 | 7.76 | 39.68 | 16.24 | 39300 |
| | Outputs Per Job | | | | | | | | | |
| 8. | Lines Printed—Av. | | 1430 | 442 | 760 | 997 | 388 | 1190 | 687 | |
| 9. | Std. Deviation | | | | 1260 | 1971 | 642 | 2380 | 1493 | |
| 10. | Median | | | | | 476 | 239 | 486 | 289 | |
| 11. | Percentiles—10th | | | | | 99 | 115 | 124 | 105 | |
| 12. | 90th | | | | | + | 652 | + | 1525 | |
| 13. | Av. Number of Char. | kBy | 188.8 | 58.3 | 100.3 | 131.6 | 51.2 | 157.1 | 90.7 | |
| 14. | Cards Punched—Av. | | | | | 124 | 33 | 78 | 95 | |
| 15. | Std. Deviation | | | | | 272 | 15 | 14 | 231 | |
| 16. | Median | | | | | 39 | 12 | 14 | 30 | |
| 17. | Percentiles—10th | | | | | 11 | 1 | 3 | 2 | |
| 18. | 90th | | | | | 160 | 71 | 90 | 125 | |
| 19. | Av. Number of Char. | kBy | | | | 9.9 | 2.6 | 6.2 | 7.6 | |
| 20. | Total Output Char. | kBy | 188.8 | 58.3 | 100.3 | 141.5 | 53.8 | 163.3 | 98.3 | 96600 |
| | Processing Per Job | | | | | | | | | |
| 21. | Total CPU Time—Av. | Sec. | 26.0 | 3.8 | 11.0 | 100.8 | 24.6 | 196.2 | 64.2 | |
| 22. | Std. Deviation | Sec. | | | 41 | 243.6 | 37.8 | 763.8 | 210.6 | |
| 23. | Median | Sec. | | | | 35.4 | 18.0 | 40.2 | 21.0 | |
| 24. | Percentiles—10th | | | | | 13.2 | 12.6 | 17.4 | 13.2 | |
| 25. | 90th | | | | | 181.2 | 33.6 | 418.8 | 114.6 | |
| 26. | CPU Speed | Kops | 909 | 909 | 909 | 227 | 227 | 227 | 227 | |
| 27. | Av. CPU Operations | Mops | 23.63 | 3.45 | 10.00 | 22.88 | 5.58 | 173.2 | 47.8 | |
| 28. | Program Length—Av. | kwds | 21.1 | 16.3 | 17.9 | 13.39 | 9.18 | 11.85 | 11.16 | 97.7 |
| 29. | Std. Deviation | kwds | | | 8.1 | 7.03 | 3.79 | 6.73 | 5.74 | |
| 30. | Median | kwds | | | | 10.48 | 8.00 | 8.10 | 8.64 | 36.5 |
| 31. | Percentiles—10th | | | | | 7.53 | 6.78 | 7.10 | 6.87 | |
| 32. | 90th | | | | | ++ | 11.27 | 20.50 | 19.70 | |
| 33. | Total I/O Char. | kBy | 228.0 | 65.9 | 118.2 | 166.1 | 61.6 | 203.0 | 114.5 | 135900 |
| | Ratios | | | | | | | | | |
| 34. | Output By./Input By. | | 4.82 | 7.67 | 5.60 | 5.76 | 6.93 | 4.11 | 6.05 | 5.25 |
| 35. | Operations Per Byte | | 103.6 | 52.3 | 84.6 | 137.7 | 90.6 | 853.2 | 417.5 | 1480 |
| 36. | I/O Char./Instruction | | 10.81 | 4.04 | 6.60 | 12.40 | 6.71 | 17.13 | 10.26 | 2008 |

*Unknown, but over 1000. +Unknown, but over 2000. ++Unknown, but over 25,000

## TABLE II.2.21.4 THE USER WORKLOAD FOR THE ATLAS COMPUTER I—NOTES

The data in this table describes the principal compute-time and input-output specifications for jobs processed on the ATLAS computer at the University of Manchester in 1966 (MorrD67). The university shared use of the computer, on about a half and half basis, with the I.C.T. Computing Service Division, and during two university terms handled roughly 2000 to 2500 jobs per week. This table and the following table represent the results of an analysis of all university jobs run during two terms.

In this table the jobs were broken down into five different categories according to the amount of computer time each job used. The range of computer time is given in the first column, and the average of the jobs in that range is given in the second. The third column shows total I/O time, in seconds, which is apparently the sum of drum transfer time, paper tape input and output time, punched card input and output time, and printer output time. (Punched card I/O and paper tape output were negligible, as can be seen in lines 40-49 of the next table.) The CPU to I/O ratio in column 4 is the ratio of column 2 to column 3.

The ATLAS system is a multiprogramming system which handles three simultaneous jobs. The programs for these jobs are stored on a magnetic drum, and the fifth column shows the drum transfer time for each class of jobs. (Drum time is not defined, but presumably includes access as well as transfer time.) The principal form of input is via punched paper tape, and input data and programs are read from that medium onto magnetic tape, where they await their turn to be processed. Column 6 shows the number of tape blocks read as input for each class of job, and column 7 shows the average number of characters per job, in thousands, assuming an average of 2000 characters per block. (The block size ranges from 500 to 4000 characters.) The principal output is printed, and the average number of lines printed and average number of characters printed per job (assuming arbitrarily an average of 80 characters per line) appear next. Line 10 shows the sum of paper tape input and printed output characters.

The source paper states that, on the average, the ATLAS computer requires three microseconds per instruction. The eleventh column shows the total number of operations carried out for each job, in thousands, based on the average compute time in column 2 and the average speed of three microseconds per instruction. The last column is then the quotient of columns 11 and 10.

## TABLE II.2.21.5 THE USER WORKLOAD FOR THE ATLAS COMPUTER II—NOTES

This table provides some additional detail on the workload at the University of Manchester. See the notes on the previous table for background information.

The workload varies from term to term and its variability is affected by weekend work. Generally speaking, during the Michaelmas term there are a number of very short development jobs from students and staff who are just learning about computers; while during the summer vacation there are a higher proportion of very long production runs from experienced users. There is also a substantial difference between usage on week days and weekends—short jobs get priority during the week, and long jobs are saved for the weekend. (The summer vacation data does not bear out this assertion, however.)

**Job Distributions.** 1-5. For each of the five categories of job size (measured in CPU time), and for each of the four times of year, these entries show what percent of all jobs lie in each category.

1a-5a. Where the first five lines show the percentage of *jobs* in each category, this group of lines shows the percentage of *compute-time* in each category. The most notable characteristic of the workload is the enormous variation in the amount of compute-time occupied by very long jobs—from zero on week days during term, to over 55% on week days during vacation. At the other extreme, note that the two small job categories, which in Michaelmas term represent about 60% of the total number of jobs, require only about 4% of CPU time.

6-8. From the job distributions of lines 1 through 5, and from the average CPU time in each category as given in the previous table, one can compute the average CPU time per job. This result is given on line 6, and the corresponding figures for I/O per job (computed from average I/O for each of the five categories of job, also from the previous table) is given on line 7. Line 8 is the ratio of line 6 to line 7. (The calculated CPU time per job on line 6 presumably should be identical to the figures on line 11 below, which appeared in the cited paper. The differences are big enough that it is difficult to explain them.)

**System Time in Various Categories.** The paper subdivides total system time into three principal parts, and implies a fourth. The four are: CPU time, line 11 (including some overlap I/O time); idle time, line 12; supervisor time, line 18; and interrupt time, line 24. (Interrupt time was not explicitly given, but was said to be "less than 5%". My estimate of interrupt time was designed to make CPU time per job be the same percentage of total time as was given in the paper.)

### TABLE II.2.21.4 THE USER WORKLOAD FOR THE ATLAS COMPUTER UNIVERSITY OF MANCHESTER, 1966. I

| Compute Time Range (secs.) | Compute Time Mean (secs.) | I/O Time (secs.) | CPU to I/O Ratio | Drum Time (secs.) | Paper Tape Input (Blocks) | Paper Tape Input (kchars.) | Printed Output (Lines) | Printed Output (kchars.) | Total I/O (kchars.) | Total Operations (000) | Operations Per Char. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-1 | 0.5 | 21.8 | .023 | 1.5 | 1.4 | 2.8 | 45 | 3.6 | 6.4 | 167 | 26.0 |
| 1-8 | 3.3 | 58.3 | .057 | 3.7 | 3.5 | 7.0 | 160 | 12.8 | 19.8 | 1100 | 55.6 |
| 8-120 | 32. | 118.0 | .271 | 13.5 | 6. | 12. | 500 | 40.0 | 52. | 10.67k | 205.1 |
| 120-960 | 310. | 148.6 | 2.09 | 50. | 7. | 14. | 720 | 57.6 | 72. | 103.3k | 1435. |
| over 960 | 1200. | 114.5 | 10.48 | 40. | 4.5 | 9.0 | 700 | 56.0 | 65. | 400k | 6153. |

## TABLE II.2.21.5 THE USER WORKLOAD FOR THE ATLAS COMPUTER UNIVERSITY OF MANCHESTER, 1966. II

| | | Units | Summer Vacation Including Weekends | Summer Vacation Excluding Weekends | Michaelmas Term Including Weekends | Michaelmas Term Excluding Weekends |
|---|---|---|---|---|---|---|
| | Percent of All Jobs Having CPU Time: | | | | | |
| 1. | 0-1 Seconds | % | 10.6 | 4.7 | 23.5 | 24.5 |
| 2. | 1-8 Seconds | % | 37.3 | 15.6 | 35.9 | 37.8 |
| 3. | 8-120 Seconds | % | 39.4 | 43.1 | 32.5 | 30.9 |
| 4. | 120-960 Seconds | % | 11.1 | 23.4 | 7.6 | 6.8 |
| 5. | Over 960 Seconds | % | 1.6 | 13.2 | 0.5 | 0 |
| | Percent of All CPU Time for Jobs: | | | | | |
| 1a. | 0-1 Seconds | % | 0.1 | 0.006 | 0.3 | 0.4 |
| 2a. | 1-8 Seconds | % | 1.9 | 0.2 | 2.8 | 3.8 |
| 3a. | 8-120 Seconds | % | 19.5 | 5.7 | 25.3 | 30.7 |
| 4a. | 120-960 Seconds | % | 48.5 | 38.0 | 59.0 | 65.1 |
| 5a. | Over 960 Seconds | % | 30.0 | 56.1 | 12.5 | 0 |
| | Resulting Computed: | | | | | |
| 6. | CPU Time/Job | sec. | 67.5 | 245.2 | 41.3 | 32.3 |
| 7. | I/O Time/Job | sec. | 88.8 | 110.9 | 76.3 | 73.9 |
| 8. | CPU-I/O Ratio (R) | | 0.76 | 2.21 | 0.54 | 0.44 |
| | System Time Distribution Reported: | | | | | |
| 9. | Compute Time/Job | sec. | 63.6 | 273.9 | 41.7 | 33.4 |
| 10. | Compile Time/Job | sec. | 5.2 | 6.8 | 3.9 | 3.7 |
| 11. | CPU Time/Job | sec. | 68.8 | 280.7 | 45.6 | 37.1 |
| 12. | Idle Time | sec. | 25.9 | 40.1 | 19.1 | 18.4 |
| 13. | Due to Drum Transfers | sec. | 10.9 | 20.6 | 7.5 | 7.1 |
| 14. | Due to Restarts | sec. | 5.7 | 5.9 | 3.4 | 3.3 |
| 15. | Due to Interjob Gaps | sec. | 2.8 | 2.8 | 4.2 | 4.3 |
| 16. | Enforced Idling | sec. | 5.6 | 9.6 | 3.1 | 3.0 |
| 17. | Other Idling | sec. | 0.9 | 1.2 | 0.9 | 0.7 |
| 18. | Supervisor Time | sec. | 13.0 | 20.6 | 9.7 | 9.3 |
| 19. | Due to User Drum Transfers | sec. | 4.7 | 8.8 | 3.2 | 3.0 |
| 20. | Due to Input | sec. | 1.3 | 1.8 | 1.2 | 1.1 |
| 21. | Due to Output | sec. | 2.1 | 2.9 | 1.7 | 1.7 |
| 22. | Due to System Drum Transfers | sec. | 1.2 | 2.6 | 1.3 | 1.3 |
| 23. | Other | sec. | 3.7 | 4.5 | 2.3 | 2.2 |
| 24. | Estimated Interrupt Time | sec. | 3.3 | 1.8 | 2.6 | 3.0 |
| 25. | Av. Total Time Per Job | sec. | 111.0 | 343.2 | 77.0 | 67.8 |
| | Percentage Distribution: | | | | | |
| 26. | Compute Time | % | 57.3 | 79.8 | 54.2 | 49.3 |
| 27. | Compile Time | % | 4.7 | 2.0 | 5.1 | 5.4 |
| 28. | CPU Time | % | 62.0 | 81.8 | 59.2 | 54.7 |
| 29. | Idle Time | % | 23.3 | 11.7 | 24.8 | 27.1 |
| 30. | Due to Drum Transfers | % | 9.8 | 6.0 | 9.7 | 10.5 |
| 31. | Due to Restarts | % | 5.1 | 1.7 | 4.4 | 4.9 |
| 32. | Due to Interjob Gaps | % | 2.5 | 0.8 | 5.5 | 6.3 |
| 33. | Enforced Idling | % | 5.0 | 2.8 | 4.0 | 4.4 |
| 34. | Supervisor Time | % | 11.7 | 6.0 | 12.6 | 13.7 |
| 35. | Due to User Drum Transfers | % | 4.2 | 2.6 | 4.2 | 4.4 |
| 36. | Due to Input | % | 1.2 | 0.5 | 1.6 | 1.6 |
| 37. | Due to Output | % | 1.9 | 0.8 | 2.2 | 2.5 |
| 38. | Due to System Drum Transfers | % | 1.1 | 0.8 | 1.7 | 1.9 |
| 39. | Other | % | 3.3 | 1.3 | 3.0 | 3.2 |
| | Input-Output | | | | | |
| 40. | Paper Tape Input–Blocks | | 4.2 | 5.7 | 3.0 | 3.6 |
| 41. | Characters | kch. | 8.4 | 11.4 | 6.0 | 7.2 |
| 42. | Card Input–Cards | | 1 | 6 | 3 | 2 |
| 43. | Characters | kch. | .08 | .36 | .24 | .16 |
| 44. | Printed Output–Lines | | 373 | 527 | 286 | 276 |
| 45. | Characters | kch. | 29.8 | 42.2 | 22.9 | 22.1 |
| 46. | Paper Tape Output–Blocks | | 0.3 | 0.3 | 0.5 | 0.5 |
| 47. | Characters | kch. | .6 | .6 | 1.0 | 1.0 |
| 48. | Card Output–Cards | | 2 | 2 | 1 | 1 |
| 49. | Characters | kch. | .16 | .16 | .08 | .08 |
| 50. | Total I/O Characters | kch. | 39.0 | 54.7 | 30.2 | 30.5 |

9-11. Total CPU time was divided into instructions obeyed during compiling and instructions obeyed during execution. The two subdivisions are given on lines 9 and 10, and their sum appears on line 11.

12-17. Idle time is time the CPU is waiting for input/output transfers which were not eliminated by multiprogramming. Total idle time is given on line 12, and it is broken down into five subcategories. Drum transfers (line 13) are required when a job needs data or program not in internal storage, and when some less-used data in internal memory is to be transfered to the drum. An average drum transfer takes twenty milliseconds, six milliseconds of which are in the supervisor (see below) while the other 14 milliseconds are used up waiting for the transfer to take place. Restarts occur after machine faults, and between operating sessions. Restart lost time occurs due to operator delays, and because of fault printouts and the necessity to reposition tapes. Interjob gaps are idle periods caused by the fact that no jobs are ready to be executed. When such a gap is longer than 30 seconds, it was assumed to have been caused by operating problems—by the fact that operations had not kept the system supplied with input data and programs from the backlog, or that operators had failed to mount magnetic tapes required by jobs in the execute phase. These long gaps were categorized as "enforced idling."

18-23. The average time spent by the processor in supervisory routines is shown on line 18, and that time is broken down into various parts on lines 19 to 23. The first item shown is an estimate of the time spent preparing drum transfers for the user's program; the fourth item is a similar estimate of time required for "system housekeeping"—a term not explained in the paper. The length of time spent handling input and output buffering is also shown. The "other" categories includes program for controlling magnetic tape, for starting and ending jobs, for storage allocation, etc.

24. The interrupt time shown is estimated, by me, to make the CPU percentages on line 28 below equal to corresonding numbers given in the referenced paper.

25. The average total time per job is the sum of lines 11, 12, 18, and 24.

26-39. These percentages are the ratios of various items on lines 9 through 24 to total time per job on line 25.

**Input-Output Data.** 40-50. Average volume of input and output data per job in various categories is shown on these lines. The paper tape input, in blocks, is shown on line 40. A paper tape block ranges in size from 500 to 4000 characters, and I arbitrarily used a 2000-character average in computing line 41. The average card input and output is shown on lines 42 and 48, and the resulting input and output characters on lines 43 and 49 were computed assuming a card contained a full 80 characters. The average printed output, in lines, is shown on line 44. No data appeared in the paper regarding the average number of characters per line, and I assumed that the average was 80 characters printed per line, in computing line 45. Total I/O characters, on line 50, is the sum of lines 40, 42, 44, 46, and 48.

## TABLE II.2.21.6 PROGRAM LOCALITY—NOTES

A paper by Gibson (GibsD67) describes the results of experiments IBM carried out in designing a cache memory—a small, high-speed memory inserted between a processor and its internal memory with the object of increasing processor speed by reducing average memory access time. Gibson pointed out that his results are applicable to any hierarchy of memories, and that they provide empirical evidence of an important property of the sequential procedures known as programs.

The data in this table is the result of an analysis of the addressing pattern of 20 customer programs running on IBM 7000 series computers. Each of the programs was run until three million address references had been made, and the three million were divided into 15 equal parts of 200,000 instructions each—the 20 programs thus providing 300 total different samples each of that size. The ratios shown are average figures for this sample.

The paper envisions an experiment in which a processor receives instructions and data from a local store of limited capacity, which in turn obtains instructions as needed from a backing store. If the processor requests information not contained in the local store, the local store acquires the data by transfer from the backing store. Whenever such a transfer is made, a block of information, including that required by the processor and also other information in adjacent storage locations, is transferred to the local store. (Each such transfer displaces an equivalent block of information in the local store, of course, and must be accompanied by a transfer of the displaced block from the local store to the backing store.)

The table shows the ratio of bits transferred from the backing store to the local store to bits transferred from local store to processor, for different local store sizes (columns) and different block sizes (rows). For example, given a block size of 128 bytes and a local store capacity of 1k bytes, the table predicts that 3.1 times as many bits must be read from the backing store as are actually needed by the processor. On the other hand, if the local store capacity is doubled to 2k bytes, the average transfer rate of data from the backing store is only .45 of the rate bits are required by the processor.

## TABLE 2.21.7 SEQUENTIAL MEMORY REFERENCES BY THREE PROGRAMS—NOTES

This data shows the average length of sequential memory references for three different programs (SissS68). Operation of the programs, written for the IBM 7094, was simulated, and for each program a magnetic tape was prepared listing the memory addresses accessed and specifying whether the access was for instructions or for data. If operand addresses were indexed, the addresses were recorded after indexing took place. One level of indirect addressing was handled by the program. However, it was not possible to analyze the sequence of commands used to execute input/output operations.

A subsequent analysis program read the tape, keeping track of "runs—a run being the number of addresses in a sequence where each address is one greater than the previous address." The program kept track of runs for instruction words, data words, and the mixture of instructions and data. Both average run length and the standard deviation from the mean were computed and are reported in columns 2-7 of the table. Column eight shows how many memory references were included in each of the three sample programs.

Data for three different programs are shown as the three lines on the table. The first program used an iterative procedure to solve a differential equation. The second was a data processing job, in which a personnel file on punched cards is read, sorted by employee number, rearranged, and printed out. The last test program simulated the instructions of a non-existent machine.

### TABLE 2.21.8 RELATIVE PROPORTION OF INSTRUCTION TYPES EXECUTED—NOTES

This table collects together some published figures on the percentage of executed instructions in each of a variety of categories. Such percentages are generally called "Gibson Mixes", though the source of the name is lost in the mists of the past—no one has been able to find a paper by Gibson describing instruction mixes. (Two of the mixes—Smith's and Newel's—were actually referred to in the referenced papers as "Gibson Mixes", though without citation as to source. Note that they differ from one another by a substantial margin.)

As one might expect, the various referenced papers did not employ a uniform categorization scheme for computer instructions. The table therefore, to some extent, represents my subjective interpretation of the authors' classifications, in some instances. Note that I have identified six main classes of instructions: data transfer; arithmetic; logical; branch; index/increment; and miscellaneous. Most sources included categories that would fit under all these headings. I should mention that the index/increment classification includes Compare commands, and that this whole category is closely associated with the branching commands—generally index/increment/compare sets some sort of flag which can later be tested by a branch.

In each column, the numbers not in parenthesis represent the main classifications and add to 100%. The numbers in parenthesis are either subtotals (for example, in Smith's Gibson Mix, the load, store, and move commands together represent 19.3% of the total) or else are redundant, if interesting, pieces of data (for example, Smith's Gibson Mix stated that 4.2% of instructions executed were multiplication commands, and 2.5% division commands. It also indicated that, of the 6.7% multiplication and division commands, 0.6% were fixed-point operation and 6.1% floating-point. Multiply/divide is thus broken down in two different ways, and one breakdown is redundant.)

Note that the data is intended to describe what proportion of all commands *executed* lie in each category. (Another tabulation might show the proportion of each type of command appearing in program listings.) The various authors tend not to be concise about the source of their data. Of the sources given, only Solomon indicated where his figures came from—and they arose very simply from the analysis of three specific programs.

### TABLE 2.21.9 INSTRUCTIONS HAVING VARIOUS TYPES OF MEMORY REFERENCE—NOTES

This data is from a paper (Freil68) reporting on the results of the application of a trace program to a number of IBM 7044 programs. Six classes of program were traced, and each of the first six numerical columns refers to one class of program. The last column is a weighted average of the other six.

The percentages of different instruction types shown are very dependent on computer instruction characteristics. The author points out that the IBM 7044 contains only two arithmetic and three index registers, while the IBM 360 has 16 general purpose registers. He reran some of the IBM 7044 programs on the 360 using FORTRAN G and COBOL F. The result was an increase in the proportion of register-type instructions by 40% to 340%, with a corresponding decrease in other types.

### TABLE II.2.21.6 PROGRAM LOCALITY AS EVIDENCED BY RATIO OF BITS TRANSFERRED TO LOCAL STORE TO BITS TRANSFERRED TO PROCESSOR

| Size of Block Transferred From Backing Store To Local Store (bytes) | Size of Local Store (bytes) 32 | 64 | 128 | 256 | 512 | 1k | 2k | 4k | 8k |
|---|---|---|---|---|---|---|---|---|---|
| 16 | 6.5 | 1.9 | 1.4 | 1.0 | 0.70 | 0.17 | 0.10 | .045 | .033 |
| 32 | | 12.1 | 3.0 | 2.0 | 1.2 | 0.37 | 0.16 | .072 | .039 |
| 64 | | | 23.2 | 4.5 | 2.5 | 1.2 | 0.27 | .14 | .043 |
| 128 | | | | 44.6 | 7.0 | 3.1 | 0.45 | .22 | .073 |
| 256 | | | | | 84.1 | 11.3 | 2.50 | .35 | .09 |
| 512 | | | | | | 157. | 6.9 | .73 | .20 |
| 1k | | | | | | | 24.6 | 1.9 | .42 |
| 2k | | | | | | | | 7.9 | 1.2 |
| 4k | | | | | | | | | 3.7 |

## TABLE II.2.22.1 TIME-SHARING USER STATISTICS—NOTES

This table summarizes the reported results of three studies of time-sharing systems. The columns labeled "Joss" describe a system by that name designed by and operated at the RAND Corporation (BryaG67). The column labeled "MAC" describes a project of that name at the Massachusetts Institute of Technology (ScheA67). And the five columns labeled "Telco Study" summarize a report from the Bell Telephone Laboratories emphasizing the communications aspects of three anonymous time-sharing systems—the first two using a computer system from one manufacturer, and the third that of another (JackP69). The latter study was of special interest because one of the systems (B) was very heavily loaded, so that the computer introduced serious delays in normal operation.

The terms used in the table are described and defined by Figure 2.22.1. Generally speaking, the terms I use are different from those used in the three papers. For example, I define "think time" as the time between the last character output from the computer and the first input by the terminal user. Scherr defines "think time" as the interval between the CPU's last action on a request and the terminal user's last input character. Let me emphasize again, however, that the data in the table consistently uses my definitions from Figure 2.22.1, and thus in general required some rearrangement of the data presented in the various papers.

Regarding the Telco data, the column labelled "average" is in every case the average of the corresponding numbers for the three individual systems, and the column labeled "S.D." is the standard deviation from that average.

**General Characteristics.** 1-5. These entries describe the applications in general terms. The Joss system used a DEC PDP-6, project MAC used an IBM 7094. System C primarily processed business applications, the others scientific applications. The number of simultaneous users (line 5) varies continuously, and the average numbers were not given in the papers—the numbers shown are my estimates from what data is given.

**Timing Data.** 6-7. The capacity of the communication line connecting terminals to the computer is shown on line 6, and the resulting transmittal time for a single character is shown on line 7.

8. The Holding Time is the number of minutes between the time a user signs on to use the system until he completes a session.

9-12. An Interaction is an input by the terminal user and a response by the computer. The average Interaction time, on line 10, is found by dividing line 8 by line 9 and converting the result to seconds. The user and computer components of an Interaction time are shown on lines 11 and 12.

**User Time Breakdown.** 13-20. These lines provide a breakdown and analysis of the user interaction time of line 11.

13-14. Think time is the interval between the final receipt of a character from the computer at the terminal and the first input of data from the keyboard. Input time is the interval during which characters are transmitted from the keyboard. The user interaction time is the sum of think time and input time.

15-19a. The number of characters input during input time is shown on line 15. The total character transmittal time, on line 16, is the product of lines 15 and 7. Characters are generally transmitted, by the user or by the computer, in "bursts" separated by time intervals called "interburst times". A burst consists of two or more characters transmitted with less than half a character time between them. The average time between bursts is shown on line 17, the average number of bursts per input time on line 18, and the average number of characters per burst on line 19. The input time on line 14 is the sum of character time (line 16), and total interburst time, found by multiplying line 17 by one less than line 18. The number of characters input on line 15, is the product of lines 18 and 19. (These relationships don't hold for the column labeled "average", because that column is the average of the entries in columns A, B, and C.) The average input data rate on line 19a is the average traffic volume from the terminal to the computer in characters per second. It is found by dividing line 15, the number of characters per user interaction, by line 10, the total interaction time.

20. Think plus total interburst time is the difference between lines 11 and 16.

**Computer Time Breakdown.** 21-32. These entries provide information on the computer interaction time of line 12.

21. Idle time is the time between transmittal of the last input character from user's keyboard until receipt of the first output character from the computer. Output time is the interval during which characters are transmitted from the computer to the terminal. The sum of idle and output times is equal to the computer interaction time on line 12.

23-27a. The number of characters output during a computer interaction is shown on line 23. The total character time, on line 24, is the product of lines 23 and 7. The average interburst time for characters from the computer is shown on line 25, the average number of the bursts on line 26, and the average number of characters per burst on line 27. Line 27a is the average data rate on the channel from the computer to the terminal, and is found by dividing line 23 by line 10.

28. Idle plus total interburst time is the difference between lines 12 and 24.

29-32. Processor time is the amount of time the processor actually spends on the user's problem during a computer interaction. Generally speaking, it overlaps idle time and output time. Processor speed is Knight's commercial speed, in thousands of operations per second. Operations per interaction is the product of lines 29 and 30; and line 32 is the quotient of line 31 and the sum of lines 15 and 23.

## TABLE 2.22.2 ANALYSIS OF HOW OPERATOR TIME IS SPENT—NOTES

The data in this table comes from a paper (GaliW69) reporting on the activities of operators in Univac installations. Twenty-five installations of Univac 1108's and 494's were included in the analysis, which was conducted in part by questionaire and in part by observing and recording operations during visits to the centers. Over 35,000 individual pieces of data were recorded during visits to the sites, and formed the basis for the statistics shown here. The data is said to apply to a "typical operator", although the paper acknowledges that there is considerable operator specialization in these large sites, with console operators, tape

## TABLE II.2.22.1 TIME-SHARING USER STATISTICS

| Line | Item | Units | Joss | | MAC | Telco Study | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Aver. | Median | | Syst. A | Syst. B | Syst. C | Av. | S.D. |
| | **Gen. Characteristics** | | | | | | | | | |
| 1. | Computer | | PDP-6 | | 7094 | Mfg.X | Mfg.X | Mfg.Y | | |
| 2. | Primary Application | | Sci | | Sci | Sci | Sci | Bus | | |
| 3. | Program Size—Mean | kwords | .65 | | 6.3 | | | | | |
| 4. | Median | kwords | .20 | | 1.5 | | | | | |
| 5. | No.—Simultaneous Users | | 25? | | 30? | | | | | |
| | **Timing Data** | | | | | | | | | |
| 6. | Line Speed | cps | 15 | | | 10 | 10 | 15 | 11.7 | |
| 7. | Character Time | ms | 66.7 | | | 100 | 100 | 66.7 | 88.9 | |
| 8. | Holding Time | min | 46 | 22 | | 17.2 | 34.0 | 21 | 24.1 | |
| 9. | Interactions Per Session | | 82 | | | 33.5 | 27.6 | 64.3 | 41.0 | 18.5 |
| 10. | Total Interaction Time | sec | 34 | 11 | 58.2 | 30.8 | 73.9 | 19.6 | 41.4 | |
| 11. | User Interaction | sec | 24 | 9.3 | 35.8 | 18.8 | 27.1 | 11.2 | 19.0 | |
| 12. | Computer Interaction | sec | 10 | 1.7 | 22.4 | 11.9 | 46.7 | 8.4 | 22.3 | |
| | User Time Breakdown | | | | | | | | | |
| 13. | Think Time | sec | | | 24.3 | | | | 4.3 | 3.4 |
| 14. | Input Time | sec | | | 11.5 | | | | 14.7 | |
| 15. | Characters Input | | 13 | 8 | | 9.0 | 9.8 | 13.4 | 10.7 | |
| 16. | Tot. Char. Time | sec | | | | 0.90 | 0.98 | 0.89 | .92 | |
| 17. | Av. Interburst Time | sec | | | | | | | 1.6 | 0.9 |
| 18. | Av. No. Bursts | | | | | | | | 11 | 3.1 |
| 19. | Char. Per Burst | | | | | | | | 1.1 | .12 |
| 19a. | Av. Input Data Rate | cps | .38 | .73 | | .29 | .13 | .68 | .37 | |
| 20. | Think + Tot. Interburst | sec | | | | 17.9 | 26.1 | 10.3 | 18.1 | |
| | Computer Time Breakdown | | | | | | | | | |
| 21. | Idle Time | sec | 3 | 0 | 8.6 | | | | 0.65 | 0.48 |
| 22. | Output Time | sec | 7 | 1.7 | 13.8 | | | | 21.7 | |
| 23. | Characters Output | | 32 | 22 | | 102.1 | 97.8 | 105.0 | 101.6 | |
| 24. | Tot. Char. Time | sec | | | | 10.2 | 9.78 | 7.0 | 9.0 | |
| 25. | Av. Interburst Time | sec | | | | | | | 16 | 25 |
| 26. | Av. No. Bursts | | | | | | | | 3.3 | 2.8 |
| 27. | Char. Per Burst | | | | | | | | 47 | 27 |
| 27a. | Av. Output Data Rate | cps | .94 | 2.0 | | 3.31 | 1.32 | 5.36 | 3.33 | |
| 28. | Idle + Tot. Interburst | sec | | | | 1.7 | 37.0 | 1.4 | 13.4 | |
| 29. | Processor Time | sec | 1.85 | .022 | 0.88 | | | | | |
| 30. | Processor Speed | kops | 32.8 | 32.8 | 95.9 | | | | | |
| 31. | Op. Per Interaction | kop | 60.7 | .72 | 84.4 | | | | | |
| 32. | Per I/O Character | kop | 1.35 | .024 | | | | | | |

operators, input operators, and output operators—this anomoly is not resolved.

The first column shows what percentage of the operator's total time he spends at various locations, and moving between locations. The second and third columns show what proportion of total time is spent inactive (or monitoring) at each unit, and active at the unit. When the operator is active, he may be loading or unloading magnetic tape, cards, or print paper; he may be operating switches and buttons; he may be writing notes or keeping a log; or he might be on the telephone. "Active" while moving between units refers to the proportion of total time the operator spends carrying material from one location to another.

The last column shows the median time spent at each location, in seconds.

## TABLE 2.22.3 COMPARING PROGRAMER EFFECTIVENESS—NOTES

This table summarizes the results of five studies, each of which was made with the object of comparing the relative effectiveness of computations carried out in the batch and in the time-sharing mode (SackH68). The ten columns of data show comparable time-sharing and batch results for each of the five studies.

**The Five Studies.** The two studies labeled "SDC" were conducted on the System Development Corporation time-sharing system in 1966 and 1967. The columns labeled "MIT" and "IBM" were both carried out on the MIT time-sharing system, which used an IBM 7094 computer. And the "Stanford" study made use of a Burroughs 5500 batch system at Stanford—in this instance there was no actual time-sharing system, and a comparison was made between two batch operations, one having a turnaround of a few minutes, the other of a few hours. The first SDC study involved nine programer trainees and two problems; the MIT study 60 undergraduate and graduate students and one problem; the second SDC study 12 experienced R & D programmers and two problems; the IBM study four undergraduate students and four problems; and the Stanford study 127 undergraduate and graduate students and six problems. Incidentally, the reported results in the Stanford study are ambiguous, for it is not clear whether the "prepare new run" time is the total preparation time required, or the preparation time *per run.* I assumed the former. If the latter were assumed, the result would be even more favorable for the slow-turnaround system, which required only 6.6 runs per student compared to 7.1 for the fast-turnaround system.

**Results.** The first eight lines show comparable pairs of man-hours spent on the batch and time-sharing problems in the different studies. The next two lines show comparable pairs of computer time employed, and (where available) elapsed time. The next lines show the very large differences between individual programmers. The eight-to-one man-hour ratio in the first column, for example, indicates that the slowest programmer, operating in the time-sharing mode, required eight times as many man-hours as did the fastest programmer.

Finally, the last two lines in the table show the ratio of time-sharing to batch times for manpower and computer time.

## II.2.23.1 AUERBACH BENCHMARK MEASURE OF SYSTEM PERFORMANCE—NOTES

As was mentioned at the beginning of Section 2.23 in Part I, the Auerbach Corporation developed a set of benchmark problems in the early sixties, and until the early seventies analyzed data processing systems of the major systems manufacturers to predict the performance of the principal systems in solving the benchmark problems. The results, published in Auerbach's *Computer Notebook* (AuerCTR) generally listed, for each computer, the time required to perform each benchmark on each of a number of standard system configurations. The benchmark times were calculated for each system, and the calculations were based on manufacturers' data on systems hardware. The contributions of Operating System performance to systems throughput were ignored.

The nature of the five benchmark problems is given in Part I. The first part of the present table gives, for each of a number of important systems, the benchmark times for each of several hardware configurations, along with the monthly rental for those configurations. (The configurations themselves are described in Table II.2.23.2, below.) The second half of the table shows the ratio of the performance of each configuration to the performance of the IBM 360/30 configuration III.

The time required for the file processing benchmark is very dependent on the proportion of master file records which must be processed. F1, F2, and F3, respectively, refer to the benchmarks for which 0, 0.1, or 1.0 transaction records must be processed for each master file record. The matrix inversion time is of course dependent on the size of the matrix, and running time is shown for a 10 x 10 and a 40 x 40 matrix.

The mathematical problem requires the evaluation of five fifth-order polynomials, and the execution of five divisions and one square root. P1, P2, and P3, respectively, refer to the benchmarks for which this calculation is performed one, ten, or 100 times for each input record of ten, eight-digit numbers.

## TABLE II.2.23.2 AUERBACH CONFIGURATIONS—NOTES

This table establishes the criteria used by Auerbach in choosing configurations for each system evaluated. The columns, identified by Roman numerals, identify the various configurations (note that VIIB and VIIIB each contains two systems, a main and a satellite). The parameters shown are the *minimum*—so that, for example, if a manufacturer only offered 300 cpm and 1000 cpm card readers, the latter would have to be included in a configuration calling for a 500 cpm reader.

### TABLE II.2.23.1 AUERBACH BENCHMARK MEASURES OF SYSTEM PERFORMANCE

| | Units | Configuration Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | IBM 1401 | | | | | IBM 1410 | | | |
| Configuration | | I | II | III | IV | | I | II | III | VIIB |
| Monthly Rental | $k | 4.33 | 5.92 | 10.81 | 11.54 | | 6.12 | 8.42 | 12.24 | 23.56 |
| File Processing—F1 | min. | - | 3.7 | 2.4 | 2.0 | | - | 2.7 | 1.4 | .85 |
| F2 | min. | - | 7.5 | 4.2 | 2.6 | | - | 3.2 | 2.0 | 1.2 |
| F3 | min. | 100 | 40. | 26. | 20. | | 80 | 20. | 20. | 3.3 |
| Random Access | min. | - | - | - | - | | - | - | - | - |
| Sorting | min. | - | 35 | 13 | 10 | | - | 30. | 9.7 | 7.0 |
| Matrix Inversion—10 | min. | 0.33 | 0.33 | 0.33 | .33 | | .17 | .17 | .17 | .17 |
| 40 | min. | - | - | | - | | 9.0 | 9.0 | 9.0 | 9.0 |
| Math. Problem P1 | ms. | 520 | - | 520 | - | | - | - | - | - |
| P2 | ms. | 5k | - | 5k | - | | - | - | - | - |
| P3 | ms. | 50k | - | 50k | - | | - | - | - | - |
| | | IBM 360/20 | | | | IBM 360/30 | | | | |
| Configuration | | I | II | IIIR | | I | II | III | IIIR | IVR |
| Monthly Rental | $k | 2.78 | 3.56 | 3.63 | | 4.10 | 4.71 | 6.96 | 6.11 | 11.66 |
| File Processing—F1 | min. | - | 6.0 | - | | - | 3.7 | 1.5 | - | - |
| F2 | min. | - | 7.0 | - | | - | 3.7 | 2.0 | - | - |
| F3 | min. | 67 | 21. | - | | 67. | 20. | 20. | - | - |
| Random Access | min. | - | - | 32 | | - | - | - | 25 | 18 |
| Sorting | min. | - | 27 | 10 | | - | 25 | 9.2 | 5.0 | 3.0 |
| Matrix Inversion—10 | min. | - | - | - | | .025 | .025 | .025 | - | - |
| 40 | min. | - | - | - | | 1.2 | 1.2 | 1.2 | - | - |
| Math. Problem P1 | ms. | - | - | - | | 100 | 100 | 100 | - | - |
| P2 | ms. | - | - | - | | 480 | 480 | 480 | - | - |
| P3 | ms. | - | - | - | | 4230 | 4230 | 4230 | - | - |
| | | IBM 360/40 | | | | | | | | |
| Configuration | | II | III | IIIR | IVR | VI | | | | |
| Monthly Rental | $k | 7.22 | 8.21 | 7.34 | 13.03 | 11.60 | | | | |
| File Processing—F1 | min. | 1.5 | 1.5 | - | - | 1.5 | | | | |
| F2 | min. | 2.0 | 2.0 | - | - | 2.0 | | | | |
| F3 | min. | 20 | 20 | - | - | 20 | | | | |
| Random Access | min. | - | - | 25 | 18 | - | | | | |
| Sorting | min. | 10.4 | 8.6 | 4.0 | 3.0 | 3.8 | | | | |
| Matrix Inversion—10 | min. | .0071 | 0.0071 | - | - | .0071 | | | | |
| 40 | min. | 0.39 | 0.39 | - | - | 0.39 | | | | |
| Math. Problem P1 | ms. | 100 | 100 | - | - | 100 | | | | |
| P2 | ms. | 150 | 150 | - | - | 150 | | | | |
| P3 | ms. | 2000 | 2000 | - | - | 2000 | | | | |
| | | IBM 360/50 | | | | | | IBM 360/65 | | |
| Configuration | | III | IV | IVR | VIIB | VIIIR | | VIIB | VIIIB | VIIIR |
| Monthly Rental | $k | 15.4 | 21.56 | 18.40 | 21.84 | 26.77 | | 35.19 | 51.94 | 43.39 |
| File Processing—F1 | min. | 1.5 | 0.38 | - | 0.38 | - | | .40 | .22 | - |
| F2 | min. | 2.0 | 1.5 | - | 0.58 | - | | .59 | .22 | - |
| F3 | min. | 2.0 | 15 | - | 2.0 | - | | 2.0 | 1.1 | - |
| Random Access | min. | - | - | 18 | - | 20 | | - | - | 20 |
| Sorting | min. | 9.7 | 2.7 | 2.1 | 2.7 | 1.9 | | 2.0 | 1.8 | 1.7 |
| Matrix Inversion—10 | min. | .0017 | .0017 | - | .0017 | - | | .00022 | .00022 | - |
| 40 | min. | 0.07 | 0.07 | - | 0.07 | - | | .012 | .012 | - |
| Math. Problem P1 | ms. | 100 | 100 | - | 9.7 | - | | 9.7 | 6.5 | - |
| P2 | ms. | 100 | 100 | - | 31. | - | | 9.7 | 6.5 | - |
| P3 | ms. | 400 | 400 | - | 280. | - | | 64 | 64 | - |
| | | IBM 370/135 | | | | | | | | |
| Configuration | | III | IV | IIIR | IVR | | | | | |
| Monthly Rental | $k | 11.6 | 14.6 | 10.9 | 14.2 | | | | | |
| File Processing—F1 | min. | 1.6 | .38 | | | | | | | |
| F2 | min. | 2.0 | 1.5 | - | - | | | | | |
| F3 | min. | 20.0 | 16.0 | - | - | | | | | |
| Random Access | min. | - | - | 2.5 | 1.8 | | | | | |
| Sorting | min. | 10.0 | 2.3 | - | - | | | | | |
| Matrix Inversion—10 | min. | .0024 | .0024 | | | | | | | |
| 40 | min. | .13 | .13 | | | | | | | |
| Math. Problem P1 | ms. | 140 | 50 | | | | | | | |
| P2 | ms. | 140 | 50 | | | | | | | |
| P3 | ms. | 600 | 600 | | | | | | | |
| | | IBM 370/145 | | | | | | | IBM 370/165 | |
| Configuration | | IV | IVR | VI | VIIA | VIIIA | VIIIR | | VIIIA | VIIIR |

**TABLE II.2.23.1 AUERBACH BENCHMARK MEASURES OF SYSTEM PERFORMANCE (continued)**

| | Units | | | | Configuration Data | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Monthly Rental | $k | 21.87 | 19.96 | 16.83 | 20.51 | 28.90 | 21.80 | | 67.75 | 63.59 |
| File Processing—F1 | min. | .38 | - | 1.4 | 1.4 | 3.8 | - | | .21 | - |
| F2 | min. | 1.1 | - | 2.0 | 2.0 | 1.1 | - | | .21 | - |
| F3 | min. | 16.0 | - | 20.0 | 20.0 | 16.0 | - | | .28 | - |
| Random Access | min. | - | 1.8 | - | - | - | 1.8 | | - | 1.8 |
| Sorting | min. | 2.3 | - | 10.0 | 2.3 | 1.7 | - | | 1.5 | - |
| Matrix Inversion—10 | min. | .0012 | - | .0012 | - | - | - | | .00008 | - |
| 40 | min. | .05 | - | .05 | - | - | - | | .0043 | - |
| Math. Problem P1 | ms. | 60 | - | 140 | 140 | 60 | - | | 9.0 | - |
| P2 | ms. | 60 | - | 140 | 140 | 60 | - | | 9.0 | - |
| P3 | ms. | 300 | - | 300 | 300 | 300 | - | | 20.0 | - |
| **RATIOS TO 360/30** | | | | | | | | | | |
| | | | **IBM 1401 Ratios** | | | | | **IBM 1410 Ratios** | | |
| Monthly Rental | | .62 | .851 | 1.55 | 1.66 | | .879 | 1.21 | 1.76 | 3.39 |
| File Processing—F1 | | - | .405 | .625 | .75 | | - | .556 | 1.07 | 1.76 |
| F2 | | - | .267 | .476 | .769 | | - | .625 | 1.0 | 1.67 |
| F3 | | .20 | .50 | .962 | 1.0 | | .25 | 1.0 | 1.0 | 6.06 |
| Random Access | | - | - | - | - | | - | - | - | - |
| Sorting | | - | .263 | .002 | .92 | | - | .307 | .948 | 1.31 |
| Matrix Inversion—10 | | .076 | .076 | .076 | .076 | | .147 | .147 | .147 | .147 |
| 40 | | - | - | - | - | | .133 | .133 | .133 | .133 |
| Math. Problem—P1 | | .192 | - | .192 | - | | - | - | - | - |
| P2 | | .096 | - | .096 | - | | - | - | - | - |
| P3 | | .085 | - | .085 | - | | - | - | - | - |
| | | **IBM 360/20 Ratios** | | | | | **IBM 360/30 Ratios** | | | |
| Monthly Rental | | .399 | .511 | .522 | | .589 | .677 | 1.00 | .878 | 1.68 |
| File Processing—F1 | | - | .25 | - | | - | .405 | 1.00 | - | - |
| F2 | | - | .286 | - | | - | .541 | 1.00 | - | - |
| F3 | | .299 | .952 | - | | .299 | 1.00 | 1.00 | - | - |
| Random Access | | - | - | .781 | | - | - | - | 1.00 | 1.39 |
| Sorting | | - | .341 | .92 | | - | .368 | 1.00 | 1.84 | 3.07 |
| Matrix Inversion—10 | | - | - | - | | 1.00 | 1.00 | 1.00 | - | - |
| 40 | | - | - | - | | 1.00 | 1.00 | 1.00 | - | - |
| Math. Problem—P1 | | - | - | - | | 1.00 | 1.00 | 1.00 | - | - |
| P2 | | - | - | - | | 1.00 | 1.00 | 1.00 | - | - |
| P3 | | - | - | - | | 1.00 | 1.00 | 1.00 | - | - |
| | | | | **IBM 360/40 Ratios** | | | | | | |
| Monthly Rental | | 1.04 | 1.18 | 1.05 | 1.87 | 1.67 | | | | |
| File Processing—F1 | | 1.00 | 1.0 | - | - | 1.00 | | | | |
| F2 | | 1.00 | 1.0 | - | - | 1.00 | | | | |
| F3 | | 1.00 | 1.0 | - | - | 1.00 | | | | |
| Random Access | | - | - | 1.00 | 1.39 | - | | | | |
| Sorting | | .885 | 1.07 | 2.30 | 3.07 | 2.42 | | | | |
| Matrix Inversion—10 | | 3.52 | 3.52 | - | - | 3.52 | | | | |
| 40 | | 3.08 | 3.08 | - | - | 3.08 | | | | |
| Math. Problem—P1 | | 1.00 | 1.0 | - | - | 1.00 | | | | |
| P2 | | 3.20 | 3.20 | - | - | 3.20 | | | | |
| P3 | | 2.12 | 2.12 | - | - | 2.12 | | | | |
| | | | | **IBM 360/50 Ratios** | | | | | **IBM 360/65 Ratios** | |
| Monthly Rental | | 2.21 | 3.10 | 2.64 | 3.14 | 3.85 | | 5.06 | 7.46 | 6.23 |
| File Processing—F1 | | 1.00 | 3.95 | - | 3.95 | - | | 3.75 | 6.82 | - |
| F2 | | 1.00 | 1.33 | - | 3.45 | - | | 3.39 | 9.09 | - |
| F3 | | 1.00 | 1.33 | - | 10.0 | - | | 10.00 | 18.18 | - |
| Random Access | | - | - | 1.39 | - | 1.25 | | - | - | 1.25 |
| Sorting | | .948 | 3.41 | 4.38 | 3.41 | 4.84 | | 4.60 | 5.11 | 5.41 |
| Matrix Inversion—10 | | 14.71 | 14.71 | - | 14.71 | - | | 113.6 | 113.6 | - |
| 40 | | 17.14 | 17.14 | - | 17.14 | - | | 100.0 | 100.0 | - |
| Math. Problem—P1 | | 1.00 | 1.00 | - | 10.31 | - | | 10.31 | 15.38 | - |
| P2 | | 4.80 | 4.80 | - | 15.48 | - | | 49.48 | 73.85 | - |
| P3 | | 10.58 | 10.58 | - | 15.11 | - | | 66.09 | 66.09 | - |
| | | | **IBM 370/135 Ratios** | | | | | | | |
| Monthly Rental | | 1.67 | 2.10 | 1.57 | 2.04 | | | | | |
| File Processing—F1 | | .94 | 3.95 | - | - | | | | | |
| F2 | | 1.00 | 1.33 | - | - | | | | | |
| F3 | | 1.00 | 1.25 | - | - | | | | | |
| Random Access | | - | - | 10.00 | 13.89 | | | | | |
| Sorting | | .92 | 4.00 | - | - | | | | | |
| Matrix Inversion 10 | | 10.42 | 10.42 | - | - | | | | | |

## TABLE II.2.23.1 AUERBACH BENCHMARK MEASURES OF SYSTEM PERFORMANCE (continued)

| | Units | Configuration Data | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 40 | | 9.23 | 9.23 | - | - | | | | |
| Math. Problem P1 | | .71 | 2.00 | - | - | | | | |
| P2 | | 3.43 | 9.60 | - | - | | | | |
| P3 | | 7.05 | 7.05 | - | - | | | | |
| | | | | IBM 370/145 Ratios | | | | IBM 370/165 | |
| Monthly Rental | | 3.14 | 2.87 | 2.42 | 2.94 | 4.15 | 3.13 | 9.73 | 9.14 |
| File Processing—F1 | | 3.95 | - | 1.07 | 1.07 | 3.95 | - | 7.1 | - |
| F2 | | 1.82 | - | 1.00 | 1.00 | 1.82 | - | 9.5 | - |
| F3 | | 1.25 | - | 1.00 | 1.00 | 1.25 | - | 71.4 | - |
| Random Access | | - | 13.89 | - | - | - | 13.89 | - | 13.9 |
| Sorting | | 4.00 | - | .92 | 4.00 | 5.41 | - | 6.1 | - |
| Matrix Inversion 10 | | 20.83 | - | 20.83 | - | - | - | 312.5 | - |
| 40 | | 24.00 | - | 24.00 | - | - | - | 279.1 | - |
| Math. Problem P1 | | 1.67 | - | .71 | .71 | 1.67 | - | 11.1 | - |
| P2 | | 8.00 | - | 3.43 | 3.43 | 3.43 | - | 53.3 | - |
| P3 | | 14.10 | - | 14.10 | 14.10 | 14.10 | - | 211.5 | - |

## TABLE II.2.23.2 AUERBACH CONFIGURATIONS

| Specifications | Units | Configurations | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | I Card | II Tape | III Tape | IIIR RAM | IV Tape | IVR RAM | V |
| Internal Memory | | | | | | | | |
| One-Address Instr. | k | 1 | 1 | 2 | 2 | 4 | 4 | 2 |
| Characters of Data | kby | 4 | 4 | 8 | 8 | 16 | 16 | 8 |
| Random-Access Storage | | | | | | | | |
| Characters of Data | Mby | 0 | 0 | 0 | 5 | 0 | 20 | 20 |
| Magnetic Tape | | | | | | | | |
| Units | | 0 | 4 | 6 | 1 | 12 | 4 | 6 |
| Nominal Speed | kbps | - | 15 | 30 | 30 | 60 | 60 | 30 |
| Simult. Transfers | | - | 0 | 1 | 1 | 2 | 2 | 1 |
| Printer Speed | klpm | 1 | .5 | .5 | .5 | 1 | 1 | .5 |
| Card Reader Speed | kcpm | 1 | .5 | .5 | .5 | 1 | 1 | .5 |
| Card Punch Speed | kcpm | .2 | .1 | .1 | .1 | .2 | .2 | .1 |
| Other Features | | | | | | | | |
| Floating-Point Arith. | | no | no | no | no | no | no | no |
| Index Registers | | 1 | 0 | 3 | 1 | 10 | 10 | 3 |

## TABLE II.2.23.2 AUERBACH CONFIGURATIONS (Continued)

| Specifications | Units | Configurations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VIIA | VIIB Paired | | VIIIA | VIIIB Paired | | VIIIR | IX | X | XI |
| | | | Main | Sat. | | Main | Sat. | | | | |
| Internal Memory | | | | | | | | | | | |
| One-Address Instr. | k | 12 | 8 | .5 | 24 | 16 | 1 | 24 | 2 | 4 | 4 |
| Characters of Data | kby | 48 | 32 | 2 | 96 | 64 | 4 | 96 | 16 | 32 | 32 |
| Random-Access Storage | | | | | | | | | | | |
| Characters of Data | Mby | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Magnetic Tape | | | | | | | | | | | |
| Units | | 10 | 8 | 2 | 20 | 16 | 4 | 4 | 0 | 0 | 4 |
| Nominal Speed | kbps | 60 | 60 | 30 | 120 | 120 | 60 | 120 | - | - | 15 |
| Simult. Transfers | | 2 | 2 | 0 | 5 | 4 | 1 | 4 | - | - | 0 |
| Printer Speed | klpm | .5 | - | .5 | 1 | - | 1 | 1 | .005 | .005 | .1 |
| Card Reader Speed | kcpm | .5 | .1 | .5 | 1 | .1 | 1 | 1 | .010 | .2 | .5 |
| Card Punch Speed | kcpm | .1 | - | .1 | .2 | - | .2 | .2 | .010 | .1 | .2 |
| Other Features | | | | | | | | | | | |
| Floating-Point Arith. | | yes | yes | no | yes | yes | no | yes | no | yes | yes |
| Index Registers | | 6 | 6 | 0 | 10 | 10 | 3 | 10 | 0 | 1 | 1 |

## TABLE II.2.23.3 CPU EFFICIENCY AND THROUGHPUT—NOTES

**Efficiency.** The first portion of this table is copied from GaveP67. It measures the ratio of CPU time to total time for a multiprogramming system having I input channels and handling J job segments simultaneously. (Gaver called this ratio "productivity" and I have called it "efficiency".) On a single-I/O channel system, each job has a ratio r of processor time to I/O time; so with I input channels the system ratio becomes Ir. The statistical distribution of the ratio r is assumed to be exponential with rate r. Average compute time was assumed to be unity, with various assumed statistical distributions, as shown in the table. Gaver assumed there always exists a backlog of jobs, and that I/O and compute functions *for a given job* are not permitted to overlap.

(In a paper in *J.ACM*, April, 1974, Balkovich *et. al* noted an unexplained discrepancy of as much as 2% between some of Gaver's figures and their own recomputations.)

**Throughput.** The second portion of the table, derived from the first, shows the ratio of system throughput to I/O capacity—system I/O capacity for an I-channel system being I times that of a single-channel system. It can easily be shown that this ratio is simply CPU efficiency divided by Ir, the system ratio of processor to I/O time.

## TABLE 2.23.4 CPU AND I/O ACTIVITY OF VARIOUS SYSTEMS—NOTES

This table describes the results of various analyses of the running time of specific systems, set up in a standard format which makes the results comparable. Similar data on some of the same systems is also shown in Table 2.23.5.

### TABLE II.2.23.3 CPU EFFICIENCY AND THROUGHPUT ●
### Part 1—Efficiency

| J | I | r | Ir | Statistical Form of Computation Time Distribution: Hyperex-ponential $\sigma^2=8$ | Hyperex-ponential $\sigma^2=4$ | Hyperex-ponential $\sigma^2=2$ | Gamma $\sigma^2=2$ | Exponen-tial $\sigma^2=1$ | Constant $\sigma^2=0$ | Hyperex-ponential $\sigma^2=.35$ | Hyperex-ponential $\sigma^2=.17$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1 | .1 | .091 | .091 | .091 | .091 | .091 | .091 | | |
| 2 | 2 | .1 | .2 | .177 | .179 | .180 | .180 | .180 | .181 | | |
| 3 | 3 | .1 | .3 | .258 | .264 | .267 | .266 | .268 | .270 | | |
| 4 | 4 | .1 | .4 | .334 | .345 | .351 | .350 | .353 | .358 | | |
| 5 | 5 | .1 | .5 | .405 | .423 | .432 | .430 | .436 | .444 | | |
| 6 | 6 | .1 | .6 | .471 | .496 | .509 | .506 | .515 | .528 | | |
| 7 | 7 | .1 | .7 | .532 | .566 | .583 | .578 | .591 | .609 | | |
| 8 | 8 | .1 | .8 | .588 | .630 | .651 | .645 | .662 | .685 | | |
| 9 | 9 | .1 | .9 | .639 | .689 | .714 | .706 | .727 | .757 | | |
| 10 | 10 | .1 | 1.0 | .685 | .743 | .771 | .762 | .785 | .821 | | |
| 1 | 1 | .2 | .2 | .167 | .167 | .167 | .167 | .167 | .167 | | |
| 2 | 2 | .2 | .4 | .310 | .319 | .322 | .321 | .324 | .328 | | |
| 3 | 3 | .2 | .6 | .432 | .455 | .465 | .462 | .470 | .482 | | |
| 4 | 4 | .2 | .8 | .536 | .575 | .593 | .586 | .602 | .625 | | |
| 5 | 5 | .2 | 1.0 | .624 | .678 | .703 | .692 | .715 | .750 | | |
| 6 | 6 | .2 | 1.2 | .697 | .764 | .794 | .780 | .808 | .853 | | |
| 7 | 7 | .2 | 1.4 | .757 | .834 | .866 | .849 | .879 | .926 | | |
| 8 | 8 | .2 | 1.6 | .807 | .888 | .918 | .901 | .930 | .970 | | |
| 9 | 9 | .2 | 1.8 | .848 | .928 | .953 | .938 | .963 | .990 | | |
| 10 | 10 | .2 | 2.0 | .880 | .956 | .975 | .963 | .982 | .998 | | |
| 1 | 1 | .2 | .2 | .167 | .167 | .167 | | .167 | | .167 | .167 |
| 2 | 2 | .2 | .4 | .310 | .319 | .322 | | .324 | | .327 | .327 |
| 3 | 3 | .2 | .6 | .432 | .455 | .465 | | .470 | | .478 | .480 |
| 4 | 3 | .2 | .6 | .464 | .504 | .522 | | .531 | | .546 | .550 |
| 5 | 3 | .2 | .6 | .479 | .521 | .543 | | .553 | | .569 | .574 |
| 6 | 3 | .2 | .6 | .498 | .539 | .562 | | .573 | | .586 | .589 |
| 7 | 3 | .2 | .6 | .513 | .551 | .573 | | .584 | | .593 | .595 |
| 8 | 3 | .2 | .6 | .526 | .560 | .580 | | .591 | | .597 | .598 |
| 9 | 3 | .2 | .6 | .537 | .568 | .585 | | .595 | | .598 | .599 |
| 10 | 3 | .2 | .6 | .546 | .573 | .589 | | .597 | | .599 | .600 |
| 1 | 1 | .2 | .2 | .167 | .167 | .167 | | .167 | | .167 | .167 |
| 2 | 2 | .2 | .4 | .310 | .319 | .322 | | .324 | | .327 | .327 |
| 3 | 3 | .2 | .6 | .432 | .455 | .465 | | .470 | | .478 | .480 |
| 4 | 4 | .2 | .8 | .536 | .575 | .593 | | .602 | | .615 | .620 |
| 5 | 5 | .2 | 1.0 | .624 | .678 | .703 | | .715 | | .736 | .743 |
| 6 | 5 | .2 | 1.0 | .657 | .730 | .763 | | .778 | | .808 | .817 |
| 7 | 5 | .2 | 1.0 | .667 | .749 | .786 | | .803 | | .838 | .850 |
| 8 | 5 | .2 | 1.0 | .690 | .776 | .817 | | .835 | | .870 | .881 |
| 9 | 5 | .2 | 1.0 | .710 | .796 | .839 | | .859 | | .891 | .901 |
| 10 | 5 | .2 | 1.0 | .728 | .812 | .856 | | .876 | | .906 | .915 |

### TABLE II.2.23.3 CPU EFFICIENCY AND THROUGHPUT (continued) ●

| J | I | r | Ir | Statistical Form of Computation Time Distribution: Hyperexponential $\sigma^2=8$ | Hyperexponential $\sigma^2=4$ | Hyperexponential $\sigma^2=2$ | Gamma $\sigma^2=2$ | Exponential $\sigma^2=1$ | Constant $\sigma^2=0$ | Hyperexponential $\sigma^2=.35$ | Hyperexponential $\sigma^2=.17$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .2 | .2 | .167 | .167 | .167 | | .167 | | .167 | .167 |
| 2 | 2 | .2 | .4 | .310 | .319 | .322 | | .324 | | .327 | .327 |
| 3 | 3 | .2 | .6 | .432 | .455 | .465 | | .470 | | .478 | .480 |
| 4 | 4 | .2 | .8 | .536 | .575 | .593 | | .602 | | .615 | .620 |
| 5 | 5 | .2 | 1.0 | .624 | .678 | .703 | | .715 | | .736 | .743 |
| 6 | 6 | .2 | 1.2 | .697 | .764 | .794 | | .808 | | .834 | .843 |
| 7 | 7 | .2 | 1.4 | .757 | .834 | .866 | | .879 | | .907 | .916 |
| 8 | 7 | .2 | 1.4 | .785 | .874 | .907 | | .921 | | .948 | .962 |
| 9 | 7 | .2 | 1.4 | .791 | .889 | .924 | | .938 | | .967 | .984 |
| 10 | 7 | .2 | 1.4 | .812 | .911 | .945 | | .958 | | .981 | .992 |
| 1 | 1 | .5 | .5 | .333 | .333 | .333 | | .333 | | .333 | .333 |
| 2 | 2 | .5 | 1.0 | .548 | .581 | .594 | | .600 | | .613 | .618 |
| 3 | 3 | .5 | 1.5 | .692 | .755 | .779 | | .789 | | .817 | .826 |
| 4 | 3 | .5 | 1.5 | .738 | .833 | .864 | | .877 | | .913 | .925 |
| 5 | 3 | .5 | 1.5 | .764 | .871 | .905 | | .919 | | .954 | .964 |
| 6 | 3 | .5 | 1.5 | .790 | .902 | .936 | | .949 | | .976 | .983 |
| 7 | 3 | .5 | 1.5 | .813 | .924 | .956 | | .967 | | .988 | .992 |
| 8 | 3 | .5 | 1.5 | .832 | .941 | .970 | | .978 | | .993 | .996 |
| 9 | 3 | .5 | 1.5 | .849 | .953 | .979 | | .986 | | .996 | .998 |
| 10 | 3 | .5 | 1.5 | .864 | .962 | .985 | | .991 | | .998 | .999 |
| 1 | 1 | .5 | .5 | .333 | .333 | .333 | | .333 | | .333 | .333 |
| 2 | 2 | .5 | 1.0 | .548 | .581 | .594 | | .600 | | .613 | .618 |
| 3 | 3 | .5 | 1.5 | .692 | .755 | .779 | | .789 | | .817 | .826 |
| 4 | 4 | .5 | 2.0 | .789 | .869 | .895 | | .905 | | .934 | .943 |
| 5 | 5 | .5 | 2.5 | .857 | .937 | .956 | | .963 | | .982 | .987 |
| 6 | 5 | .5 | 2.5 | .886 | .967 | .981 | | .986 | | .996 | .998 |
| 7 | 5 | .5 | 2.5 | .901 | .981 | .991 | | .994 | | .999 | 1.000 |
| 8 | 5 | .5 | 2.5 | .918 | .989 | .996 | | .997 | | 1.000 | 1.000 |
| 9 | 5 | .5 | 2.5 | .931 | .994 | .998 | | .999 | | 1.000 | 1.000 |
| 10 | 5 | .5 | 2.5 | .943 | .997 | .999 | | 1.000 | | 1.000 | 1.000 |

### TABLE II.2.23.3 CPU EFFICIENCY AND THROUGHPUT ●
### Part 2—Ratio of Throughput to I/O Capacity

| J | I | Statistical Form of Computation Time Distribution: Hyperexponential $\sigma^2=8$, r=.1 | Hyperexponential $\sigma^2=8$, r=.2 | Hyperexponential $\sigma^2=8$, r=.5 | Hyperexponential $\sigma^2=4$, r=.2 | Exponential $\sigma^2=1$, r=.2 |
|---|---|---|---|---|---|---|
| 1 | 1 | .91 | .835 | .666 | - | - |
| 2 | 2 | .885 | .775 | .548 | - | - |
| 3 | 3 | .860 | .720 | .461 | - | - |
| 4 | 4 | .835 | .670 | .395 | - | - |
| 5 | 3 | - | .798 | .509 | - | - |
| 5 | 5 | .810 | .624 | .343 | - | - |
| 6 | 6 | .785 | .581 | - | - | - |
| 7 | 7 | .760 | .541 | - | - | - |
| 8 | 8 | .735 | .504 | - | - | - |
| 9 | 9 | .710 | .471 | - | - | - |
| 10 | 3 | - | .910 | .576 | .955 | .995 |
| 10 | 5 | - | .728 | .377 | .812 | .876 |
| 10 | 7 | - | .580 | - | .651 | .684 |
| 10 | 10 | .685 | .440 | - | .478 | .491 |

The meaning of the various columns can be described as follows: CPU Active is the percentage of time the CPU is actually processing instructions. It comprises two parts, identified in the next two columns: the percentage of time that both CPU and I/O are in operation, and the proportion of time that the CPU is in operation and the I/O system is idle. The next six data columns represent a breakdown of the time when the CPU is idle and the I/O system is in operation. The first of these columns shows total CPU idle time. The next four show the percentage of total time occupied by disk transfers only, magnetic tape transfers only, unit record equipment (card equipment and line printers) only, and unspecified non-disk I/O equipment only. The last column in this portion of the table shows the proportion of time two or more of these classes of I/O equipment were in operation. The column headed "idle" shows the proportion of time both CPU and I/O were idle. Finally, the last column shows the ratio of total CPU to total I/O time, r, computed from the previous columns. It is the ratio of the "CPU Active" column to the sum of the columns labeled "total I/O only" and "CPU-I/O Overlap only".

**IBM 7094 (1966).** This data (from ArbuR66) was taken from an IBM 7094 installation which acted as a job shop, processing a great many different kinds of small jobs. The jobs were segregated into three categories: short FORTRAN II jobs were less than seven minutes in duration and together occupied 50% of total time; the other FORTRAN jobs, seven minutes or longer in duration, took up 30% of total time; and the remaining 20% of system time was occupied by miscellaneous jobs. The "total" figures given did not appear in the paper, but represent a weighted average of the three categories.

**IBM 7074 (1966).** This data also come from ArbuR66, and represents an analysis of a particular run on a IBM 7074. It does *not* represent the operation of a system over any long period of time.

**ATLAS (1967).** The British ATLAS computer was built by I.C.T. and operated by the University of Manchester, in England. A report published in 1967 (MorrD67) describes operation of that system in considerable detail, and these figures come from that report. Total elapsed time is broken into three parts: *compute time*, during which the CPU compiles new programs and executes compiled programs; *idle time*, while the CPU is waiting for magnetic and peripheral equipment transfers; and *supervisor time*, which is the time the CPU spends in the software supervisor. The figures shown here are idle time and its inverse, CPU active time.

**IBM 360/67 (1970).** The time-sharing software for the IBM 360 system is called TSS. A report (DoheW70) from an IBM research center showed how the performance of a 360/67 was improved over a three month period in 1969 and 1970 by changing scheduling strategies embodied in the TSS system. The data shown in this table is my interpretation of some results reported in that paper. The specific results were: CPU time per elapsed time increased from an average of 45% to 80%; problem state per CPU increased from an average of 20% to 50%; and supervisor state per CPU decreased from an average of 80% to 50%. I assume that "CPU per elapsed time" represents the proportion of time that the CPU is active.

**XDS Sigma 7 (1972).** The XDS UTS time sharing software permits a mixture of on-line terminal jobs and batch jobs to be handled simultaneously. Furthermore, the software contains a variety of built-in measuring tools which make it possible for a system operator to understand and improve system functions. The data included in this section of the table comes from a private communication reporting on the operation of three different UTS installations in three quite different applications: installation 1 is industrial; 2 is also industrial with a heavy FORTRAN load; and 3 is a university. Data from each installation is reported on two lines, the first of which gives average figures, and the second standard deviations. The averages are typically the average of several tens or a few hundreds of "snapshots", recording operation of the system over a relatively short period of time. The columns labeled "disk only", "non-disk only", and "two or more", are identified by UTS software as "swap wait", "I/O wait", and "I/O and swap wait", respectively.

**IBM 360/65 (1973).** The RAND Corporation conducted a series of tests investigating the performance of their IBM 360/65 with 2.5 MBytes and with 3.5 MBytes of internal memory (LockJ74). Hour-long experiments were run twice a day over a period of three weeks, and a Boole and Babbage monitor (CUE) was used to measure CPU utilization. (Internal memory size was reduced in the second week, and added back during the third.)

## TABLE II.2.23.4 INCREASES IN I/O TRANSFERS CAUSED BY PROGRAM FRAGMENTATION—NOTES

The data for this table was collected on an experimental time sharing system designed by IBM Research (BrawB68) and run on an IBM 7044 computer with a large (non-standard) core memory and two 1301 II disks. A variety of experiments were conducted, only one of which is described here. The experimental machine had software designed to permit a user to write programs without worrying about the specific configuration his programs would run on. In particular, the software was intended to enable a user to write programs bigger than the internal memory capacity of the computer—the software would then segment the user's job, reading new segments from disk to internal memory as often as necessary.

The paper reports on experiments carried out using two versions of each of three different programs, and running each of the six programs with a variety of different internal memory capacities. Typically, a given program would run quite efficiently, only infrequently requiring transfers between disks and internal memory, as long as internal memory was large enough. However, as the size of internal memory was reduced, the supervisory program would have to initate drum/internal memory transfers more and more frequently.

The table shows how many transfers were required for each of six programs under the variety of internal memory capacities. Comments:

a. The matrix inversion programs invert a matrix of order 100, and are written in FORTRAN IV. The data correlation program, also written in FORTRAN, reconstructs the most probable tracks of several ships, given a large set of data representing relative and absolute position measurements. The sorting program sorts 10,000 ten-word items.

b. For each example, the "casual" program in every instance is a program written in a straightforward fashion without regard to memory limitations. The "improved" program in each case is a simple modification to the "casual" code, aimed at taking into account the fact that system software would actually be working with a restricted memory capacity.

c. Memory capacity is given in kwords, or multiples of 1024 words. An input-output "transmission" is the transfer of a one kword page between disk and internal memory.

d. As internal memory size increases, the duration of each program tends to approach a minimum value based solely on problem complexity. The minimum run time for the matrix inversion program was 600 seconds, for data correlation 400 seconds, and for sorting 200 seconds. An average disk seek and transmit time was determined to be 0.21 seconds. Thus, 1000 I/O transmissions can increase run time by about 210 seconds.

e. The memory capacity occupied by the six programs are as follows (in kwords, with the size of the casual program given first): matrix inversion, 42, 35; data correlation, 54, 45; sorting, 129, 129.

f. The data in the table is taken from curves plotted in the paper.

## TABLE 2.23.5 CPU OVERHEAD OF VARIOUS SYSTEMS—NOTES

This table provides additional data on some of the systems described in Table 2.23.4 (q.v.). The first column of data shows the percent of total elapsed time that the CPU is idle, and is identical to a corresponding column in the previous table. The next column, entitled "Supervisory" was given exactly that designation in the IBM and ATLAS papers. In the Sigma 7 studies it was referred to as "time spent in the monitor". A further breakdown of supervisor time in ATLAS system is given in the notes to Table II.2.21.5. The category "user service" is identified by the XDS UTS software as time spent in the monitor for services required by user programs. Such services are always executed in the unmapped master mode, while user programs themselves are executed mapped in the slave mode. The column "user execution" is referred to as "problem state" in the IBM paper, and as "compute and compile time" in the ATLAS study. User total time, in the last column, is the sum of the preceeding two columns.

## TABLE II.2.23.5 MAINTAINABILITY RECORDS OF SOME U.S. GOVERNMENT SYSTEMS—NOTES

The data in this table comes from ArmyMIS71 (see Table II.2.21.1), and the system identifier shown in the first column is the same as that used in the previous table. Although many of the applications described in the reference are actually carried out on hardware used for other applications (for example, the two IBM 7080's and the 1401 used for AF3 are also used for AF14), I have removed all such duplications in this table.

For each system, the report provides a pie chart showing typical or average system usage—the report does not specify the conditions under which the pie chart data was collected. For the Air Force systems, the pie chart distinguishes unscheduled maintenance time, machine error or lost time, scheduled maintenance time, idle time, and off-time. For the Army systems, the pie charts generally do not distinguish scheduled and unscheduled maintenance (system AR11 is an exception), and distinguish only a category known as "down time". I have assumed that such time is really unscheduled maintenance, and have entered it accordingly. The Army pie charts also do not have a category known as "off-time", and it is apparent that what the Air Force calls "off-time" is included in the Army's "idle time".

### TABLE II.2.23.4 INCREASES IN I/O TRANSFERS CAUSED BY PROGRAM FRAGMENTATION

| Size of Internal Memory (kwords) | Number of I/O Transmissions: Matrix Inversion, Casual Program | Matrix Inversion, Improved Program | Data Correlation, Casual Program | Data Correlation, Improved Program | Sorting, Casual Program | Sorting, Improved Program |
|---|---|---|---|---|---|---|
| 10 | | 5727 | | | | |
| 12 | | 1550 | | | | |
| 14 | | 200 | | | | 1400 |
| 16 | | | | | | 700 |
| 18 | | | | | | |
| 20 | | | | | | 400 |
| 22 | | | | 6600 | | |
| 24 | 7335 | | | 400 | | |
| 26 | 100 | | | | | |
| 28 | | | | | | |
| 30 | | | | | | |
| 32 | | | 8100 | | | 300 |
| 34 | | | 3900 | | | |
| 36 | | | 200 | | | |
| 80 | | | | | 13653 | |
| 88 | | | | | | |
| 96 | | | | | 3850 | 100 |
| 104 | | | | | 900 | |
| 112 | | | | | 100 | |

I have assumed that the category "machine error lost" is nonproductive time caused by system failures, and have added it to unscheduled maintenance time to get a total unscheduled lost time. I then add scheduled maintenance time to get a total maintenance lost time. Finally, I compute system "on" time, for the Air Force systems by subtracting "off" time from a 730-hour month, and for Army systems by reading the comments associated with the pie chart, which generally tell how many hours per month the system is suppose to operate.

The last two columns are computed as percentages of "on time". Unscheduled maintenance is simply the ratio of the unscheduled maintenance column to the on time column, multiplied by 100. Availability is the ratio of maintenance lost time to on time, subtracted from one and then multiplied by 100. Note that I am not counting time lost due to machine errors as part of available time.

## TABLE II.2.23.6 MAINTAINABILITY RECORDS FOR SYSTEMS AT THREE POINTS IN TIME—NOTES

It is difficult to locate data on system reliability. Reliability is a subject manufacturers are loath to talk about; and users, who should be extraordinarily interested in the subject and eager to collect and exchange data about it, are seemingly too well controlled by the manufacturers to take effective action. Generally speaking, then, the only data we have available has been collected by one of the biggest users—the U.S. government.

Though I will treat the data in this table as if it were truly and completely comparable, in fact, there has been no consistently-used definition of "availability", and the results should correspondingly be treated with some caution.

**1952.** Starting in 1949, the Office of Naval Research published *Digital Computer Newsletter* as a medium for exchanging information about computers and computer use. When the *Journal of the Association for Computing Machinery* was started, in January of 1954, it republished the *Newsletter*, and continued to do so until the end of 1957. The EDVAC, ORDVAC, and ENIAC figures shown in the table are from the first issue of the *JACM.* An article in the *Newsletter* distinguished five categories of time: scheduled engineering, unscheduled engineering, problem set-up and check, production, and idle time. Average figures were given for 1952 and 1953, though only the 1952 results are reproduced—the data for 1953 was much the same. My figures for "unscheduled maintenance" are the ratios of "unscheduled engineering" to total hours; and my figures for availability are the ratios of problems set-up plus production plus idle time to total hours. Average hours per month for the three systems in 1952 were 152.2, 145.8, and 139.3, respectively.

Data on the next three systems in the table comes from the *Proceedings of the 1953 Eastern Joint Computer Conference*, published in 1954 by the Institute of Radio Engineers. The Univac I data was reported by the Air Force for an 18 month period starting in June, 1952. The 20% of "on" time not shown in the table was used for preventive maintenance. And the Air Force reported their highest monthly figure for availability was 74%, the lowest 49%, during those 18 months. The IBM 701 time was reported by Los Alamos for a six month period. The report (page 46) distinguished four categories: good calculate time, maintenance time, lost time due to 701 error, and lost time due to human error. My figure for availability is based on the sum of the first and last of these categories. For the seven month period, the worst availability was 65.2%, and the best was 87.2%.

The SEAC figure is the ratio of productive computation to total assigned time—the remainder of assigned time constituting machine errors, overrun of engineering time into scheduled operating time, and down time due to debugging. For the three year period, availability was reported by quarters, with the worst figure being about 60% and the best about 85%.

MADAM was a British computer at Manchester University. The data shown here was reported in the proceedings of a symposium held at the National Physical Laboratory in March, 1953. The MADAM data covered a period of a little over one year, and the report (page 36) distinguished scheduled maintenance time, fault time, and computing time. I show the latter two as unscheduled maintenance and availability.

The eighth line in the table provides an average of the seven previous systems, along with their distribution expressed as a percentage of the seven systems.

**1958.** The data shown for the next 119 systems of five different kinds is abstracted from WeikM61. Weik distinguishes "good time" and "attempt to run time", and I assume that availability is the ratio of these two figures. To establish the figures shown, which generally were reported for periods of time between 1956 and 1960, I took a (hopefully random) sample of the data given by Weik.

The averages shown, for the 70 IBM systems, the 49 Burroughs and Bendix systems, and the 119 total systems, were computed by averaging all pertinent *systems*, and not by averaging the figures for system types.

**1965.** The last entries in the table are a summary of the data from Table II.2.23.5.

## TABLE II.2.23.5 MAINTAINABILITY RECORDS OF SOME U.S. GOVERNMENT SYSTEMS

| System | Computer | Time (hours) | | | | | | | Percent | | PM/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Unsch. Maint. | Mach. Error Lost | Unsch. Lost Subtot. | Schd. Maint. | Maint. Lost Subtot. | Idle Time | On Time | Unsch. Maint. | Avail-ability | CM Ratio |
| AF1 | IBM 7040 | 3 | - | 3 | 20 | 23 | 123 | 520 | .58 | 95.6 | 6.7 |
| | IBM 1401 | 11 | - | 11 | 12 | 23 | 159 | 503 | 2.19 | 95.4 | 1.1 |
| AF2 | NCR 390 | 9 | - | 9 | 8 | 17 | - | 304 | 2.96 | 94.4 | 0.9 |
| AF3 | IBM 7080 | 9 | 11 | 20 | 43 | 63 | 24 | 632 | 1.42 | 90.0 | 2.2 |
| | IBM 7080 | 1 | 9 | 10 | 48 | 58 | 15 | 611 | .16 | 90.5 | 4.8 |

**TABLE II.2.23.5 MAINTAINABILITY RECORDS OF SOME U.S. GOVERNMENT SYSTEMS (continued)**

| System | Computer | Time (hours) Unsch. Maint. | Mach. Error Lost | Unsch. Lost Subtot. | Schd. Maint. | Maint. Lost Subtot. | Idle Time | On Time | Percent Unsch. Maint. | Avail-ability | PM/ CM Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | IBM 1401 | 4 | - | 4 | 10 | 14 | 18 | 573 | .70 | 97.6 | 2.5 |
| AF4 | GE 225 | 15 | - | 15 | 96 | 111 | 68 | 441 | 3.40 | 74.8 | 6.4 |
| AF5 | IBM 7094 | 16 | - | 16 | 14 | 30 | 32 | 730 | 2.19 | 95.9 | 0.9 |
| | IBM 7094 | 13 | - | 13 | 4 | 17 | 364 | 730 | 1.78 | 97.7 | 0.3 |
| | IBM 1401 | 7 | - | 7 | 5 | 12 | 165 | 730 | .96 | 98.4 | 0.7 |
| | IBM 1401 | 4 | - | 4 | 2 | 6 | 345 | 730 | .55 | 99.2 | 0.5 |
| AF6 | RCA 501 | 15 | 26 | 41 | 42 | 83 | 24 | 663 | 2.26 | 87.5 | 1.0 |
| | RCA 501 | 1 | 16 | 17 | 58 | 75 | 17 | 662 | .15 | 88.7 | 3.4 |
| | RCA 301 | 15 | 4 | 19 | 31 | 50 | 82 | 681 | 2.20 | 92.7 | 1.6 |
| | IBM 1401 | 4 | 1 | 5 | 11 | 16 | 96 | 509 | 3.14 | 96.9 | 2.2 |
| AF7 | Uni 1050 | 8 | 1 | 9 | 36 | 45 | 12 | 383 | 2.09 | 88.3 | 4.0 |
| | Uni 1107 | 5 | 13 | 18 | 51 | 69 | 17 | 469 | 1.07 | 85.3 | 2.8 |
| AF8 | IBM 7094 | 0 | 2 | 2 | 2 | 4 | 20 | 676 | 0 | 99.4 | 1.0 |
| | IBM 1401 | 3 | - | 3 | 2 | 5 | 323 | 592 | .51 | 99.2 | 0.7 |
| | IBM 1401 | 8 | - | 8 | - | 8 | 277 | 602 | 1.33 | 98.7 | 0.0 |
| AF9 | IBM 7044 | 1 | 1 | 2 | 10 | 12 | 42 | 670 | .15 | 98.2 | 5.0 |
| | IBM 1460 | 2 | 1 | 3 | 12 | 15 | 343 | 666 | .30 | 97.7 | 4.0 |
| AF10 | RCA 301 | 21 | 5 | 26 | 81 | 107 | 464 | 719 | 2.92 | 85.1 | 3.1 |
| | RCA 301 | 21 | 5 | 26 | 81 | 107 | 464 | 719 | 2.92 | 85.1 | 3.1 |
| AF11 | Hon 200 | 2 | - | 2 | 7 | 9 | 166 | 646 | .31 | 98.6 | 3.5 |
| | Hon 800 | 9 | 8 | 17 | 55 | 72 | 19 | 663 | 1.36 | 89.1 | 3.2 |
| AF12 | BGH 5500 | 29 | 45 | 74 | 79 | 153 | 27 | 707 | 4.10 | 78.4 | 1.1 |
| AF16 | Phi 2000 | 5 | 1 | 6 | 57 | 63 | 94 | 730 | .68 | 91.4 | 9.5 |
| | Phi 2000 | 3 | 1 | 4 | 54 | 58 | 149 | 730 | .41 | 92.1 | 13.5 |
| AF17 | IBM 1410 | 33 | 16 | 49 | 11 | 60 | 191 | 670 | 4.93 | 91.0 | 0.2 |
| AF18 | Uni 1050 | - | - | - | 15 | 15 | 12 | 665 | N.A. | 97.7 | |
| AR1 | IBM 7080 | 2.5 | - | 2.5 | 51 | 53.5 | | 730 | .34 | 92.7 | 20.4 |
| | IBM 1460 | 39 | - | 39 | 26 | 65 | | 730 | 5.34 | 91.1 | 0.7 |
| AR2 | CDC 3304 | 75 | | 75 | 52 | 127 | | 603 | 12.44 | 78.9 | 0.7 |
| AR7 | IBM 1410 | 14.1 | | | | 14.1 | | 720 | 1.96 | 98.0 | |
| | IBM 1401 | 4.9 | | | | 4.9 | | 720 | .68 | 99.3 | |
| AR11 | IBM 360/30 | 15.0 | | 15.0 | 24.4 | 39.4 | | 603 | 2.49 | 93.5 | 1.6 |
| AR12 | Uni 1005 | 22 | | | | 22 | | 352 | 6.25 | 93.8 | |
| AR19 | BGH 5500 | | | | | 63 | | 730 | N.A. | 91.4 | |

**TABLE II.2.23.6 MAINTAINABILITY RECORDS FOR SYSTEMS AT THREE POINTS IN TIME**

| Approx Date | System(s) | Percent of "On" Time Unsched. Maint. | Avail-ability | Percent of Systems Having Availability Between: 0-49% | 50-74% | 75-89% | 90-94% | 95-97% | 98-100% |
|---|---|---|---|---|---|---|---|---|---|
| 1952 | 1 EDVAC | 46.3 | 31.1 | | | | | | |
| | 1 ORDVAC | 18.7 | 65.0 | | | | | | |
| | 1 ENIAC | 25.6 | 65.5 | | | | | | |
| | 1 UNIVAC I | 19. | 61. | | | | | | |
| | 1 IBM 701 | | 77.1 | | | | | | |
| | 1 SEAC | | 74. | | | | | | |
| | 1 MADAM | 11.0 | 72.0 | | | | | | |
| | 7 Systems | | 63.7 | 14 | 71 | 14 | 0 | 0 | 0 |
| 1958 | 16 IBM 650's | | 94.9 | 0 | 0 | 13 | 19 | 44 | 25 |
| | 15 BGH 205's | | 95.3 | 0 | 0 | 7 | 33 | 27 | 33 |
| | 27 IBM 705's | | 91.9 | 0 | 0 | 33 | 33 | 15 | 19 |
| | 27 IBM 704's | | 94.1 | 0 | 0 | 11 | 30 | 41 | 19 |
| | 34 Ben G-15's | | 94.1 | 0 | 0 | 12 | 26 | 44 | 18 |
| | 70 IBM Syst. | | 93.4 | 0 | 0 | 20 | 29 | 31 | 20 |
| | 49 Oth. Syst. | | 94.5 | 0 | 0 | 10 | 29 | 39 | 22 |
| | 119 Systems | | 93.9 | 0 | 0 | 16 | 29 | 34 | 21 |
| 1965 | 8 IBM 1401's | 1.26 | 98.1 | 0 | 0 | 0 | 0 | 38 | 62 |
| | 21 IBM Syst. | 1.59 | 96.0 | 0 | 0 | 0 | 29 | 33 | 38 |
| | 18 Oth. Syst. | 2.21 | 88.5 | 0 | 6 | 50 | 33 | 6 | 6 |
| | 39 Syst. | 1.85 | 92.5 | 0 | 3 | 23 | 31 | 21 | 23 |

### TABLE II.2.23.7 MAINTAINABILITY—PERCENT LOST TIME PER $100,000 OF COMPUTER SYSTEM PRICE

This table shows lost time for the same systems as were described in the previous table. "Maintenance lost time", in the third column, is the opposite of Availability, and is computed by subtracting the Availability figures of column 4 of Table II.2.23.6 from 100%. The assumed rent, in column 4 of this table, comes from an early issue of *EDP/IR*. Maintenance lost time per $100k of computer price is computed assuming a ratio of 45 to 1 for price to rent. For example, the first entry in the table is found by multiplying the UNIVAC I rental by 45, to get an assumed sales price of $1125k, dividing that number by 100 to convert it to units of $100k, and finally dividing that result into the maintenance lost time of 39%.

### TABLE II.2.23.8 MAINTAINABILITY—PERCENT LOST TIME PER $100,000 OF COMPUTER SYSTEM PRICE

The computers shown here are the same as those in Table II.2.23.5. The rental price, in column three, is from Table II.2.21.1. The purchase to rental ratio in column 4 comes from SharpW69, page 272, where Sharpe shows ratios of purchase price to total rental for each of the major manufacturers. The selling price, in column 5, is the product of columns 3 and 4. Finally, the maintenance time percentages per $100k of price are computed by dividing the appropriate percentages computed from the columns in Table II.2.23.5 by the selling price in units of $100k. For example, the scheduled maintenance figure (column 7) for the first computer in this table is computed by dividing scheduled maintenance time by on-time, using the data in Table II.2.23.5 (20 divided by 520, times 100), and then dividing that result by 8.434, which is the selling price of the IBM 7040 in units of $100k.

### TABLE II.2.23.9 FAILURE ANALYSIS OF BURROUGHS 5500 SYSTEMS

The data in this table is from YourE72. In his article, Yourdon states that the figures are a summary of failure statistics on Burroughs 5500 systems over a 15-month period. Apparently the data came from a newsletter published monthly by the Cooperative Users of Burroughs Equipment (CUBE). Yourdon had had an opportunity over some period of time to work with Burroughs computers, and states that the data is a reasonably accurate description of how Burroughs' users view the reliability of their equipment.

The first half of the table provides a count of system failures per month in six categories, along with a total for five of the categories. The second half shows the five categories as percentages of the total. Yourdon described and discussed the various types of failure as follows:

**Unexpected I/O Interrupts.** This type of failure, common to many systems, is recorded when the software responds to an input/output interrupt signifying that some I/O action has taken place, but discovers that it has no record having initiated such an action. It is thus an indication of some form of hardware or software error.

**Disk Failures.** Yourdon comments that he suspects the figures on disk failures are inaccurate, for it is the experience of Burroughs' users that disk parity errors occasionally cause a single *job* to be restarted, but seldom cause the entire system to "crash". He adds that a possible explanation may be that the operating system runs out of allocatable disk space, types out a message to that effect to the operator, and that the operator then may decide to restart the entire system instead of simply aborting one of the jobs. If that were the reason for most of the failures, I should not be including them with hardware/software reliability problems—see the discussion below on "insufficient memory".

**TABLE II.2.23.7 MAINTAINABILITY—PERCENT LOST TIME PER $100,000 OF COMPUTER SYSTEM PRICE**

| Approx. Date | System(s) | Mainten. Lost Time (%) | Assumed Rent ($k/mo) | Lost Time %/$100k From Assumption | Lost Time %/$100k From II.2.23.8 |
|---|---|---|---|---|---|
| 1952 | 1 UNIVAC I | 39. | 25.0 | 3.47 | |
| | 1 IBM 701 | 22.9 | 5.0 | 10.18 | |
| 1958 | 16 IBM 650's | 5.1 | 5.0 | 2.27 | |
| | 15 BGH 205's | 4.7 | 4.6 | 2.27 | |
| | 27 IBM 705's | 8.1 | 30.0 | 0.60 | |
| | 27 IBM 704's | 5.9 | 32.0 | 0.41 | |
| | 34 Ben G-15's | 5.9 | 1.7 | 7.71 | |
| 1965 | 8 IBM 1401's | 1.9 | 4.5 | 0.93 | 0.49 |
| | 3 IBM 7080's | 8.9 | 55.0 | 0.36 | 0.29 |
| | 3 IBM 7094's | 2.3 | 72.5 | 0.07 | 0.07 |
| | 2 IBM 1460's | 5.6 | 9.0 | 1.38 | 1.04 |
| | 2 IBM 1410's | 5.5 | 14.2 | 0.86 | 0.62 |
| | 1 IBM 360/30 | 6.5 | 7.2 | 2.01 | 0.75 |
| | 1 IBM 7040 | 4.4 | 18 | 0.54 | 0.52 |
| | 1 IBM 7044 | 1.8 | 35.2 | 0.11 | 0.12 |
| | 1 NCR 390 | 5.6 | 1.85 | 6.73 | 1.81 |
| | 1 GE 225 | 25.2 | 8.0 | 7.00 | 6.00 |
| | 2 RCA 501's | 11.9 | 14.0 | 1.89 | 1.49 |
| | 3 RCA 301's | 12.4 | 6.0 | 4.59 | 3.20 |

### TABLE II.2.23.7 MAINTAINABILITY—PERCENT LOST TIME PER $100,000 OF COMPUTER SYSTEM PRICE (continued)

| Approx. Date | System(s) | Mainten. Lost Time (%) | Assumed Rent ($k/mo) | Lost Time %/$100k From Assumption | Lost Time %/$100k From II.2.23.8 |
|---|---|---|---|---|---|
| 2 | Uni 1050's | 7.0 | 8.0 | 1.94 | 2.30 |
| 1 | Uni 1107 | 14.7 | 45.0 | 0.73 | 0.63 |
| 1 | Uni 1005 | 6.2 | 2.4 | 5.74 | 3.65 |
| 1 | HIS 200 | 1.4 | 5.7 | 0.55 | 0.47 |
| 1 | HIS 800 | 10.9 | 22.0 | 1.10 | 1.87 |
| 2 | BGH 5500 | 15.1 | 20.0 | 1.68 | 0.56 |
| 2 | Phi 2000 | 8.3 | 52.0 | 0.35 | 0.25 |
| 1 | CDC 3304 | 21.1 | 15.0 | 3.13 | 1.55 |

### TABLE II.2.23.8 MAINTAINABILITY—PERCENT LOST TIME PER $100,000 OF COMPUTER SYSTEM PRICE

| System | Computer | Rental $k Per mo. | P/R Ratio | Selling Price ($k) | Percent Per $100k Cost: Unsch. Maint. | Sched. Maint. | Maint. Lost |
|---|---|---|---|---|---|---|---|
| AF1 | IBM 7040 | 18.295 | 46.1 | 843.4 | .07 | .46 | .52 |
| | IBM 1401 | 8.940 | 46.1 | 412.1 | .53 | .58 | 1.11 |
| AF2 | NCR 390 | 6.421 | 48.0 | 308.2 | .96 | .85 | 1.81 |
| AF3 | IBM 7080 | 69.945 | 46.1 | 3224.5 | .04 | .21 | .31 |
| | IBM 7080 | 69.945 | 46.1 | 3224.5 | .01 | .24 | .29 |
| | IBM 1401 | 6.421 | 46.1 | 296.0 | .24 | .59 | .83 |
| AF4 | GE 225 | 9.400 | 44.6 | 419.2 | .81 | 5.19 | 6.00 |
| AF5 | IBM 7094 | 72.430 | 46.1 | 3339.0 | .07 | .06 | .12 |
| | IBM 7094 | 72.430 | 46.1 | 3339.0 | .05 | .01 | .07 |
| | IBM 1401 | 19.633 | 46.1 | 905.1 | .11 | .08 | .18 |
| | IBM 1401 | 19.633 | 46.1 | 905.1 | .06 | .03 | .09 |
| AF6 | RCA 501 | 16.151 | 49.6 | 801.1 | .28 | .79 | 1.56 |
| | RCA 501 | 16.151 | 49.6 | 801.1 | .02 | 1.09 | 1.41 |
| | RCA 301 | 8.364 | 49.6 | 414.9 | .53 | 1.10 | 1.77 |
| | IBM 1401 | 8.130 | 46.1 | 374.8 | .21 | .58 | .84 |
| AF7 | Uni 1050 | 7.61 | 38.8 | 295.3 | .71 | 3.18 | 3.98 |
| | Uni 1107 | 60.390 | 38.8 | 2343.1 | .05 | .46 | .63 |
| AF8 | IBM 7094 | 85.825 | 46.1 | 3956.5 | - | .01 | .01 |
| | IBM 1401 | 7.33 | 46.1 | 337.9 | .15 | .10 | .25 |
| | IBM 1401 | 7.33 | 46.1 | 337.9 | .39 | 0 | .39 |
| AF9 | IBM 7044 | 31.315 | 46.1 | 1443.6 | .01 | .10 | .12 |
| | IBM 1460 | 7.490 | 46.1 | 345.3 | .09 | .52 | .65 |
| AF10 | RCA 301 | 7.660 | 49.6 | 379.9 | .77 | 2.97 | 3.92 |
| | RCA 301 | 7.660 | 49.6 | 379.9 | .77 | 2.97 | 3.92 |
| AF11 | HIS 200 | 6.590 | 44.6 | 293.9 | .11 | .37 | .47 |
| | HIS 800 | 13.033 | 44.6 | 581.3 | .23 | 1.43 | 1.87 |
| AF12 | BGH 5500 | 48.065 | 49.7 | 2388.8 | .17 | .47 | .91 |
| AF16 | Phi 2000 | 75.390 | 44 | 3317.2 | .02 | .24 | .26 |
| | Phi 2000 | 75.390 | 44 | 3317.2 | .01 | .22 | .24 |
| AF17 | IBM 1410 | 17.640 | 46.1 | 813.2 | .61 | .20 | 1.10 |
| AF18 | Uni 1050 | 9.284 | 38.8 | 360.2 | - | .63 | .63 |
| AR1 | IBM 7080 | 61.800 | 46.1 | 2849.0 | .01 | .25 | .26 |
| | IBM 1460 | 13.533 | 46.1 | 623.9 | .86 | .57 | 1.43 |
| AR2 | CDC 3304 | 33.815 | 40.1 | 1356.0 | .92 | .64 | 1.55 |
| AR7 | IBM 1410 | 30.208 | 46.1 | 1392.6 | .14 | - | .14 |
| | IBM 1401 | 6.475 | 46.1 | 298.5 | .23 | - | .23 |
| AR11 | IBM 360/30 | 19.019 | 46.1 | 876.8 | .28 | .46 | .75 |
| AR12 | Uni 1005 | 4.407 | 38.8 | 171.0 | 3.65 | | 3.65 |
| AR19 | BGH 5500 | 83.653 | 49.7 | 4157.6 | | | .21 |
| Average | IBM | | | | | | .46 |
| | Non-IBM | | | | | | 1.93 |
| | All | | | | | | 1.14 |

**Operating System Bugs.** The counts in this category seem to Yourdon to be uncommonly low. He says that, between April 1969 and July 1970, Burroughs released two or three new revisions of their operating system as well as several hundred other minor changes, patches, and "improvements". It thus seems fairly unlikely that only an average of 3.3 errors per month were caused by the operating system. Of course, many operating system bugs may actually appear in the "unexplained" category below.

**Multiplexor "Hang-ups".** Transient hardware failures in the data communications interface cause that device to occasionally get itself into a permanently "busy" state, where it fails to handle inputs from terminals or outputs from CPU. Under that circumstance, the operator must stop the system, manually reset the interface, and then restart the system.

**Unexplained Failures.** Failures in this category may have been caused by operator errors, operating system bugs, power fluctuations, or various other mysterious causes. Yourdon comments that the very nature of the Burroughs 5500 system discourages the user from investigating such failures.

**Total Failures.** This line is the sum of the previous five categories, and is used as the basis for the percentage computations given below. It does *not* include the "insufficient memory" category described next.

**Insufficient Memory.** When the Burroughs operating system doesn't have enough allocatable memory to continue with the application programs already in progress, it may reach a point where no one program can proceed with its execution. It then types out a cryptic message "NO MEM", and waits for the computer operator to take some action. In many cases, though the situation could be remedied by terminating just one of the two jobs, the operator nevertheless chooses to restart the entire system. Although this represents a system failure as far as the user is concerned, it is of the nature of an operator error (or a mistake in software system design) and I therefore choose not to include it with other system errors.

**Comment.** The records apparently show no failures specifically attributable to hardware problems like processor failures, memory parity errors, or peripheral equipment breakdowns. Yourdon does not comment on this fact, except to imply that peripheral failures rarely cause a failure of the entire *system*, because the system can usually continue to run in a degraded mode.

## TABLE II.2.23.10 RELIABILITY OF AN OPERATING SYSTEM—NOTES

Between 1970 and 1973 the Chi Corporation in Cleveland, Ohio, designed an operating system called Chi/05 for the Univac 1108. The data in this table describes system reliability during the first thirteen months the system was in operation (LyncW75). The system operates 22 days per month, in that time handling about 35,000 service bureau jobs. Seventy-five percent of the workload comes from commercial accounts, the rest from academic and administrative jobs for Case Western Reserve University.

The table is self-explanatory, though "minutes lost" is not precisely defined (does it include job rerun time? system reload and initialization?) and "system crashes" are defined only as "operationally observed deficiencies" (do they include deficiencies like ambiguous messages to a computer operator or to a remote batch terminal?) Total operating time was not reported, though the software failures were said to have cost less than one percent of available system time.

## TABLE II.2.23.11 RELIABILITY OF A DUAL IBM 370/165 SYSTEM—NOTES

In June, 1972, Hughes Aircraft Company completed installation of a dual IBM 370/165 to handle a mixed batch and time-sharing load. The computer center managers reported (ReynC75), "It soon became clear that we couldn't keep the systems running very well. In discussions with IBM, we could get no satisfactory answers as to why or what we could do about it." The data shown in the table was collected to help identify and solve the problems.

The first section of the table shows various categories of failures, apparently over the two-and-one-half year period from the middle of 1972 to the end of 1974. A "failure" is undefined, but probably is a system crash requiring an Initial Program Load (IPL).

The second portion of the table shows operating times, number of IPL's, average down time, and some factors computed from these numbers for the five half-years and for the total period. Operational time is the difference between total time and scheduled down time. Available time is the difference between operational and unscheduled down time (except for the second half of 1974, which may be a misprint). Percent available is the ratio of available to operational time. Note the number of unscheduled IPL's is within 5% of the number of failures in the first part of the table. Mean Time Between Failures (MTBF) is the ratio of available hours to number of IPL's, and Mean Down Time the ratio of unscheduled down time to number of IPL's.

The paper gave no data about service interruptions which did not lead to IPL's—inclusion of such problems would make the statistics worse, of course. It did point out that the median MTBF was about half the average MTBF.

### TABLE II.2.23.9 FAILURE ANALYSIS OF BURROUGHS 5500 SYSTEMS

| | Month and Year Failures Occurred | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4/69 | 8/69 | 9/69 | 10/69 | 11/69 | 5/70 | 6/70 | 7/70 | Aver. |
| **Failures per Month** | | | | | | | | | |
| Unexpected I/O Intercepts | 1.1 | 1.2 | 2.3 | 2.4 | 0.8 | 1.7 | 1.2 | 2.0 | 1.6 |
| Disk Failures | 13.6 | 5.9 | 12.3 | 16.1 | 14.9 | 13.2 | 17.5 | 14.2 | 13.5 |
| Operating System Bugs | 2.2 | 2.4 | 3.1 | 3.1 | 3.7 | 3.7 | 4.6 | 3.3 | 3.3 |
| Multiplexor "hang-ups" | 2.3 | 0.4 | 0.6 | 1.8 | 0.6 | 1.3 | 0.2 | 0.5 | 1.0 |
| Unexplained | 19.0 | 20.6 | 24.8 | 28.4 | 23.2 | 16.2 | 19.8 | 18.0 | 21.3 |
| Total Failures | 38.2 | 30.5 | 43.1 | 51.8 | 43.2 | 36.1 | 43.3 | 38.0 | 40.5 |
| Insufficient Memory | 10.2 | 7.6 | 5.4 | 6.6 | 8.7 | 7.4 | 10.3 | 11.2 | 8.4 |
| **Percent of Tot. Failures** | | | | | | | | | |
| Unexpected I/O Intercepts | 2.9 | 3.9 | 5.3 | 4.6 | 1.9 | 4.7 | 2.8 | 5.3 | 4.0 |
| Disk Failures | 35.6 | 19.3 | 28.5 | 31.1 | 34.5 | 36.6 | 40.4 | 37.4 | 33.3 |
| Operating System Bugs | 5.8 | 7.9 | 7.2 | 6.0 | 8.6 | 10.2 | 10.6 | 8.7 | 8.1 |
| Multiplexor "hang-ups" | 6.0 | 1.3 | 1.4 | 3.5 | 1.4 | 3.6 | 0.5 | 1.3 | 2.5 |
| Unexplained | 49.7 | 67.5 | 57.5 | 54.8 | 53.7 | 44.9 | 45.7 | 47.4 | 52.6 |

### TABLE II.2.23.10 RELIABILITY OF AN OPERATING SYSTEM

| Date | Software Failures | | | Hardware Failures | | |
|---|---|---|---|---|---|---|
| | Number of | Minutes Lost | | Number of | Minutes Lost | |
| | Crashes | Total | Per Crash | Crashes | Total | Per Crash |
| 12/73 | 20 | 529 | 26.5 | 14 | 171 | 12.2 |
| 1/74 | 14 | 157 | 11.2 | 15 | 179 | 11.9 |
| 2/74 | 13 | 193 | 14.8 | 11 | 166 | 15.1 |
| 3/74 | 12 | 265 | 22.1 | 6 | 185 | 30.8 |
| 4/74 | 9 | 79 | 8.8 | 9 | 201 | 22.3 |
| 5/74 | 9 | 61 | 6.8 | 7 | 121 | 17.3 |
| 6/74 | 9 | 143 | 15.9 | 6 | 44 | 7.3 |
| 7/74 | 8 | 336 | 42.0 | 11 | 948 | 86.2 |
| 8/74 | 7 | 81 | 11.6 | 5 | 84 | 16.8 |
| 9/74 | 6 | 47 | 7.8 | 7 | 121 | 17.3 |
| 10/74 | 6 | 53 | 8.8 | 2 | 75 | 37.5 |
| 11/74 | 2 | 9 | 4.5 | 2 | 8 | 4.0 |
| 12/74 | 6 | 30 | 5.0 | 6 | 27 | 4.5 |
| Total | 121 | 1983 | 16.4 | 101 | 2330 | 23.1 |

### TABLE II.2.23.11 RELIABILITY OF A DUAL IBM 370/165 SYSTEM

| Time Period: | | Total | 1972 | 1973 | | 1974 | |
|---|---|---|---|---|---|---|---|
| | Units | | 2nd Half | 1st Half | 2nd Half | 1st Half | 2nd Half |
| Failure Distribution | | | | | | | |
| By Cause of Failure | | | | | | | |
| Hardware | | 966 | | | | | |
| Software | | 478 | | | | | |
| Applications | | 36 | | | | | |
| Operations | | 139 | | | | | |
| Other | | 343 | | | | | |
| Unknown | | 40 | | | | | |
| Reconfiguration | | 172 | | | | | |
| Total | | 2174 | | | | | |
| Time Distribution | | | | | | | |
| Total | hrs. | 21,912 | 4,392 | 4,368 | 4,392 | 4,368 | 4,392 |
| Scheduled Down | hrs. | 1,874 | 248 | 359 | 379 | 369 | 519 |
| Operational | hrs. | 20,038 | 4,144 | 4,009 | 4,013 | 3,999 | 3,873 |
| Unscheduled Down | hrs. | 1,628 | 421 | 356 | 379 | 247 | 325 |
| Available | hrs. | 18,286 | 3,723 | 3,653 | 3,634 | 3,752 | 3,524 |
| Percent Available | % | 91.8 | 89.8 | 91.1 | 90.6 | 93.8 | 91.6 |
| Unscheduled IPL's* | | 2,063 | 484 | 458 | 405 | 326 | 390 |
| MTBF | hrs. | 8.86 | 7.69 | 7.98 | 8.97 | 11.51 | 9.04 |
| Mean Down Time | hrs. | 0.79 | 0.87 | 0.78 | 0.94 | 0.76 | 0.83 |

*IPL = Initial Program Load

## TABLE II.3.11.1 COMPUTER INSTALLATIONS BY SIC CODE—NOTES

This table provides data showing how the use of computers has grown and changed in various industries since the early fifties. The industries are categorized by the U.S. Government's Standard Industrial Classification numbers. Each major section of the table, identified by boldface type in the discussion below, contains data on these important segments of American industry.

**Percent of All U.S. GP Computers in Use.** The columns in this section of the table provide data from various sources on the distribution, by percent, of computers in the various industrial classifications. The columns are arranged chronologically, and each provides information on a different year. In subsequent sections of this table, I will use the data for the years 1953, 1959, 1966, and 1969. Data for the years 1957, 1967, 1968, and 1974 is included for purposes of comparison.

Data for the years 1953, 1959, and 1966 comes from a study carried out for the Business Equipment Manufacturers Association (BoozA68). In that report, the sources given are: 1953, Survey of Automatic Digital Computers by Office of Naval Research; 1959, Census of Installed Computers by the General Electric Corporation; and 1966, International Data Corporation Census.

The 1957 data is from an article in *Computers and Automation* which reported the results of a survey of 81 IBM 650 sites. (FiedE57) The survey reported no U.S. government computer usage, and so I have adjusted the results by arbitrarily adding enough computers that federal government installations become one-third of the total. Of the manufacturing installations, the article identified 25% as "general manufacturing", 11% as "oil and gas" and 9% as "aircraft".

The 1967 data is derived from Table II.3.11.3. In that table I calculate the number of computers in each major industrial classification; and the numbers in the 1967 columns here are percentages derived from those numbers.

### TABLE II.3.11.1 COMPUTER INSTALLATIONS BY SIC CODE ●

| SIC Code | Industry | 1953 | 1957 | 1959 | 1966 | 1967 | 1968 | 1969 | 1974 |
|---|---|---|---|---|---|---|---|---|---|
| | **Percent of All U.S. GP Computers in Use** | | | | | | | | |
| | Source: | BEMA | C & A | BEMA | BEMA | IDC | C & A | IDC | C & A |
| 01-09 | Agriculture, Forestry, & Fisheries | 0 | | 0 | 0.2 | 0.1 | 0.3 | *0.2* | 0.3 |
| 10-14 | Mining | 0 | | 0.3 | 2.0 | 1.5 | 0.9 | 2.2 | 0.9 |
| 15-17 | Construction | 0 | | 0.4 | 0.4 | 0.3 | 0.5 | 0.4 | 0.9 |
| 19-39 | Manufacturing | 18.7 | 45 | 42.4 | 36.8 | 38.9 | 33.6 | 36.2 | 34.7 |
| 28 | Chemicals | 0 | | 4.0 | 3.4 | | 2.7 | 3.4 | 2.7 |
| 29 | Petroleum Refining | 3.3 | 11 | 5.8 | 0.6 | | 1.1 | | 0.7 |
| 35 | Machinery | 9.9 | | 3.4 | 5.4 | | 5.1 | 4.5 | 4.8 |
| 36 | Electrical Machinery | 1.1 | | 7.0 | 4.8 | | 4.9 | 4.5 | 4.8 |
| 37 | Transportation Equipment | 3.3 | 9 | 11.9 | 4.7 | | 2.2 | 4.4 | 2.4 |
| | Other Manufacturing | 1.1 | | 10.3 | 17.9 | | 17.6 | | 19.3 |
| 40-49 | Transportation, Commun., Utilities | 3.3 | 3 | 8.2 | 7.9 | 6.5 | 6.1 | 6.3 | 5.7 |
| | Transportation | 0 | | 3.0 | 3.0 | | 3.0 | | 3.1 |
| 48 | Communications | 2.2 | | 1.1 | 2.4 | | 1.5 | | 1.2 |
| 49 | Electric, Gas, Sanitary Serv. | 1.1 | | 4.1 | 2.5 | | 1.5 | | 1.4 |
| 50-59 | Wholesale & Retail Trade | 0 | | 1.3 | 6.9 | 7.2 | 10.5 | 7.8 | 12.7 |
| 60-67 | Finance, Ins., & Real Estate | 1.1 | 13 | 9.9 | 17.3 | 17.3 | 15.3 | 16.1 | 11.8 |
| 60 | Banking | 0 | | 2.6 | 8.5 | | | 7.9 | |
| 63 | Insurance | 1.1 | | 6.7 | 6.7 | | | 5.4 | 3.7 |
| | Other | 0 | | 0.6 | 2.1 | | | 2.8 | |
| 70-89 | Services | 23.1 | | 14.6 | 14.5 | 14.9 | 23.1 | 17.5 | 24.5 |
| 73 | Business Services | 0 | | 8.5 | 6.0 | | 11.2 | 9.4 | 13.3 |
| 82 | Education | 19.8 | | 6.1 | 6.4 | | 9.5 | 6.3 | 7.3 |
| | Other | 3.3 | | 0 | 2.1 | | 2.4 | 1.8 | 3.9 |
| 91-94 | Government | 53.8 | | 22.9 | 13.4 | 13.3 | 9.8 | 12.1 | 8.5 |
| 91 | Federal | 53.8 | 33 | 20.5 | 9.6 | 9.3 | | 7.5 | |
| | Other | 0 | | 2.4 | 3.8 | 4.0 | | 4.6 | |
| 99 | Non-Classifiable | 0 | 7 | 0 | 0.6 | | | 1.2 | |
| | **No. of Computers in Use GP U.S. (000)**—Total | .091 | 1.26 | 3.11 | 28.3 | 35.6 | 41.0 | 46.0 | 65.0 |
| 01-09 | Agriculture, Forestry, & Fisheries | 0 | | 0 | .057 | | | .092 | |
| 10-14 | Mining | 0 | | .009 | .566 | | | 1.012 | |
| 15-17 | Construction | 0 | | .012 | .113 | | | .184 | |
| 19-39 | Manufacturing | .017 | | 1.319 | 10.414 | | | 16.652 | |
| 49-49 | Transportation, Commun., Utilities | .003 | | .255 | 2.236 | | | 2.898 | |
| 50-59 | Wholesale & Retail Trade | 0 | | .040 | 1.953 | | | 3.588 | |
| 60-67 | Finance, Ins., & Real Estate | .001 | | .308 | 4.896 | | | 7.406 | |
| 70-89 | Services | .021 | | .454 | 4.104 | | | 8.050 | |
| 91-94 | Government | .049 | | .712 | 3.792 | | | 5.566 | |

**TABLE II.3.11.1 COMPUTER INSTALLATIONS BY SIC CODE (continued) ●**

| SIC Code | Industry | 1953 | 1957 | 1959 | 1966 | 1967 | 1968 | 1969 | 1974 |
|---|---|---|---|---|---|---|---|---|---|
| | **National Income ($B)** | | | | | | | | |
| 01-09 | Agriculture, Forestry, & Fisheries | 16.8 | | 16.3 | 22.5 | | | 24.8 | 45.6 |
| 10-14 | Mining | 5.5 | | 5.5 | 6 | | | 6.8 | 11.3 |
| 15-17 | Construction | 15.2 | | 21.7 | 35 | | | 40.7 | 60.6 |
| 19-39 | Manufacturing | 97.3 | | 119.6 | 191.8 | | | 221.9 | 306.1 |
| 40-49 | Transportation, Commun., Utilities | 26.2 | | 33.0 | 49.7 | | | 58.6 | 86.0 |
| 50-59 | Wholesale & Retail Trade | 52.4 | | 66.4 | 91.5 | | | 114.8 | 166.1 |
| 60-67 | Finance, Ins., & Real Estate | 26.4 | | 40.1 | 67.1 | | | 82.8 | 127.3 |
| 70-89 | Services | 28.8 | | 45.9 | 71.0 | | | 94.6 | 150.1 |
| 91-94 | Government | 34.9 | | 49.0 | 84.6 | | | 114.3 | 177.9 |
| | Total | 306 | 367 | 401 | 621 | 654 | 711 | 776 | 1143 |
| | **Employment (Millions)** | | | | | | | | |
| 01-09 | Agriculture, Forestry, & Fisheries | NA | | NA | NA | | | NA | NA |
| 10-14 | Mining | .852 | | .676 | .628 | | | .628 | .672 |
| 15-17 | Construction | 2.622 | | 2.767 | 3.281 | | | 3.411 | 3.985 |
| 19-39 | Manufacturing | 17.23 | | 16.168 | 19.081 | | | 20.121 | 20.016 |
| 40-49 | Transportation, Commun., Utilities | 4.221 | | 3.902 | 4.137 | | | 4.448 | 4.699 |
| 50-59 | Wholesale & Retail Trade | 10.52 | | 11.385 | 13.220 | | | 14.644 | 17.011 |
| 60-67 | Finance, Ins., & Real Estate | 2.038 | | 2.425 | 3.086 | | | 3.559 | 4.161 |
| 70-89 | Services | 5.538 | | 6.525 | 9.582 | | | 11.103 | 13.506 |
| 91-94 | Government | 6.645 | | 8.127 | 10.850 | | | 12.227 | 14.285 |
| | **Proprietorships, Partnerships, Corporations (000)** | | | | | | | | |
| 01-09 | Agriculture, Forestry, & Fisheries | 3088 | | 3750 | 3326 | | | 3412 | |
| 10-14 | Mining | 55 | | 65 | 71 | | | 84 | |
| 15-17 | Construction | 614 | | 724 | 858 | | | 903 | |
| 19-39 | Manufacturing | 373 | | 375 | 405 | | | 405 | |
| 40-49 | Transportation, Commun., Utilities | 306 | | 344 | 371 | | | 367 | |
| 50-59 | Wholesale & Retail Trade | 2292 | | 2537 | 2497 | | | 2694 | |
| 60-67 | Finance, Ins. & Real Estate | 759 | | 925 | 1248 | | | 1258 | |
| 70-89 | Services | 1835 | | 2136 | 2645 | | | 2868 | |
| 91-94 | Government | Inap. | | Inap. | Inap. | | | Inap. | |
| | **Computers in Use** | | | | | | | | |
| | **Per $B National Income** | | | | | | | | |
| 01-09 | Agriculture, Forestry, & Fisheries | 0 | | 0 | 2.53 | | | 3.71 | |
| 10-14 | Mining | 0 | | 1.64 | 94.3 | | | 148.8 | |
| 15-17 | Construction | 0 | | .55 | 3.23 | | | 4.52 | |
| 19-39 | Manufacturing | .17 | | 11.03 | 54.3 | | | 75.0 | |
| 40-49 | Transporation, Commun., Utilities | .11 | | 7.73 | 45.0 | | | 49.5 | |
| 50-59 | Wholesale & Retail Trade | 0 | | .60 | 21.3 | | | 31.3 | |
| 60-67 | Finance, Ins., & Real Estate | .03 | | 7.68 | 73.0 | | | 89.4 | |
| 70-89 | Services | .73 | | 9.89 | 57.8 | | | 85.1 | |
| 91-94 | Government | 1.40 | | 14.53 | 44.8 | | | 48.7 | |
| | Total | 0.30 | 3.43 | 7.76 | 45.57 | 54.43 | 57.67 | 59.28 | 56.87 |
| | **Per Million Employed** | | | | | | | | |
| 01-09 | Agriculture, Forestry, & Fisheries | NA | | NA | NA | | | NA | |
| 10-14 | Mining | 0 | | 13.3 | 901 | | | 1611 | |
| 15-17 | Construction | 0 | | 4.34 | 34.4 | | | 53.9 | |
| 19-39 | Manufacturing | .99 | | 81.6 | 546 | | | 828 | |
| 40-49 | Transporation, Commun., Utilities | .71 | | 65.4 | 540 | | | 652 | |
| 50-59 | Wholesale & Retail Trade | 0 | | 3.51 | 148 | | | 245 | |
| 60-67 | Finance, Ins., & Real Estate | .49 | | 127 | 1587 | | | 2081 | |
| 70-89 | Services | 3.79 | | 69.6 | 428 | | | 725 | |
| 91-94 | Government | 7.37 | | 87.6 | 349 | | | 455 | |
| | **Per Thousand Organizations** | | | | | | | | |
| 01-09 | Agriculture, Forestry, & Fisheries | 0 | | 0 | .017 | | | .027 | |
| 10-14 | Mining | 0 | | .138 | 7.97 | | | 12.05 | |
| 15-17 | Construction | 0 | | .017 | .132 | | | .204 | |
| 19-39 | Manufacturing | .046 | | 3.52 | 25.7 | | | 41.1 | |
| 40-49 | Transportation, Commun., Utilities | .010 | | .741 | 6.03 | | | 7.90 | |
| 50-59 | Wholesale and Retail Trade | 0 | | .016 | .782 | | | 1.33 | |
| 60-67 | Finance, Ins., & Real Estate | .001 | | .333 | 3.92 | | | 5.89 | |
| 70-89 | Services | .011 | | .213 | 1.55 | | | 2.81 | |
| 91-94 | Government | Inap. | | Inap. | Inap. | | | Inap. | |

The 1968 and 1974 data is from two surveys based on records of computer installations owned by *Computers and Automation* (BurnE69 and BurnE75). Although there is some confusion in the table headings in the referenced articles, it seems clear that *the percentages shown here are percentages of total locations where computers are installaed, and not percentages of installed computers.* The figures are therefore not exactly comparable with others in this table. In addition, the 1974 data from BurnE75 has been modified by the addition of a number of computer installations in the "Service Bureau" category. Burnett omitted this category in his 1974 census, because he had estimated there were over 10,000 installations in service bureaus—a number far in excess of other estimates. I added enough installations to keep the proportion of 1974 "Service Bureau" installations at 9.1%, the same value Burnett had estimated for 1968.

Finally, the 1969 data is from *EDP/IR* of May 29, 1970. That issue contains a breakdown of computer installations in substantially more detail than I have included here.

**Number of Computers in Use.** The first line in this section of the table is from Table II.1.21. Other lines in the table were computed by applying the percentages from the first section of this table to the number on the first line.

**National Income and Employment.** The data in this portion of the table represents official government statistics from various issues of CenStatAb.

**Proprietorships, Partnerships, and Corporations.** This data also comes from CenStatAb. However, the Department of Commerce changed its data analysis procedures during the period of time covered here, and I was unable to find 1953 and 1959 data comparable to the 1966 and 1969 data. Specifically, the earlier data counted "firms" rather than proprietorships, partnerships, and corporations; and I derived the 1953 and 1959 data by adjusting the reported figures on "firms", taking into account the ratio of firms to PP & C's in each industry. I established this ratio by locating one year (1958) when data was available by industry on both bases.

**Computers in Use.** The last three sections of the table, showing computers in use per billion dollars of national income, per million people employed, and per thousand proprietorships, partnerships, and corporations, were computed by dividing the figures on number of computers in use by the data in national income, employment, and organizations from appropriate earlier sections of this table.

### TABLE II.3.11.2 INTERNATIONAL COMPUTER INSTALLATIONS BY SIC CODE—NOTES

Although the industrial classifications for countries other than the United States are not exactly the same as the American ones, one can interpret industry names in a fairly straightforward fashion. This table is the result of such an interpretation. The first two columns, describing British installations in 1963 and 1968, are from EmOff72, page 68. I interpreted the phrase "distributive trades" to mean "wholesale and retail trade". The only difficulty with the data appears to be that "business services" is lumped in with "insurance, banking, and finance", with the result that the latter category is somewhat understated and the former somewhat overstated in my derived table.

The Japanese figures are from JCUsag70, page 34. The principal difficulty of interpretation here is a category called "association and agricultural cooperative", which I lumped with "agriculture, forestry, and fisheries". Of the 166 computers in this latter category, 162 appeared as entries under "association and agricultural cooperative".

Note that the first line in the table shows the number of computer installations as given in the referenced sources. The numbers do not agree with our "consensus" figures in Table II.1.28.

### TABLE II.3.11.2 INTERNATIONAL COMPUTER INSTALLATIONS BY SIC CODE

| | Great Britain 1963 | Great Britain 1968 | Japan 1969 |
|---|---|---|---|
| Number Installed | 703 | 2108 | 5601 |
| Percent of Number Installed: | | | |
| Agriculture, Forestry, & Fisheries | 0.1 | 0.1 | 3.0 |
| Mining | 2.1 | 0.8 | 0.4 |
| Construction | 0.6 | 1.3 | 1.3 |
| Manufacturing | 46.9 | 48.5 | 40.1 |
| Transportation, Commun., Utilities | 9.5 | 6.4 | 5.4 |
| Wholesale & Retail Trade | 5.8 | 8.5 | 15.8 |
| Finance, Insurance, Real Estate | 18.3 | 16.7 | 10.5 |
| Services | 4.3 | 5.0 | 13.5 |
| Government | 12.2 | 12.6 | 9.8 |
| Misc. | | | 0.1 |

**TABLE II.3.11.3 COMPUTER INSTALLATIONS BY ORGANIZATION SIZE ●**

| Number of Employees: | 0-19 | 20-99 | 100-249 | 250-499 | 500-999 | 1k-2.49k | 2.5k-4.9k | Over 5000 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **1967 Establishments** | | | | | | | | | |
| Agriculture (01-09)—Plants | 28,305 | 1,478 | 90 | 12 | 1 | 0 | 0 | 0 | 29,886 |
| Percent with Computers | 0 | 0.29 | 12.22 | 66.67 | 100.0 | - | - | - | 0.08 |
| Number with Computers | 0 | 4 | 11 | 8 | 1 | - | - | - | 24 |
| Mining/Const. (10-18)—Plants | 295,757 | 30,189 | 3,354 | 752 | 220 | 68 | 9 | 1 | 330,350 |
| Percent with Computers | 0 | 0.23 | 1.94 | 10.64 | 27.73 | 100.0 | 100.0 | 100.0 | 0.11 |
| Number with Computers | 0 | 69 | 65 | 80 | 61 | 68 | 9 | 1 | 353 |
| Manufacturing (20-39)—Plants | 181,763 | 74,511 | 19,255 | 7,649 | 3,457 | 1,657 | 464 | 209 | 288,965 |
| Percent with Computers | 0.04 | 0.43 | 3.24 | 14.66 | 52.88 | 100.0 | 100.0 | 100.0 | 2.18 |
| Number with computers | 73 | 320 | 623 | 1120 | 1828 | 1657 | 464 | 209 | 6,294 |
| Nat. Prod. (20-31)—Plants | 110,263 | 44,133 | 11,562 | 4,354 | 1,656 | 645 | 111 | 20 | 172,744 |
| Percent with Computers | 0.04 | 0.40 | 3.12 | 11.60 | 42.70 | 100.0 | 100.0 | 100.0 | 1.49 |
| Number with Computers | 44 | 177 | 361 | 505 | 707 | 645 | 111 | 20 | 2,570 |
| Dur. Goods (32-39)—Plants | 71,500 | 30,378 | 7,693 | 3,295 | 1,801 | 1,012 | 353 | 189 | 116,221 |
| Percent with Computers | 0.04 | 0.47 | 3.41 | 18.70 | 62.24 | 100.0 | 100.0 | 100.0 | 3.20 |
| Number with Computers | 29 | 143 | 262 | 615 | 1,121 | 1,012 | 353 | 189 | 3,724 |
| Commun./Trans. (40-49)—Plants | 104,494 | 18,765 | 3,064 | 944 | 407 | 228 | 86 | 56 | 128,044 |
| Percent with Computers | 0.01 | 1.07 | 7.08 | 14.51 | 43.98 | 85.09 | 100.0 | 100.0 | 0.85 |
| Number with Computers | 10 | 201 | 217 | 137 | 179 | 194 | 86 | 56 | 1,080 |
| Trade (50-59)Plants | 1,217,463 | 113,595 | 8,760 | 1,905 | 575 | 280 | 67 | 19 | 1,342,664 |
| Percent with Computers | 0 | 0.23 | 4.65 | 17.74 | 31.13 | 50.70 | 100.0 | 100.0 | 0.11 |
| Number with Computers | 0 | 261 | 407 | 338 | 179 | 142 | 67 | 19 | 1,413 |
| Banking/Fin. (60-69)—Plants | 303,757 | 20,584 | 2,743 | 728 | 330 | 153 | 26 | 16 | 328,337 |
| Percent with Computers | 0.11 | 5.40 | 46.26 | 92.86 | 100.0 | 100.0 | 100.0 | 100.0 | 1.20 |
| Number with Computers | 348 | 1,112 | 1,269 | 676 | 330 | 153 | 26 | 16 | 3,930 |
| Personal Serv. (70-79)—Plants | 438,170 | 31,139 | 3,534 | 865 | 271 | 94 | 12 | 4 | 474,039 |
| Percent with Computers | 0 | 0.55 | 3.76 | 6.13 | 22.51 | 60.64 | 100.0 | 100.0 | 0.10 |
| Number with Computers | 0 | 171 | 133 | 53 | 61 | 57 | 12 | 4 | 491 |
| Medical/Edu. (80-89)—Plants | 442,275 | 24,512 | 3,777 | 1,391 | 850 | 319 | 50 | 16 | 473,190 |
| Percent with Computers | 0.09 | 4.68 | 11.36 | 16.10 | 31.29 | 76.18 | 100.0 | 100.0 | 0.59 |
| Number with Computers | 398 | 1,147 | 429 | 224 | 266 | 243 | 50 | 16 | 2773 |
| Totals—Number of Plants | 3,011,934 | 314,773 | 44,577 | 14,246 | 6,111 | 2,799 | 714 | 321 | 3,395,475 |
| Percent with Computers | 0.03 | 1.04 | 7.08 | 18.50 | 47.54 | 90.14 | 100.0 | 100.0 | 0.48 |
| Number with Computers | 829 | 3,285 | 3,154 | 2,636 | 2,905 | 2,514 | 714 | 321 | 16,358 |
| **1967 Computers** | | | | | | | | | |
| Computers Per Plant | 1.00 | 1.08 | 1.18 | 1.28 | 1.40 | 2.00 | 3.00 | 5.00 | 1.49 |
| Total Computers—Agriculture | 0 | 4 | 13 | 10 | 1 | - | - | - | 28 |
| Mining & Construction | 0 | 75 | 77 | 102 | 85 | 136 | 27 | 5 | 507 |
| Manufacturing | 73 | 346 | 735 | 1,434 | 2,559 | 3,314 | 1,392 | 1,045 | 10,898 |
| Commun./Trans. | 10 | 217 | 256 | 175 | 251 | 388 | 258 | 280 | 1,835 |
| Trade | 0 | 282 | 480 | 433 | 251 | 284 | 201 | 95 | 2,026 |
| Banking/Finance | 348 | 1,201 | 1,497 | 865 | 462 | 306 | 78 | 80 | 4,837 |
| Services | 398 | 1,423 | 663 | 355 | 458 | 600 | 186 | 100 | 4,183 |
| Subtotal | 829 | 3,548 | 3,721 | 3,374 | 4,067 | 5,028 | 2,142 | 1,605 | 24,314 |
| Government Syst.—Federal | | | | | | | | | 2,600 |
| State & Local | | | | | | | | | 1,120 |
| Grand Total Systems | | | | | | | | | 28,034 |
| **1971 Establishments** | | | | | | | | | |
| Total Number of Plants | 3,260,000 | 371,400 | 54,500 | 17,550 | 7,110 | 3,620 | 935 | 422 | 3,715,537 |
| Percent with Computers | 0.05 | 2.14 | 15 | 46 | 75 | 90 | 98 | 99.5 | 0.96 |
| Number with Computers | 1,630 | 7,950 | 8,290 | 8,000 | 5,330 | 3,260 | 915 | 420 | 35,795 |
| Computers Per Plant | 1.0 | 1.078 | 1.18 | 1.28 | 1.40 | 2.0 | 3.0 | 5.0 | 1.37 |
| Total Computers | 1,630 | 8,570 | 9,810 | 10,215 | 7,460 | 6,520 | 2,745 | 2,100 | 49,050 |
| Government Syst.—Federal | | | | | | | | | 3,585 |
| State & Local | | | | | | | | | 2,725 |
| Grand Total Systems | | | | | | | | | 55,360 |

## TABLE II.3.11.3 COMPUTER INSTALLATIONS BY ORGANIZATION SIZE—NOTES

The first and the larger section of this table describes computer usage in 1967; the latter portion shows a comparable distribution, in less detail, for 1971.

**1967 Establishments.** The data in this table comes from a private report which itself was based on an IDC report. For each of the major SIC codes, it provides three lines of information on each of eight plant (or establishment) sizes, where the size is based on the number of employees in the plant. The first of the three items is the number of plants, and represents Department of Commerce figures as of March 1968. The second line shows what percent of those plants have computers; and the third line, derived from the first and second, shows the number of plants with computers. At the end of this section of the table is a three-line entry entitled "Totals". The total number of plants, and total number of plants with computers was found by summing appropriate entries earlier in the table. The figure for "Percent with Computers" was derived by dividing the total number of plants with computers by the total number of plants.

**1967 Computers.** The first entry in this portion of the table, showing the numbers of GP computers per plant having at least one computer, was taken directly from the section of the table below on 1971 establishments. In other words, I assume that, for each size plant, the number of computers per plant having computers did not change between 1967 and 1971.

The next seven lines on the table were found by multiplying the "computers Per Plant" figure by the appropriate "number (of plants) with computers" from the earlier portion of the table. The next line, "subtotal", is the sum of the lines above it.

The private report included no estimate of the number of computers used by the government. The entries for federal and state and local government computers are my own estimates, based in part on the data from Table II.3.11.6 below, and in part on the data for 1971 establishments given in the next section. The resulting grand total of computers does *not* agree with the data base (line 107 of Table II.1.21) which shows 28,300 GP computers installed in the U.S. at the end of 1966, and 35,600 installed at the end of 1967.

The August 6, 1969 issue of *EDP/IR* shows the total number of units having computers in each plant size category, and the results agree closely with the totals shown above. The *EDP/IR* article states that the data is derived from their 1967 file, and it is that data which I have used here. The private report, based on presumably the same information and resulting in the same numbers, states that the installation data is as of the middle of 1968.

**1971 Establishments.** The information in this part of the table is from the *EDP/IR* issue of March 3, 1972. The article in that issue showed the number of establishments in each plant size category, along with the number of sites having computers and the total number of GP computers. From the latter two numbers, I computed the number of computers per site in each plant size category—it was these ratios which I used in connection with the 1967 data above. *EDP/IR* states that their figures on the number of plants in each size category as of the end of 1971 is an extrapolation of the Department of Commerce's 1968 data, which appears earlier in this table.

## TABLE II.3.11.4 BANKING AND HOSPITAL COMPUTER USE (Mid-1973)—NOTES

The raw data for both these tables comes from *EDP/IR*—the banking information from the March 27, 1974, issue, and the hospital information from the February 27, 1974, issue. Both reports were apparently summaries of more detailed IDC studies resulting from an analysis of the mid-1973 IDC file of computer installations. Note that these figures only take into account organizations which have computers; and that the column headings here refer to the value of computer equipment at each site, and not to the size of the banking or hospital organization.

For each of the two industry types, and for each category of installation size, the raw data specifies how many sites exist, how many CPU's are installed at those sites, and the total value of the computer equipment at those sites. From these figures I have computed the average value of equipment in each site, the average value per CPU at each site, and the average number of CPU's per site. Finally, I show percentage distributions for sites, CPU's and total value. For example, the table states that: 8% of all banking sites but only 2% of all hospital sites are in the size range of $2M to $4M; that 14% of all the banking CPU's but only only 4% of all the hospital CPU's appear in installations that size; and that 19% of the total value of all computer equipment used in banking, and only 12% of that used in hospitals, is installed at sites in this size range.

## TABLE II.3.11.5 INSURANCE COMPANY COMPUTER USE—NOTES

The raw data in this table also comes from *EDP/IR*, representing another analysis of their mid-1973 data base summarized in the issue dated January 30, 1974. This analysis shows the number of corporations having computer equipment in each of a variety of *corporate* size categories, as contrasted with Table II.3.11.4, where the data is organized by *computer system* size categories. The first portion of the table gives data on six different corporate sizes all with less than $0.5B in assets. In the lower part of the table, the first four columns describe computer usage in four larger size categories; the fifth column is a subtotal summary of the previous ten; the sixth gives data on computer installations at corporations whose size is not known; and the last column is a summary of all previous columns.

The basic data describes the average assets, number of corporation sites and CPU's, and the total value of computer equipment in each corporate size category. From this data, a number of averages are computed. In addition, percentage distributions are shown. Note that the percentage distributions are based only on the data for corporations whose size was identified.

## TABLE II.3.11.6 COMPUTER USAGE DATA FOR SOME SPECIFIC ORGANIZATIONS—NOTES

This table provides data on the chronology of computer usage for a variety of different kinds of organizations. The organization types were chosen solely on the grounds that data was available.

**Federal Government.** The U.S. government has, from the beginning, been a big user of computer equipment. It has sponsored the development of special systems, and has purchased commercially available systems. Because of the importance of the computer to government operations, and

TABLE II.3.11.4 BANKING AND HOSPITAL COMPUTER USE (MID-1973)

| | Units | Value of Computer Equipment at a Site | | | | | | Totals |
|---|---|---|---|---|---|---|---|---|
| | | Under $500k | $500k to $1M | $1M to $2M | $2M to $4M | $4M to $8M | Over $8M | |
| **Banking Installations** | | | | | | | | |
| No. of Sites | | 607 | 341 | 195 | 110 | 50 | 24 | 1327 |
| No. of CPU's | | 655 | 453 | 414 | 322 | 260 | 261 | 2365 |
| Value of Systems | $M | 155 | 227 | 269 | 296 | 273 | 323 | 1543 |
| Average—Value Per Site | $k | 255.4 | 665.7 | 1379.5 | 2690.9 | 5460.0 | 13458.3 | 1162.8 |
| Value Per CPU | $k | 236.7 | 501.1 | 649.8 | 919.3 | 1050.0 | 1237.5 | 652.4 |
| CPU's Per Site | | 1.08 | 1.33 | 2.12 | 2.93 | 5.20 | 10.88 | 1.78 |
| Percentage Distributions | | | | | | | | |
| All Sites | % | 45 | 26 | 15 | 8 | 4 | 2 | 100 |
| All CPU's | % | 28 | 19 | 17 | 14 | 11 | 11 | 100 |
| Total Value in Use | % | 10 | 15 | 17 | 19 | 18 | 21 | 100 |
| **Hospital Installations** | | | | | | | | |
| No. of Sites | | 531 | 140 | 53 | 15 | 3 | 0 | 742 |
| No. of CPU's | | 613 | 187 | 115 | 38 | 11 | 0 | 964 |
| Value of Systems | $M | 100.4 | 97.1 | 71.2 | 37.6 | 13.8 | 0 | 320.1 |
| Average—Value Per Site | $k | 189.1 | 693.6 | 1343 | 2507 | 4600 | - | 431.4 |
| Value Per CPU | $k | 163.8 | 519.3 | 619.1 | 989.4 | 1254.5 | - | 332.1 |
| CPU's Per Site | | 1.15 | 1.34 | 2.17 | 2.53 | 3.67 | - | 1.30 |
| Percentage Distributions | | | | | | | | |
| All Sites | % | 72 | 19 | 7 | 2 | - | - | 100 |
| All CPU's | % | 64 | 20 | 12 | 4 | 1 | - | 100 |
| Total Value in Use | % | 31 | 30 | 22 | 12 | 4 | - | 100 |

TABLE II.3.11.5 INSURANCE COMPANY COMPUTER USE (1973)

| | | Corporate Assets, Where Known | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Under $1M | $1M -$5M | $5M -$10M | $10M -$50M | $50M -$100M | $100M -$0.5B | |
| Average Assets | $M | 0.6 | 2.4 | 6 | 24 | 60 | 240 | |
| No. of—Corporations | | 28 | 70 | 73 | 139 | 71 | 26 | |
| Sites | | 28 | 70 | 73 | 139 | 71 | 26 | |
| CPU's | | 32 | 84 | 83 | 189 | 134 | 73 | |
| Value of Systems | $M | 3.0 | 16.4 | 31.7 | 137.7 | 126.9 | 95.1 | |
| Averages—Value Per Corp. | $k | 107 | 234 | 434 | 991 | 1787 | 3658 | |
| Value Per Site | $k | 107 | 234 | 434 | 991 | 1787 | 3658 | |
| Value Per CPU | $k | 94 | 195 | 382 | 729 | 947 | 1303 | |
| Value Per Asset $ | % | 17.9 | 9.8 | 7.2 | 4.1 | 3.0 | 1.5 | |
| CPU Per Corp. | | 1.14 | 1.20 | 1.14 | 1.36 | 1.89 | 2.81 | |
| CPU Per Site | | 1.14 | 1.20 | 1.14 | 1.36 | 1.89 | 2.81 | |
| Sites Per Corp. | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| Percentage Distributions | | | | | | | | |
| All Sites | % | 5.1 | 12.6 | 13.2 | 25.1 | 12.8 | 4.7 | |
| All CPU's | % | 3.0 | 7.8 | 7.7 | 17.6 | 12.5 | 6.8 | |
| Value in Use | % | 0.3 | 1.7 | 3.3 | 14.6 | 13.4 | 10.1 | |
| | | Corporate Assets, Where Known | | | | | Assets | Total |
| | | $0.5B -$1B | $1B -$5B | $5B -$10B | Over $10B | Sub-Total | Un-known | Assets |
| Average Assets | | 600 | 2000 | 6000 | 21700 | 332.0 | Unk. | Unk. |
| No. of—Corporations | | 34 | 17 | 7 | 4 | 469 | 306 | 775 |
| Sites | | 81 | 20 | 32 | 14 | 554 | 306 | 860 |
| CPU's | | 193 | 84 | 77 | 123 | 1072 | 438 | 1510 |
| Value of Systems | $M | 174.7 | 107.9 | 112.6 | 139.6 | 945.6 | 344.0 | 1289.6 |
| Averages—Value Per Corp. | $k | 5138 | 6348 | 16079 | 34900 | 2016 | 1124 | 1664 |
| Value Per Site | $k | 2157 | 5395 | 3519 | 9971 | 1719 | 1124 | 1500 |
| Value Per CPU | $k | 905 | 1285 | 1462 | 1135 | 882 | 785 | 854 |
| Value Per Asset $ | % | 0.86 | 0.32 | 0.27 | 0.16 | 0.62 | Unk. | Unk. |
| CPU Per Corp. | | 5.68 | 4.94 | 11.00 | 30.75 | 2.29 | 1.43 | 1.95 |
| CPU Per Site | | 2.38 | 4.20 | 2.41 | 8.79 | 1.95 | 1.43 | 1.76 |
| Sites Per Corp. | | 2.38 | 1.18 | 4.57 | 3.50 | 1.17 | 1.00 | 1.11 |
| Percentage Distributions | | | | | | | | |
| All Sites | % | 14.6 | 3.6 | 5.8 | 2.5 | 100 | | |
| All CPU's | % | 18.0 | 7.8 | 7.2 | 11.5 | 100 | | |
| Value in Use | % | 18.5 | 11.7 | 11.9 | 14.8 | 100 | | |

because of the large amounts of money spent for their procurement and operation, there has always been a good deal of interest in federal computer usage. The data in this section of the table comes from a series of annual reports (GSAInv) describing and quantifying the federal government's inventory of computers.

1-3. These lines show the number of computers in use within the federal government on June 30 of each year. For purposes of the inventory, a computer is a digital, stored-program central processing unit. General Management computers "have general utility characteristics" and are subject to a full reporting of costs, man-power, and use. Special Management computers are either part of control systems, or are systems whose physical location is classified, or are mobile systems located on ships, planes, or vans. The "special" category thus includes many minicomputers and many specially-designed systems. However, some minisystems appear in the "general management" category, and some GP systems in the "special" category, so no generalizations can be made about the relationship between these government inventories and the (quite arbitrary, of course) GP and mini categories we established in Chapter 1 of this book.

Although many fire-control systems meet all the above "special managment" criteria, none are included in the government inventory.

**Purchased vs. Leased Systems.** 4-9. Lines 4, 6, and 8 show the total number of computers, and the number of computers in the GM and Special categories, that are owned by the government. Lines 5, 7, and 9 show lines 4, 6, and 8 as percentages of lines 1, 2, and 3.

**Manufacturers.** 10-29. Lines 10 through 19 show the number of computers manufactured by each of the major system manufacturers; and lines 20 through 29 show those numbers as a percentage of the total number of computers on line 1.

**System Value.** 30-33. The original purchase price of all systems in use is given on line 30, and lines 31 and 32 break that total down into General Management and Special computer systems. The data for 1971 and 1972 comes from GSAInv73. The other figures are from private communications from the General Services Administration. Line 33 is the quotient of line 30 and line 1.

**Annual Costs.** The next entries show annual costs as described and detailed below. For the years up until and including 1966, all operating costs are included; for the years since 1967, the costs include all General Management system costs plus the costs of the mobile systems in the "Special" category. In addition, *these costs include the costs of operating punched card accounting machines*, though those machines are not included in the inventories described above.

34-35. Equipment purchases are the monies spent for computers, punched card accounting machines, and other hardware (like continuous form bursters and magnetic tape storage files) unique to the support of data processing operations. Site preparation costs include expenditures for construction, modification, or alteration of space in preparation for the installation of data processing equipment.

36. Equipment rental includes the cost of peripheral and off-line equipment as well as the rental of processors and memories. Punched card accounting machines are included, as usual, and maintenance costs are included when they are part of the basic rental price.

37-38. Salaries include the regular time and overtime salaries of civilian employees, and the base pay and allowances of military personnel. All personnel directly identified with automatic data processing functions *as their principal duty* are included. Contractual services include the cost of outside machine time, of system analysis and programming services, of machine maintenance (when not included in the rental price above), of keypunching and key verifying services, and other similar services purchased from outside vendors.

39. Supplies include magnetic tapes, disk packs, printing paper, punched cards, and printer ribbons. It also includes spare parts and repair parts purchased for in-house maintenance of government-owned equipment.

40-41. The "other" category includes operating costs not specifically identified in earlier categories. And line 41 is the total of lines 34 to 40.

**Federal Government Users.** 42-65. Lines 42 through 53 show the number of computers (both general and special management) employed by each major government agency; and lines 54 through 65 show those numbers as a percentage of the total number of systems in use.

66-88. Lines 66 through 76 show how the various government agencies spent the monies shown on line 41 above; and lines 77 through 88 show those individual costs as a percent of line 41. Note that only the capital and operating costs associated with general management systems are shown here. There are no public records for the costs of operating the special systems.

**Banking Applications.** 89-98. This data is from *Banking* magazine, which conducted detailed surveys in 1963, 1966, and 1969 regarding the use of computing equipment and services by banks. (RideB69.) Line 89 shows the total number of banks in the United States, and lines 90 through 93 estimate the number of banks having computers, using computer services, planning to employ computers or computer services, and having no plans. Lines 95 through 98 express lines 90 through 93 as a percentage of line 89. The percentages shown for 1972 and 1974 are from IDC's *Autotransaction Industry Report* for October 1, 1975, summarizing more recent *Banking* studies. The data I show in the 1974 column was actually for 1975. Line 94 shows the total number of CPU's installed in banks. (The 1973 data comes from *EDP/IR* of March 27, 1974.) For the years 1959, 1966, and 1969, the data on line 94 was derived from Table II.3.11.1, which shows the proportion of all U.S. GP computers installed in banks in those years.

**Process Control Applications.** 99-107. The data in this portion of the table comes from two sources, and is partly domestic and partly international. For the years up to and including 1964, the source is Dr. Thomas M. Stout, the president of Profimatics, Inc., and a pioneer in the application of computers to process control. His figures include installations in the United States only. For the years 1965 and later, the data is from an annual survey of worldwide process control applications, carried out and published by *Oil and Gas Journal*, and normally included in one of their December issues. The *Journal* only notes installations in the four categories given in lines 99 to 102.

**Insurance.** 108-111. The data on lines 108 to 110 comes from GropA70, page 102. The entries on line 111 for the

## TABLE II.3.11.6 COMPUTER USAGE DATA FOR SOME SPECIFIC ORGANIZATIONS

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Federal Government** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Total Computers | 3.11.20 | k | .045 | .090 | .160 | .250 | .403 | .531 | .730 | 1.030 | 1.326 | 1.862 | 2.412 | 3.007 | 3.692 | 4.232 | 4.660 | 5.277 | 5.934 | 6.731 | 7.149 | 7.830 |
| 2. | Genl. Management | | k | | | | | | | | | | | | | 2.754 | 2.909 | 3.039 | 3.404 | 3.389 | 3.433 | 3.432 | 3.487 |
| 2a. | Percent of Total | 3.11.20 | % | | | | | | | | | | | | | 74.6 | 68.7 | 65.1 | 64.5 | 57.1 | 51.0 | 48.0 | 44.5 |
| 3. | Special | | k | | | | | | | | | | | | | .938 | 1.323 | 1.627 | 1.873 | 2.545 | 5.298 | 3.717 | 4.343 |
| 4. | Computers Owned–Number | | k | | | | | .080 | .098 | .113 | .175 | .282 | .740 | 1.206 | 1.604 | 2.128 | 2.434 | 2.790 | 3.372 | 4.320 | 5.222 | 5.807 | 6.614 |
| 5. | Percent of Total | 3.11.21 | % | | | | | 19.8 | 18.5 | 15.4 | 17.0 | 21.3 | 39.7 | 50.0 | 53.3 | 57.6 | 57.5 | 59.8 | 63.9 | 72.8 | 77.6 | 81.2 | 84.5 |
| 6. | Genl. Management | | k | | | | | | | | | | | | | 1.362 | 1.405 | 1.527 | 1.753 | 2.049 | 2.165 | 2.304 | 2.481 |
| 7. | Percent of All G.M. | 3.11.21 | % | | | | | | | | | | | | | 49.5 | 48.3 | 50.2 | 51.5 | 60.5 | 63.1 | 67.1 | 71.1 |
| 8. | Special | | k | | | | | | | | | | | | | .766 | 1.029 | 1.263 | 1.619 | 2.271 | 3.057 | 3.503 | 4.133 |
| 9. | Pct. of All Special | 3.11.21 | % | | | | | | | | | | | | | 81.7 | 77.8 | 77.6 | 86.4 | 89.2 | 92.7 | 94.2 | 95.2 |
| 10. | Number Manufactured by–BGH | | | | | | | | 55 | | | | | 161 | 175 | 194 | 193 | 195 | 204 | 208 | 271 | | |
| 11. | CDC | | | | | | | | 1 | | | | | 249 | 332 | 352 | 400 | 404 | 404 | 459 | 482 | | |
| 12. | DEC | | | | | | | | 0 | | | | | 14 | 72 | 159 | 214 | 331 | 500 | 710 | 976 | | |
| 13. | HIS | | | | | | | | 1 | | | | | 106 | 145 | 193 | 247 | 271 | 298 | 465 | 550 | | |
| 14. | IBM | | | | | | | | 291 | | | | | 1020 | 1032 | 1105 | 1200 | 1311 | 1397 | 1428 | 1429 | | |
| 15. | NCR | | | | | | | | 7 | | | | | 195 | 188 | 194 | 249 | 268 | 321 | 298 | 239 | | |
| 16. | RCA | | | | | | | | 5 | | | | | 136 | 145 | 157 | 176 | 189 | 184 | 171 | 199 | | |
| 17. | Uni | | | | | | | | 50 | | | | | 352 | 596 | 796 | 903 | 950 | 1014 | 1053 | 1266 | | |
| 18. | XDS | | | | | | | | 0 | | | | | 14 | 112 | 162 | 186 | 209 | 229 | 283 | 314 | | |
| 19. | Other | | | | | | | | 121 | | | | | 165 | 210 | 380 | 464 | 538 | 726 | 886 | 1005 | | |
| 20. | Percent of Tot.–BGH | 3.11.22 | % | | | | | | 10.4 | | | | | 6.7 | 5.8 | 5.3 | 4.6 | 4.2 | 3.9 | 3.5 | 4.0 | | |
| 21. | CDC | 3.11.22 | % | | | | | | 0.2 | | | | | 10.3 | 11.1 | 9.5 | 9.5 | 8.7 | 7.7 | 7.7 | 7.2 | | |
| 22. | DEC | 3.11.22 | % | | | | | | 0 | | | | | 0.6 | 2.4 | 4.3 | 5.1 | 7.1 | 9.5 | 11.9 | 14.5 | | |
| 23. | HIS | | % | | | | | | 0.2 | | | | | 4.4 | 4.8 | 5.2 | 5.8 | 5.8 | 5.6 | 7.8 | 8.2 | | |
| 24. | IBM | 3.11.22 | % | | | | | | 54.8 | | | | | 42.3 | 34.3 | 29.9 | 28.4 | 28.1 | 26.4 | 24.0 | 21.2 | | |
| 25. | NCR | | % | | | | | | 1.3 | | | | | 8.1 | 6.3 | 5.3 | 5.8 | 5.7 | 6.1 | 5.0 | 3.6 | | |
| 26. | RCA | | % | | | | | | 0.9 | | | | | 5.4 | 4.8 | 4.2 | 4.2 | 4.0 | 3.5 | 2.9 | 3.0 | | |
| 27. | Uni | 3.11.22 | % | | | | | | 9.4 | | | | | 14.7 | 19.8 | 21.6 | 21.3 | 20.4 | 19.2 | 17.7 | 18.8 | | |
| 28. | XDS | | % | | | | | | 0 | | | | | 0.6 | 3.7 | 4.4 | 4.4 | 4.5 | 4.3 | 4.7 | 4.7 | | |
| 29. | Other | | % | | | | | | 22.8 | | | | | 6.9 | 7.0 | 10.3 | 10.9 | 11.5 | 13.8 | 14.9 | 14.8 | | |
| 30. | Value in Use–All Systems | | $B | | | | | | | | | | | | | 2.015 | 2.053 | 2.357 | 2.801 | 3.06 | 3.19 | | |
| 31. | Genl. Management | | $B | | | | | | | | | | | | | | | | | 2.27 | 2.27 | | |
| 32. | Special | | $B | | | | | | | | | | | | | | | | | .79 | .92 | | |
| 33. | Average Value–All Systems | | $k | | | | | | | | | | | | | 546 | 485 | 505 | 531 | 516 | 459 | | |
| | Ann. Costs–Genl. Mgnt. Comp. | | | | | | | | | | | | | | | | | | | | | | |
| 34. | Capital Costs–Eq. Purch. | | $M | | | | | | | | | | | | | 114 | 144 | 120 | 165 | 252 | 188 | 237 | 186 |
| 35. | Site Preparation | | $M | | | | | | | | | | | | | 17 | 16 | 25 | 33 | 17 | 26 | 29 | 30 |
| 36. | Oper. Costs–Eq. Rent | 3.11.23 | $M | | | | | | | | | | | | | 270 | 312 | 345 | 369 | 451 | 406 | 430 | 428 |
| 37. | Salaries | 3.11.23 | $M | | | | | | | | | | | | | 722 | 838 | 947 | 1099 | 1177 | 1267 | 1350 | 1372 |
| 38. | Contractual Services | | $M | | | | | | | | | | | | | 194 | 203 | 235 | 280 | 271 | 335 | 408 | 415 |
| 39. | Supplies | | $M | | | | | | | | | | | | | * | * | 84 | 85 | 82 | 83 | 85 | 98 |
| 40. | Other | | $M | | | | | | | | | | | | | 128 | 140 | 74 | 94 | 132 | 122 | 112 | 133 |
| 41. | Grand Total | 3.11.23 | $M | | | | | | 464 | 541 | 595 | 785 | 1096 | 1112 | 1284 | 1445 | 1653 | 1830 | 2125 | 2382 | 2427 | 2651 | 2662 |
| | Fed. Govt. Users | | | | | | | | | | | | | | | | | | | | | | |
| 42. | Number of Computers–AEC | | | | | | | | | | | | | | 256 | 324 | 415 | 559 | 754 | 954 | 1148 | | |
| 43. | Agriculture | | | | | | | | | | | | | | 28 | 32 | 37 | 39 | 42 | 68 | 66 | | |
| 44. | Commerce | | | | | | | | | | | | | | 47 | 41 | 53 | 59 | 73 | 99 | 142 | | |
| 45. | GSA | | | | | | | | | | | | | | 24 | 31 | 24 | 27 | 27 | 33 | 29 | | |
| 46. | HEW | | | | | | | | | | | | | | 45 | 57 | 80 | 84 | 96 | 88 | 67 | | |
| 47. | Interior | | | | | | | | | | | | | | 27 | 34 | 35 | 47 | 46 | 39 | 51 | | |

# TABLE II.3.11.6 COMPUTER USAGE DATA FOR SOME SPECIFIC ORGANIZATIONS

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48. | NASA | | | | | | | | | | | | | | 489 | 616 | 639 | 642 | 692 | 812 | 934 | | |
| 49. | Transportation | | | | | | | | | | | | | | 31 | 58 | 61 | 100 | 118 | 149 | 236 | | |
| 50. | Treasury | | | | | | | | | | | | | | 58 | 52 | 59 | 68 | 77 | 90 | 106 | | |
| 51. | V.A. | | | | | | | | | | | | | | 17 | 29 | 35 | 40 | 41 | 64 | 77 | | |
| 52. | Other Civil | | | | | | | | | | | | | | 62 | 83 | 100 | 103 | 112 | 150 | 142 | | |
| 53. | DOD | | | | | | | | | | | | | | 1923 | 2335 | 2694 | 2898 | 3199 | 3415 | 3733 | | |
| 54. | Percent of Tot. No.–AEC | 3.11.24 | % | | | | | | | | | | | | 8.5 | 8.8 | 9.8 | 12.0 | 14.3 | 16.0 | 17.1 | | |
| 55. | Agriculture | | % | | | | | | | | | | | | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 1.1 | 1.0 | | |
| 56. | Commerce | | % | | | | | | | | | | | | 1.6 | 1.1 | 1.3 | 1.3 | 1.4 | 1.7 | 2.1 | | |
| 57. | GSA | | % | | | | | | | | | | | | 0.8 | 0.8 | 0.6 | 0.6 | 0.5 | 0.6 | 0.4 | | |
| 58. | HEW | | % | | | | | | | | | | | | 1.5 | 1.5 | 1.9 | 1.8 | 1.8 | 1.5 | 1.0 | | |
| 59. | Interior | | % | | | | | | | | | | | | 0.9 | 0.9 | 0.8 | 1.0 | 0.9 | 0.7 | 0.8 | | |
| 60. | NASA | 3.11.24 | % | | | | | | | | | | | | 16.3 | 16.7 | 15.1 | 13.7 | 13.1 | 13.6 | 13.9 | | |
| 61. | Transportation | | % | | | | | | | | | | | | 1.0 | 1.6 | 1.4 | 2.1 | 2.2 | 2.5 | 3.5 | | |
| 62. | Treasury | 3.11.24 | % | | | | | | | | | | | | 1.9 | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 | 1.6 | | |
| 63. | V.A. | | % | | | | | | | | | | | | 0.6 | 0.8 | 0.8 | 0.9 | 0.8 | 1.1 | 1.1 | | |
| 64. | Other Civil | | % | | | | | | | | | | | | 2.1 | 2.3 | 2.4 | 2.2 | 2.1 | 2.5 | 2.1 | | |
| 65. | DOD | 3.11.24 | % | | | | | | | | | | | | 63.9 | 63.2 | 63.6 | 62.1 | 60.5 | 57.2 | 55.5 | | |
| | Genl. Mgnt. Ann. Cost–AEC | | $M | | | | | | | | | | | | | 99 | 120 | 135 | 130 | 160 | 116 | 124 | 147 |
| 66. | Agriculture | | $M | | | | | | | | | | | | | 21 | 18 | 24 | 26 | 34 | 49 | 50 | 43 |
| 67. | Commerce | | $M | | | | | | | | | | | | | 23 | 33 | 38 | 39 | 47 | 59 | 67 | 68 |
| 68. | GSA | | $M | | | | | | | | | | | | | 16 | 14 | 11 | 14 | 17 | 20 | 19 | 30 |
| 69. | HEW | | $M | | | | | | | | | | | | | 57 | 68 | 80 | 94 | 109 | 89 | 139 | 132 |
| 70. | Interior | | $M | | | | | | | | | | | | | 8 | 11 | 14 | 17 | 22 | 19 | 22 | 24 |
| 71. | NASA | | $M | | | | | | | | | | | | | 140 | 151 | 140 | 172 | 149 | 147 | 150 | 156 |
| 72. | Transportation | | $M | | | | | | | | | | | | | 12 | 14 | 14 | 17 | 23 | 24 | 32 | 31 |
| 73. | Treasury | | $M | | | | | | | | | | | | | 113 | 140 | 170 | 205 | 233 | 288 | 298 | 324 |
| 74. | V.A. | | $M | | | | | | | | | | | | | 18 | 20 | 30 | 40 | 32 | 37 | 44 | 39 |
| 75. | Other Civil | | $M | | | | | | | | | | | | | 58 | 72 | 81 | 90 | 139 | 163 | 207 | 198 |
| 76. | DOD | | $M | | | | | | | | | | | | | 880 | 992 | 1093 | 1281 | 1417 | 1416 | 1499 | 1470 |
| 77. | Percent of Tot. Cost–AEC | 3.11.25 | % | | | | | | | | | | | | | 6.9 | 7.3 | 7.4 | 6.1 | 6.7 | 4.8 | 4.7 | 5.5 |
| 78. | Agriculture | | % | | | | | | | | | | | | | 1.5 | 1.1 | 1.3 | 1.2 | 1.4 | 2.0 | 1.9 | 1.6 |
| 79. | Commerce | | % | | | | | | | | | | | | | 1.6 | 2.0 | 2.1 | 1.8 | 2.0 | 2.4 | 2.5 | 2.6 |
| 80. | GSA | | % | | | | | | | | | | | | | 1.1 | 0.9 | 0.6 | 0.7 | 0.7 | 0.8 | 0.7 | 1.1 |
| 81. | HEW | | % | | | | | | | | | | | | | 3.9 | 4.1 | 4.4 | 4.4 | 4.6 | 3.7 | 5.2 | 5.0 |
| 82. | Interior | | % | | | | | | | | | | | | | 0.6 | 0.7 | 0.8 | 0.8 | 0.9 | 0.8 | 0.8 | 0.9 |
| 83. | NASA | 3.11.25 | % | | | | | | | | | | | | | 9.7 | 9.1 | 7.7 | 8.1 | 6.3 | 6.1 | 5.7 | 5.9 |
| 84. | Transportation | | % | | | | | | | | | | | | | 0.8 | 0.8 | 0.8 | 0.8 | 1.0 | 1.0 | 1.2 | 1.2 |
| 85. | Treasury | 3.11.25 | % | | | | | | | | | | | | | 7.8 | 8.5 | 9.3 | 9.6 | 9.8 | 11.9 | 11.2 | 12.2 |
| 86. | V.A. | | % | | | | | | | | | | | | | 1.2 | 1.2 | 1.6 | 1.9 | 1.3 | 1.5 | 1.7 | 1.5 |
| 87. | Other Civil | | % | | | | | | | | | | | | | 4.0 | 4.4 | 4.4 | 4.2 | 5.8 | 6.7 | 7.8 | 15.0 |
| 88. | DOD | 3.11.25 | % | | | | | | | | | | | | | 60.9 | 60.0 | 59.7 | 60.3 | 59.5 | 58.3 | 56.5 | 55.2 |
| | **Banking** | | | | | | | | | | | | | | | | | | | | | | |
| 89. | Number of Banks–Total | | k | | | | | | | | | 14.00 | | | 13.995 | | | 13.574 | | | | | |
| 90. | Having Computers | | k | | | | | | | | | .485 | | | .943 | | | 1.032 | | | | 1.327 | |
| 91. | Using Computer Service | | k | | | | | | | | | .585 | | | 2.055 | | | 5.362 | | | | | |
| 92. | Planning to Automate | | k | | | | | | | | | 1.265 | | | 1.358 | | | .475 | | | | | |
| 93. | Having no Plans | | k | | | | | | | | | 11.665 | | | 9.638 | | | 6.706 | | | | | |
| 94. | No. of Comps.–Total | 3.11.14 | k | | | | | .081 | | | | | | | 2.41 | | | 3.63 | | | | 2.365 | |
| 95. | Percent of Banks–No Plans | | % | | | | | | | | | 83.3 | | | 68.9 | | | 49.4 | | | 34. | | 8. |
| 96. | Having Computers | 3.11.14 | % | | | | | | | | | 3.5 | | | 6.7 | | | 7.6 | | | 10. | | 35. |

## TABLE II.3.11.6 COMPUTER USAGE DATA FOR SOME SPECIFIC ORGANIZATIONS

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 97. | Using Comp. Services | 3.11.14 | % | | | | | | | | | 4.2 | | | 14.7 | | | 39.5 | | | 50. | | 55. |
| 98. | Planning to Automate | 3.11.14 | % | | | | | | | | | 9.0 | | | 9.7 | | | 3.5 | | | 6. | | 2. |
| | **Process Control** | | | | | | | | | | | | | | | | | | | | | | |
| 99. | Comps. in Use–Chemical | 3.11.26 | | | | | | 2 | 9 | 16 | 27 | 34 | 58* | 125 | 200 | 226 | 268 | 315 | 463 | 535 | 590 | 713 | 1029 |
| 100. | Refining | 3.11.26 | | | | | | 2 | 2 | 8 | 15 | 18 | 27* | 52 | 94 | 115 | 134 | 181 | 291 | 317 | 404 | 445 | 481 |
| 101. | Pipelines | 3.11.26 | | | | | | 1 | 1 | 2 | 5 | 7 | 12* | 21 | 34 | 71 | 115 | 125 | 164 | 247 | 273 | 313 | 353 |
| 102. | Petroleum Prodn. | 3.11.26 | | | | | | | | | | | 1* | 8 | 20 | 30 | 38 | 54 | 65 | 73 | 99 | 142 | 216 |
| 103. | Subtotal | 3.11.26 | | | | | | 5 | 12 | 26 | 47 | 59 | 98 | 206 | 348 | 442 | 555 | 675 | 983 | 1172 | 1366 | 1613 | 2079 |
| 104. | Power | | | | | | 1 | 2 | 11 | 20 | 38 | 71 | 101 | | | | | | | | | | |
| 105. | Steel | | | | | | | | 4 | 16 | 24 | 32 | 61 | | | | | | | | | | |
| 106. | Other | | | | | | | 1 | 2 | 4 | 7 | 20 | 44 | | | | | | | | | | |
| 107. | Total | | | | | | 1 | 8 | 29 | 66 | 116 | 182 | 303 | | | | | | | | | | |
| | **Insurance** | | | | | | | | | | | | | | | | | | | | | | |
| 108. | Companies with Computers | | | 17 | 35 | 57 | 78 | 107 | 126 | 160 | 201 | 226 | | | | | | | | | | | |
| 109. | Av. Comps. per Company | 3.11.15 | | 1.4 | 1.8 | 1.7 | 1.8 | 1.7 | 1.8 | 2.4 | 2.7 | 3.0 | | | | | | | | | | 1.95 | |
| 110. | Number of Computers | 3.11.15 | | 24 | 63 | 97 | 140 | 180 | 225 | 385 | 545 | 680 | | | | | | | | | | | |
| 111. | Other Estimates | 3.11.15 | | | | | | 208 | | | | | | | 1896 | | | 2484 | | | | 1510 | |

## TABLE II.3.11.7 MANUFACTURING COMPANIES' DATA PROCESSING STATUS IN 1968

| Company Size | Computer Status: Non-Users (%) | Outside Services (%) | Small Computers (%) | Larger Computers (%) | Number of Companies (Number) | Percent of Companies (%) |
|---|---|---|---|---|---|---|
| **By No. of Employees** | | | | | | |
| Under 50 | 87 | 12 | 1 | 0 | 165 | 11 |
| 50-99 | 71 | 27 | 2 | 0 | 255 | 17 |
| 100-199 | 66 | 27 | 7 | 0 | 315 | 21 |
| 200-299 | 46 | 32 | 22 | 0 | 180 | 12 |
| 300-399 | 41 | 26 | 33 | 0 | 105 | 7 |
| 400-499 | 30 | 28 | 42 | 0 | 75 | 5 |
| 500-999 | 17 | 15 | 65 | 3 | 180 | 12 |
| 1000-1999 | 8 | 7 | 79 | 6 | 90 | 6 |
| 2000 and over | 1 | 4 | 52 | 43 | 135 | 9 |
| Total | 48 | 21 | 26 | 5 | 1500 | 100 |
| **By Sales Volume** | | | | | | |
| Under $1M | 88 | 10 | 2 | 0 | 135 | 9 |
| $1M to $3M | 73 | 25 | 2 | 0 | 405 | 27 |
| $3M to $5M | 65 | 28 | 7 | 0 | 210 | 14 |
| $5M to $7M | 50 | 31 | 19 | 0 | 150 | 10 |
| $7M to $10M | 43 | 21 | 36 | 0 | 120 | 8 |
| $10M to $25M | 23 | 20 | 55 | 2 | 240 | 16 |
| $25M to $50M | 11 | 15 | 67 | 7 | 105 | 7 |
| Over $50M | 1 | 2 | 52 | 45 | 135 | 9 |
| Total | 49 | 21 | 25 | 5 | 1500 | 100 |

years 1959, 1966, and 1969 are derived from Table II.3.11.1, which estimates the percentage of all U.S. computers which were installed in the insurance industry in those years. The 1973 data is from *EDP/IR* January 30, 1974.

### TABLE II.3.11.7 MANUFACTURING COMPANIES' DATA PROCESSING STATUS IN 1968 — NOTES

Data in this table is from RIASurv69, which gave comparable figures on a smaller sample of Distribution and Service companies. The "Non-User" category is self-explanatory. "Outside Services" is defined as companies which use such services and have no computer of their own. A "small computer" is defined as an IBM 1400 series machine, a System/360 Model 20 or 30, a Honeywell H110, NCR Century 100, or an equivalent machine from other manufacturers. Apparently companies categorized as having "small computers" had such computers only, while companies with "larger computers" may have had both large and small machines.

The data is compiled from over 2400 questionaires returned by companies of various sizes, in various industries. The Research Institute made no attempt to extrapolate the results of its study to all companies, and expressed no opinion as to the "typicalness" of the respondents.

### TABLE 3.12.1 COMPUTER APPLICATIONS PER 100 INSTALLATIONS—NOTES

The data on computer applications supplied in this table comes from four different surveys covering a period of 13 years. In each study, a questionaire was sent to a variety of computer installations, and included one or more questions on the uses to which the installation's computers were put. The results appear here in a standard form, as the percent of respondents reporting they had implemented the specified application. Because some of the "applications" were more than usually ambiguous, I have chosen to show the actual reported application titles even though many of them undoubtably overlap. For example, the applications General Bookkeeping, General Ledger, Accounting, Financial Accounting, Accounts Receivable, and Accounts Payable are likely to overlap one way or another—the studies in general did not employ common nomenclature. In fact, as nearly as I can tell from available information, none of the studies even attempted to provide definitions of the different applications, and undoubtably the various respondents interpreted application titles in different ways.

Data in the first column is from FiedE67, and reports on a survey of 81 IBM 650 installations. The data is shown here exactly as it appeared in the original paper. The original format of the questionaire, and the exact calculations used in deriving the figures shown were not given. The fact that some sort of manipulation was carried out is indicated by the statement "the uses to which the computer is put were weighted to establish averages which would reflect the importance or rank of each use."

The next two columns provide results of two surveys of British computer usage, as reported in EmOff72. The questionaire which elicited the responses summarized here was published in the reference. It asks the question "What work is your ADP installation used for?", and provides seven specific choices plus the general choice "Other Office Work". (The categories "Invoicing and Billing", "Stock Control", and "General Statistics", I have categorized as "Billing", "Inventory Control", and "Engineering/Scientific Calculations". One category, entitled "Management Information Services", I included with "Other Identified Applications".) Note that all but 12% of the users in 1964 were able to categorize their applications in the seven groups shown, while in 1969 45% of the installations had to specify "Other" uses.

The data in the next six columns comes from a survey conducted by the Research Institute of America (RIASurv69). The report summarized "initial" and "present" applications for small computers (the equivalent of an IBM 360/20 or 30), medium computers (the equivalent of 360/40 or 50), and large computers (having the power and performance of a 360/65 or its equivalent). The actual dates corresponding to "initial" and "present" were not given, but I assumed that the latter referred to 1968, and derived the former from data given on the length of time each user had his own computer.

In the original report, the data was not given in the form presented here. Instead, the report showed the average number of applications per computer, and the percentages of all reported applications. For example, it indicated that there were originally a total of 3.9 applications per small computer in manufacturing companies, and that payroll, the most common initial application, represented 18% of all applications reported. Therefore, 100 installations would report 390 applications, and 18% of those applications, or a total of 70, would be payroll. The entries shown under "Other" in these six columns were computed by subtracting the sum of the identified computer applications from the grand total.

The particular applications shown in the RIA report were specifically listed in the questionaire. Apparently no provision was made for a user to identify any applications other than these 18.

Data in the last two columns comes from IDCAppl69. (See Table II.3.12.1 for more detail.) This study reported the results of a survey of over 2000 computer user organizations in the United States. The survey was conducted during the first six months of 1969, and included user companies in every sector of the economy. The two columns report the results from the manufacturing organizations, which represented 36% of the total, and from all respondents taken together.

The original report showed the total number of applications mentioned by each major industry grouping in each of 30 different categories. In addition, for each industry group there was reported a number under the heading "Other" representing specific applications which occurred less frequently than the first 30. I derived the numbers in Table 3.12.1 from the report by dividing the number of mentions by the total number of companies included in the survey. The survey indicated that "over 2000" companies responded, and I therefore use the number 2000 in my calculations—the number of applications per 100 installations would be lower than those shown, obviously, if a larger number of companies were used as the basis.

I have done a certain amount of combining and interpreting in putting together these figures. Specifically, I combined "Material Control" with "Inventory"; "Payroll/Banking" with "Payroll"; and "Shop Scheduling" with "Production Control". For example, the report showed that there were 1049 mentions of "Payroll" and 81 mentions of "Payroll/Banking" by all 2000 companies. I thus computed the number of payroll applications per hundred installations by adding 1049 to 81 and dividing the result by 20.

The report mentions that "over 300 applications" were identified in the course of the study. One category appearing in the summary is "Miscellaneous", and that very small relative number appears as the next to last entry in the table. I have assumed that other responses to the questionaire, not specifically shown in the tables, were nevertheless specific applications from the total group of 300. I therefore computed the "Other Identified Applications" by subtracting all other entries in each column (including "Miscellaneous") from the grand total at the bottom of the column.

## TABLE II.3.12.1 DISTRIBUTION OF COMPUTER TIME PER 100 SITES I—NOTES

The data in this table is from IDCAppl69, or was derived from that source. The first column shows the amount of computer time spent per month in each of the indicated applications in 100 installations. (The original source shows the total amount of computer time spent per month on each application by all installations responding to the questionaire. Since there were approximately 2000 different installations involved, I computed the numbers in the first column by dividing those in the source document by 20.) From the grand total at the bottom of this column, we deduce that, on the average, each installation operated 322 hours per month. The next column shows the entries in the first column as percentages of the total.

The third column, giving the average number of computer hours spent on each application at an installation which had implemented that application, was computed (according to the source document) by dividing the total hours per month by the number of installations which had implemented the application. However, the actual data in the report is inconsistent with that method of calculation, as is indicated by the last two columns of the table. These columns show the number of applications of each type per 100 installations, first as computed by dividing column 1 by column 3, and then as given in the original report. Note the two numbers differ by roughly 10%—apparently a 10% correction of some kind was made, though no explanation was made so far as I can tell. (To give an example of the inconsistency in terms of the numbers actually appearing in the report, I submit the following example: 1049 installations reported they had implemented the payroll application. Those installations reported a total of 36,417 computer hours per month on that application. Dividing 36,417 by 1049, one concludes that 34.7 hours per month of computer time were spent on payroll by each installation which computed payrolls. The report, however, states the average computer time spent per month on payroll was 38.5 hours.) Note that, in Table 3.12.1, I used the data in the last column of Table II.3.12.1, and not the data implied by the average number of hours per application.

The average computer time per month spent on an application, averaged over *all* applications, was 81.5 hours as shown at the bottom of the third column. This number was explicitly given in the source document. Making use of it and other data in the table, I was able to compute the numbers on the last three lines as follows. In the first column, the "subtotal" is the sum of all the applications above it in the table, the "grand total" was given in the original report, and the "all others" entry is the difference between the two. In the fourth column, the "grand total" is the quotient of the corresponding entries in the first and third columns; the "subtotal" entry is the sum of all the applications above it in the table; and the "all other" entry is once again the difference between the two. In the third column, the "subtotal" and "all others" entries are the quotients of the corresponding figures in the first and fourth columns.

## TABLE II.3.12.1 DISTRIBUTION OF COMPUTER TIME PER 100 SITES AMONG VARIOUS APPLICATIONS I.

| Applications | Tot. Hrs. Per. Mo. | % of Tot. Hrs. | Av. Hrs. /Appl. | Appl./100 Sites Comp. | Appl./100 Sites Given |
|---|---|---|---|---|---|
| Accounting | 3706.6 | 11.51 | 79 | 46.92 | 51.95 |
| Inventory Control | 2690.2 | 8.35 | 79 | 34.05 | 37.60 |
| Billing | 1886.4 | 5.86 | 98.5 | 19.15 | 20.60 |
| Payroll | 1820.9 | 5.65 | 38.5 | 47.30 | 52.45 |
| Demand Deposit | 1527.8 | 4.74 | 220 | 6.94 | 7.70 |
| Sales Analysis | 1414.3 | 4.39 | 51 | 27.73 | 31.25 |
| Engineering | 1144.6 | 3.55 | 150 | 7.63 | 8.45 |
| Order Analysis | 1108.9 | 3.44 | 100 | 11.09 | 12.35 |
| Savings | 706.3 | 2.19 | 101 | 6.99 | 7.75 |
| Programming | 687.0 | 2.13 | 280 | 2.45 | 2.65 |
| Production Control | 684.9 | 2.13 | 73 | 9.38 | 10.50 |
| Teaching | 577.7 | 1.79 | 189 | 3.06 | 3.30 |
| Research (Education) | 516.4 | 1.60 | 178 | 2.90 | 3.25 |
| Miscellaneous | 462.9 | 1.44 | 101 | 4.58 | 5.35 |
| Mortgage Loans | 455.7 | 1.42 | 125 | 3.65 | 4.00 |
| Govt. Accounting | 433.6 | 1.35 | 170 | 2.55 | 3.00 |
| Mailing Operations | 412.0 | 1.28 | 125 | 3.30 | 3.60 |
| Student Records | 411.4 | 1.28 | 91 | 4.52 | 5.30 |
| General Ledger | 383.2 | 1.19 | 31 | 12.36 | 14.00 |
| Insurance | 378.8 | 1.18 | 176 | 2.15 | 2.38 |
| Material Control | 369.5 | 1.15 | 110 | 3.36 | 3.60 |
| Statistical Analysis | 367.9 | 1.14 | 179 | 2.06 | 2.28 |
| Cost Accounting | 365.7 | 1.14 | 31.5 | 11.61 | 12.60 |
| Management Reports | 350.6 | 1.09 | 83 | 4.22 | 4.65 |
| Banking | 314.5 | 0.98 | 185 | 1.70 | 1.88 |
| Installment Loans | 275.3 | 0.85 | 68 | 4.05 | 4.50 |
| Hospital Billing | 257.1 | 0.80 | 166 | 1.55 | 1.72 |
| Labor Distribution | 240.5 | 0.75 | 43 | 5.59 | 6.20 |
| Insurance Accounting | 216.1 | 0.67 | 98 | 2.21 | 2.60 |
| Actuarial Research | 204.1 | 0.63 | 120 | 1.70 | 1.88 |
| Subtotal | 24370.9 | 75.68 | 82.13 | 296.75 | 329.34 |
| All Others | 7829.8 | 24.32 | 79.61 | 98.35 | 109.66 |
| Grand Total | 32200.7 | 100.00 | 81.5 | 395.10 | 439.00 |

## TABLE II.3.12.2 DISTRIBUTION OF COMPUTER TIME AMONG VARIOUS APPLICATIONS II—NOTES

The survey of British applications (EmOff72) also provided some data on the computer time spent in various applications. This table compares the British data with that from the IDC Report (IDCAppl69).

The British data is shown in the first eight columns. The first five of those eight come directly from the report (page 14) and show the percentage of total computer time spent in each of the main application categories. The first column shows the percentages in 1964, for all sites. The fifth column shows the percentages for all sites as of 1969; and the intermediate three show corresponding 1969 percentages for large, medium, and small installations. Installation sizes were defined according to the capital costs of hardware, excluding data preparation equipment. Assuming a conversion factor of $2.40 per English pound, the sizes are: large installations—over $1.2M; medium installations—$240k to $1.2M; and small installations—$48k to $240k. Installations with EDP equipment costing less than $48k were not included in the study.

The next three columns provide more detail on all sites in 1969. (No breakdown was provided for large, medium, and small sites.) The report did not provide a figure for the average monthly computer time per installation. However, it did show the number of installations having a "weekly hours of use" of EDP equipment in each of five categories ranging from less than 40 hours per week to more than 120. From that distribution, I computed an estimated average computer time per month of 315.9 hours, as shown at the bottom of the sixth column. Applying the percentages of the fifth column to that total, I got the distribution shown in the sixth column. The number of applications per hundred sites, in the seventh column, appears in the report and is in fact the same as the third column of Table 3.12.1. Finally, the number of hours per month spent on each application by an installation reporting that application was found by dividing columns 6 by column 7 and multipying the result by 100. These numbers are presumably comparable to the corresponding figures from the IDC report (see Table II.3.12.1), some of which are reproduced in the last three columns of the table.

## TABLE II.3.12.3 EQUIPMENT USED TO MAKE PAYROLL CALCULATIONS (1969)—NOTES

This table shows the results of a survey carried out by the Internal Revenue Service in June, 1969. It was published in SmBus72 (page 812). Each column shows how payroll calculations are carried out by employers whose size (in terms of number of employees) is shown at the top of the column. The first seven rows in the table give a complete breakdown showing what kind of equipment is used in payroll calculations. The next two rows summarize the entries in the first six. All of the entries in the first nine rows show the percentages of employers of each size category employing the type of equipment shown at the left.

The bottom half of the table shows the number of employers in each of the first five size categories, and deduces (from the percentages in the first half) how many machines of each type were in use in 1969.

## TABLE II.3.21.1 DATA COLLECTION COST FACTORS—NOTES

This table provides data useful in estimating the cost of transcribing data from one form (usually an original document of some kind) to another (either a standard document of some kind useful in later processing operatings, or some machine-readable format). I assume that the time required to carry out an operation in this table has two components: a fixed time required to get ready to perform a series of operations; and a veriable time proportional to the number of characters handled. The columns labelled "data unit" and "time per unit" describe the first, setting-up operation. The next three columns show the time required per character, as a function of the quality of the document from which data is being transcribed. A "good" source document is easily handled, quite legible, and contains data in the same order that it must be transcribed. A "fair" quality document requires excessive handling, is not easily readable, or presents data in a different order from that in which it is to be transcribed. A "poor" quality document requires excessive handling, and presents data in a complex sequence with poor legibility. The last column in the table represents the cost of correcting errors, as a percent of the original cost of entering the data. Note that the cost of *detecting* errors is not included in this precentage.

The first three data rows in the table describe time factors involved in copying data manually from an original form to a standard form. The figures represent my own personal estimate of the required times—I was unable to find a published source analyzing or describing this kind of operation.

The last half of the table describes the cost of keyboard operations. The basic source is ORMan69, though I also drew on HayeR70 and some other private sources. My starting point is the timing for keypunch operations, which ORMan69 gives with four-digit precision. The data is to be interpreted as follows: when a "fair" source document is being transcribed, we require 0.936 seconds every time a new card is to be punched, and then an additional 0.432 seconds for each character which must be punched in that card. Furthermore, the cost of correcting errors is 2% of the original keypunch cost.

Unfortunately, the reference source does not give consistent data on keyboard-to-tape, keyboard-to-disk, or OCR-typing speeds. The data it does provide, in words per minute, is as follows: keypunching, 10.5; keyboard to magnetic tape, 13.8; typing for OCR, 20.0; and proofchecking, 25.0. (Note that the figure of 10.5 words per minute for keypunching is very slow compared with the figures given in the table—and yet both figures come from the same source document.) Based on this data, on some other private data, and on some personal guessing and estimating, I arrived at the figures shown in the table. Note that I assume: keyboard-to-tape and keyboard-to-disk operations are equally fast, and are about 20% faster than keypunching, assuming a keypunched record contains about 40 characters; keyboard-to-tape/disk operations require no fixed time per record comparable to the time required to feed a card into keypunch; OCR typing is about 40% faster than keypunching; and both OCR typing and keyboard-to-tape or disk operations have an error rate less than half that of keypunching (the latter figures I adopted directly from ORMan69).

The source document states that verifying operations are performed at the same speed as are the original data entry operations. The next two entries on the table are therefore duplicates of earlier entries. My estimate of proofreading

### TABLE II.3.12.2 DISTRIBUTION OF COMPUTER TIME AMONG VARIOUS APPLICATIONS II

| | British Survey | | | | | | | | IDC Report 1969 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent of Total Computer Hours | | | | | 1969: All Sites | | | | | |
| | 1964 | 1969: Size of Site | | | | | | | | | |
| | | Large | Med. | Small | All | Total Hours Per Month | Appl. Per 100 Sites | Hours Per Appl. | Total Hours Per Month | Percent of Total Hours | Hours Per Appl. |
| Financial Accounting | 21 | 31 | 20 | 20 | 23 | 72.7 | 82 | 88.7 | 37.1 | 11.5 | 79 |
| Invoicing and Billing | 13 | 20 | 17 | 18 | 18 | 56.9 | 67 | 84.9 | 18.9 | 5.9 | 98.5 |
| Mgmt. Information Services | 18 | 11 | 15 | 16 | 14 | 44.2 | 81 | 54.6 | | | |
| Payroll | 21 | 8 | 13 | 12 | 11 | 34.7 | 69 | 50.3 | 18.2 | 5.7 | 38.5 |
| Stock Control | 16 | 9 | 9 | 11 | 10 | 31.6 | 64 | 49.4 | 26.9 | 8.4 | 79 |
| Production Control | 4 | 7 | 7 | 5 | 7 | 22.1 | 32 | 69.0 | 6.8 | 2.1 | 73 |
| General Statistics | 7 | 3 | 5 | 7 | 5 | 15.8 | 61 | 25.9 | | | |
| Other Office Work | - | 11 | 12 | 10 | 11 | 34.7 | 45 | 77.1 | | | |
| Work For Other Organizns. | - | - | 2 | 1 | 1 | 3.2 | - | | | | |
| Totals | 100 | 100 | 100 | 100 | 100 | 315.9 | 501 | 63.1 | 322.0 | | 81.5 |

### TABLE II.3.12.3 EQUIPMENT USED BY EMPLOYERS TO MAKE PAYROLL CALCULATIONS (1969)

| Equipment | Number of Employees | | | | | | All |
|---|---|---|---|---|---|---|---|
| | 1-3 | 4-7 | 8-19 | 20-40 | 50-250 | Over 250 | Firms |
| **Equipment Used** | | | Percent of Firms Using Equipment | | | | |
| Bookkeeping Machines—Mech. | 1.3% | 2.3% | 6.2% | 11.3% | 18.3% | 14.2% | 4.5% |
| Electronic | - | 0.2% | 1.0% | 1.3% | 11.1% | 11.6% | 1.1% |
| Punched-Card Equipment (EAM) | - | - | - | - | 2.6% | 7.0% | 0.2% |
| Computer Systems—Card | - | - | 0.7% | 0.7% | 3.1% | 23.1% | 0.6% |
| Magnetic Tape | - | 1.0% | - | 1.3% | 3.5% | 18.3% | 0.8% |
| Magnetic Disk | - | - | - | - | 1.7% | 6.4% | 0.3% |
| None (Manual) | 98.7% | 96.5% | 92.1% | 85.4% | 59.7% | 19.4% | 92.5% |
| Totals—Computer Systems | - | 1.0% | 0.7% | 2.0% | 8.3% | 47.8% | 1.7% |
| Book. Mach./EAM | 1.3% | 2.5% | 7.2% | 12.6% | 32.0% | 32.8% | 5.8% |
| **Number of Employers** | 1.798M | 720.4k | 586.1k | 265.4k | 136.4k | | |
| **Equipment Used** | | Number of Firms Using Equipment | | | | | |
| Bookkeeping Machines—Mech. | 23.4k | 16.6k | 36.3k | 30.0k | 25.0k | | |
| Electronic | - | 1.4k | 5.9k | 3.5k | 15.1k | | |
| Punched-Card Equipment (EAM) | - | - | - | - | 3.5k | | |
| Computer Systems—Card | - | - | 4.1k | 1.9k | 4.2k | | |
| Magnetic Tape | - | 7.2k | - | - | 4.8k | | |
| Magnetic Disk | - | - | - | - | 2.3k | | |

### TABLE II.3.21.1 DATA COLLECTION COST FACTORS

| | Data Unit | Time Per Unit | Time Per Character Source Document Quality | | | Error Cost As Percent Of Entry Cost |
|---|---|---|---|---|---|---|
| | | | Good | Fair | Poor | |
| | | (sec.) | (sec.) | (sec.) | (sec.) | (%) |
| **Handprint Operation** | | | | | | |
| Copy Data From Source To Standard Form | | | | | | |
| Numeric Data | Form | 2 | 0.5 | 0.6 | 0.7 | 2 |
| Alphanumeric Data | Form | 2 | 0.7 | 0.8 | 0.9 | 2 |
| Verify Copied Data | Form | 2 | 0.3 | 0.35 | 0.4 | |
| **Keyboard Operation** | | | | | | |
| Keypunch | Card | 0.936 | 0.3276 | 0.4320 | 0.5328 | 2 |
| Key-To-Tape/Disk | Record | - | 0.29 | 0.38 | 0.46 | .9 |
| Typing for OCR | Page | 4 | 0.26 | 0.34 | 0.41 | .9 |
| Verify—Keypunch | Card | 0.936 | 0.3276 | 0.4320 | 0.5328 | |
| Key-To-Tape/Disk | Record | - | 0.29 | 0.38 | 0.46 | |
| Proofread Page | Page | 2 | 0.13 | 0.17 | 0.21 | |
| Typing Normal Text | Page | 4 | 0.125 | 0.15 | 0.20 | 2 |

time is based on the above-mentioned ratio of 25 words per minute for proofchecking vs. 10.5 for keypunching. And the last entries, on times required to type normal text, are based on typing speeds of 50, 65, and 80 words per minute.

### TABLE II.3.22.1 STORAGE MEDIA COSTS—NOTES

This table shows the cost, area, and data-storage capacity of various forms of storage media. It also shows the cost per kilobyte, the storage capacity per unit area, and the cost per square inch of the media, as derived from the first three factors. The column labelled "units" identifies the entity whose characteristics are given in the remainder of the table. For example, in the first line the media is 1,000 sheets of 8 1/2x11 inch paper typewritten on one side. The cost of the paper (not including the labor necessary to type it) is $4.50. The useable area is 62,000 square inches—based on each sheet having a useable area about 6.5x9.5 inches. Such a page should contain about 500 words, typed single-spaced—or about 3,000 bytes. (Note that units in the "capacity" column are kbytes, so that an entry of 3.0k means three million bytes.) The cost per kilobyte is found by dividing 450 cents by 3,000 kilobytes; the capacity per unit area is the quotient of 3000 kilobytes and 62,000 square inches; and the cost per square inch is the quotient of 450 cents and 62,000 square inches.

**Human-Readable Data.** Sources for this portion of the table are ORMan69 and HayeR70. Some comments: the 8 1/2x11 inch *printed* page capacity was determined by an actual count on a printed page, where the printing occupied an area 6 5/8 inches by 9 inches. The capacity of a 6x9 inch (normal, book-size) printed page was determined by estimating the printing area at 6 3/4 inches by 4 1/4 inches, and assuming roughly the same number of characters per square inch as was counted in the larger page. (Hayes states that a 8 1/2x11 inch page has a capacity of only 1500 characters, which seems unreasonably low. LockW70 estimates 500 words per printed page for the average library book.) The cost of 250-page book is estimated at one-quarter the cost of 1,000 6x9 inch sheets, plus about $0.40 for binding. I assume roughly the same printing density for cards as for sheets. Hayes gives microfilm capacity as 3,000 frames on a 100-foot cartridge, and 72 frames on a microfiche card.

**Machine-Readable Data.** Most of the cost data in this portion of the table comes from Table II.1.27. The area given for the 96-column card is that of 1.75 inch by 2.75 inch area in which holes are punched—the card itself is actually 2 5/8 inches by 3 1/4 inches. The magnetic tape area I assumed to be one-half inch wide and 2400 feet long. Disk pack areas is derived directly from Table II.2.12.1; and disk pack capacity also comes from that table. The diskette data is from the IBM Consultants Manual, late in 1975.

### TABLE II.3.22.2 STORAGE EQUIPMENT CHARACTERISTICS—NOTES

The various media described in the previous table may be stored in a number of different pieces of equipment, and this table describes the characteristics of the equipment. The column identify the devices, the media stored on those devices, the maximum capacity of the device with media, the "working" space required by the device, the time required to access a random element of data in the device, and the purchase price of the device. The last two columns show the computed equipment cost per million bytes stored, and the density in millions of bytes stored per square foot of floor space required.

**Human-Readable Data.** Data on the four-drawer filing cabinet comes from ORMan69. Information on the card filing cases, and on the Sperry-Rand Kardveyer (trademark) was obtained through conversations with firms which supply office equipment. The filing cabinet for 3x5 inch cards contains seventy drawers each fifteen inches deep. The cabinet is 42.75 inches wide and 18 inches deep, and is 63.5 inches tall. The Kardveyor (TM) access times include two seconds to enter an address on control buttons, four or five seconds for the device to move to the position where the appropriate drawer is accessible, and four seconds to pick a card from the drawer.

The library data is from RaffJ69 (Raffel/Shisko, "Systematic Analysis of University Libraries"., MIT Press, 1969). A library section is defined as three linear feet of single-faced shelves, 7.5 feet high. Such a section occupies from 5.2 to 8.7 square feet, depending on the width and length of the aisles. I used an average of seven square feet. A section holds from 105 to 168 volumes, depending on the type—with bound periodicals requiring a great deal of space, and fiction relatively little. I assumed an average of 150 volumes per section, which generally does not allow space on the shelves for expansion of the library. The access time figure is my own estimate, and is suppose to include the time to find a volume and then to find a required page within that volume. The purchase price is based on Raffel's figure of $4.00 per square foot of stacks.

The microfilm data, like the other filing equipment data referred to above, came from informal conversations with vendors of microfilm equipment. The floorspace estimated includes space for an operator.

**Machine-Readable Data.** This data is from Tables II.12.1, II.12.3, and II.120.2. The devices represented are the IBM 3410-1 tape unit, the IBM 3330-1 moving-head file, the IBM 2321 data cell, and the IBM 3540 diskette drive. The area required by these units includes space for access by operators and maintenance men. It is computed from the actual floor space occupied by the units by multiplying that floor space by a factor of 7.5.

### TABLE II.3.22.1 STORAGE MEDIA COSTS

| | Unit | Cost (1970) ($) | Usable Area (sq.in.) | Maximum Capacity (KBytes) | Cost per KByte (cents) | Capacity per Area (KBypsi) | Cost per Sq.In. (cents) |
|---|---|---|---|---|---|---|---|
| **Human-Readable Data** | | | | | | | |
| Paper | | | | | | | |
| Sheets—8 1/2x11 in., Typewritten | 1k sheets, 1 side | 4.5 | 62k | 3.0k | .150 | .048 | .007 |
| Printed | 1k sheets, 2 sides | 4.5 | 120k | 13.0k | .035 | .108 | .004 |
| 6x9 in., Printed | 1k sheets, 2 sides | 2.5 | 57k | 6.0k | .042 | .105 | .004 |
| Book, 6x9 in., Printed | 250 sheets, 2 sides | 1.0 | 14k | 1.5k | .067 | .107 | .007 |
| Cards—3x5 in., Typewritten | 1k cards, 1 side | 1.5 | 11k | 0.5k | .300 | .045 | .014 |
| Printed | 1k cards, 1 side | 1.5 | 11k | 1.1k | .136 | .100 | .014 |
| 5x8 in., Typewritten | 1k cards, 1 side | 2.0 | 34k | 1.5k | .133 | .044 | .006 |
| Printed | 1k cards, 1 side | 2.0 | 34k | 3.4k | .059 | .100 | .006 |
| Microfilm—of 8 1/2x11 Printed | 100-ft. cartridge | 6.0 | .45k | 19.5k | .031 | 43.3 | 1.333 |
| of 3x5 Typewritten | 100-ft. cartridge | 6.0 | .45k | 1.5k | .400 | 3.33 | 1.333 |
| Microfiche—of 8 1/2x11 Printed | 100 fiche | 10.0 | 2k | 46.8k | .021 | 23.4 | .500 |
| of 3x5 Typewritten | 100 fiche | 10.0 | 2k | 3.6k | .278 | 1.8 | .500 |
| **Machine-Readable Data** | | | | | | | |
| Punched Cards—80 Col. | 1k cards | 0.8 | 21k | 80 | 1.000 | .004 | .004 |
| 96 column | 1k cards | 0.6 | 4.8k | 96 | .625 | .020 | .013 |
| Magnetic Tape—200 bpi | 1 reel | 11 | 14.4k | 5k | .220 | .347 | .076 |
| 1600 bpi | 1 reel | 11 | 14.4k | 23.5k | .047 | 1.63 | .076 |
| Disk Pack—1316 | 1 pack | 300 | .71k | 7.25k | 4.138 | 10.2 | 42.3 |
| 2316 | 1 pack | 400 | 1.41k | 29k | 1.379 | 20.6 | 28.4 |
| 3336 | 1 pack | 1000 | 1.34k | 100k | 1.000 | 74.6 | 74.6 |
| Diskette | 1 pack | 8('73) | 27.6 | 243 | 3.292 | 8.8 | 29.0 |

### TABLE II.3.22.2 STORAGE EQUIPMENT CHARACTERISTICS

| Units: | Media | Maximum Capacity Media | Maximum Capacity Characters (Mbytes) | Floor Space (Sq.Ft.) | Access Time (msec.) | Price (1970) Purchase ($k) | Price (1970) Per Byte ($/MBy) | Storage Density (MBypsf) |
|---|---|---|---|---|---|---|---|---|
| **Human-Readable Data** | | | | | | | | |
| Filing Cabinet, 4-drawer | 8.5x11 in. Sheets | 16k | 48 | 5.3 | 5000 | .040 | .83 | 9.1 |
| Card Filing Case | 3x5 in. Cards | 84k | 42 | 10.7 | 5000 | .900 | 21.43 | 3.9 |
| Card Filing Case | 5x8 in. Cards | 38k | 57 | 10.7 | 5000 | .750 | 13.16 | 5.3 |
| Sperry-Rand Kardveyer (TM) | | | | | | | | |
| 4370- | 3x5 in. Cards | 125k | 62.5 | 33 | 10,000 | 3.500 | 56.00 | 1.9 |
| 4370- | 8.5x11 in. Sheets | 80k | 120 | 38 | 11,000 | 4.400 | 36.67 | 3.2 |
| Library Bookcase Section | Book | 150 | 112.5 | 7 | 15,000 | .028 | .25 | 16.1 |
| Microfilm Viewer | 100-ft. Cartridge | 1 | 19.5 | 25 | 3000 | .300 | 15.38 | 0.8 |
| Microfiche Viewer | Fiche | 1 | .468 | 25 | 500 | .150 | 320.51 | .02 |
| **Machine-Readable Data** | | | | | | | | |
| Magnetic Tape Unit | Reel of Tape | 1 | 23.5 | 44 | 90,000 | 7.7 | 327.66 | 0.5 |
| Moving-Head File | Disk Pack | 1 | 100 | 34 | 38.3 | 25.97 | 259.70 | 2.9 |
| Data Cell | Data Cell | 1 | 400 | 120 | 390 | 109.2 | 273.00 | 3.3 |
| Diskette Unit (1975) | Diskette | 1 | .243 | 56 | 2008 | 11.5 | 47,325.00 | .004 |

## TABLE II.3.22.3 STORAGE COST FACTORS—NOTES

**Walking Speed.** The basic figure of 4.17 feet per second comes from ORMan69, where it is used in a discussion of the time savings achieved through reducing distances office people walk. Equivalent speeds are shown in miles per hour and steps per second (assuming three feet to a step). The range—in the format Low (Nominal) High—is my own estimate.

**Filing Cards.** The formulae shown in this portion of the table were derived from a graph given in HayeR70 (page 351). The chart actually showed two parallel lines on a log-log scale, and the coefficient 7 (representing the number of seconds required to file one card) corresponds to a line midway between the lines on the graph. The other two lines are described by the other two coefficients given in the "Range" column.

**Microfilming Times.** The upper and lower ranges for microfilming time come from ORMan69. The "estimated values" I derived from the range in such a way that the ratio of estimated to low value is the same as the ratio of the high to estimated value.

## TABLE II.3.22.4 FILING SYSTEM CHARACTERISTICS FOR VARIOUS SYSTEM CAPACITIES—NOTES

This table describes how the storage capacity of each of six types of system may be increased, and presents calculations deriving system access times, and the cost of equipment and media, as these parameters change with increasing capacity. The basic data on equipment and media comes from Tables II.3.22.1-3.

**Systems.** 1-3. The systems under discussion are identified here. The filing cabinets store letter-size sheets and 3x5 inch cards containing typewritten data on one side. The microfilm and microfiche frames each reproduce an 8.5x11 inch *printed* sheet. The magnetic tape is recorded at 1600 bpi, and the disk pack contains 100M Bytes. I assume that, in every case, the media is full to capacity with data. Note that the first four systems require an operator. The tape and disc do not, since I assume the media is never changed for the basic system.

4-6. Increased capacity can be achieved in various ways—by adding equipment or operators or by changing or adding media. The particular variations studied here are described in these lines. For the filing cabinet systems we add cabinets and media but continue with only one operator (filing clerk). For the microfilm systems we add media stored in drawers within the operator's reach. This limits the system size to about four drawers, with thirty microfilm rolls or 600 microfiche cards per drawer. For the machine-readable systems, we add media along with an operator to select and load the media on the units.

**Basic System.** 7-9. The characteristics of the basic systems come from Table II.3.22.2.

**Add One Unit.** 10-11. The first increment is the addition of one unit of equipment or media, as shown here.

12-16. The addition of the unit increases the access time in different ways for different units, as shown here. For the last four systems, the operator must begin by removing the media from the equipment, and I assume operator times as shown on line 12. For the tape, removal time includes the time to rewind it from its average position, half way down the tape. For the moving-head-file, removal time includes the time necessary for the disk to stop rotating. For the filing cabinets, it is necessary for the operator to walk to the second cabinet half the time. Walking time per cabinet added is discussed in connection with line 20 below. There is no walking time for the microfilm systems, because I assume capacity is limited to that contained in drawers within the operator's reach. There will in general be walking time for the operator to reach and select a tape or disc (generally located some distance from the drives), but I assume that time is overlapped by media removal time. The time to load the media is my estimate. For the moving-head-file it includes the time necessary for the disc to get up to speed, ready to read or write. Unit access time is the basic access time once the operator has reached a cabinet, or once the media is loaded—it is the same as line 9. Line 16 is the sum of lines 12 to 15.

**Add n Units.** 17. The capacity of n units is n times the capacity of one unit. Remember that a unit is sometimes another equipment set and sometimes additional media, as specified on line 10.

19-20. Line 19 is the same as line 12. The average walking time is derived from the following arguments. A four-drawer file cabinet is sixteen inches wide, and the seventy-drawer card filing cabinet is 42.75 inches wide. Assume the operator is stationed in the center of a row of n cabinets, and that his average walking speed is 4.17 feet per second (2.84 mph). For an average access to data, he will travel half way down the row, going to the right or left depending on where the data is. His walking distance to the proper cabinet will thus be (n/4)x(cabinet width)/walking speed, and his total walking time (including the time to return to his starting point) will be twice that.

21-24. The time required to select the proper microfilm or microfiche from the drawer and to replace the previously-used one is estimated on line 21. The select time for tapes and discs are assumed to overlap media removal time once again. Lines 22 and 23 are the same as lines 14 and 15, and line 24 is the sum of lines 19 to 23.

For the filing cabinet systems consider the situation where we want to reference s items in a file of f units. Let us assume that the batch of s items has been sorted, so our filing method will be to go to the furthest item, find it, then walk back to the other items in sequence. The time required for the s items will be a five-second finding time for each item (the time to locate it once the operator has reached the cabinet) plus the time to travel from the operator's starting position in the center, to the furthest item in one direction, back to the furthest item in the other direction, and then back to the starting position. The average location of the "furthest item" is a function of batch size s. For simplicity, let us assume it is a constant distance 3/4 of the maximum, or 1.5 times the average for one item. If we apply this result to the card file, we must note that a cabinet contains 84,000 cards (Table II.3.22.2). The travel time is then (2x.42x1.5/84,000)f. And the total time for a batch of s items would be 5s + (1.26/84,000)f.

25. The cost per megabyte for equipment plus media for each system is shown on line 25. Since we add both cabinets and media to the first two systems, their cost is independent

### TABLE II.3.22.3 STORAGE COST FACTORS

| Factor | Units | Estimated Value | Range |
|---|---|---|---|
| **Walking Speed–Ft.** | ft/sec | 4.17 | 3.7 (4.17) 4.7 |
| Steps | st/sec | 1.39 | 1.2 (1.39) 1.6 |
| Miles per Hour | mph | 2.84 | 2.5 (2.84) 3.2 |
| **Filing 3x5 in. Cards** | | | |
| File s Items in a File | | | |
| Containing f Items: | | | |
| Per Item | sec | $7(f/s)^{0.222}$ | 4 (7) 9.5 |
| All s Items | sec | $7f^{0.222}s^{0.778}$ | 4 (7) 9.5 |
| **Microfilming Times** | | | |
| Per Machine Per Operator | | | |
| Filming–Large Drawings | images/day | 310 | 120 (310) 800 |
| Uniform Letters–Roll | images/day | 8660 | 5k (8.66k) 15k |
| Microfiche | images/day | 2450 | 2k (2.45k) 3k |
| Index Cards or Checks | images/day | 44,800 | 20k (44.8k) 100k |
| Processing (Silver) | feet/day | 1740 | .55k (1.74k) 5.5k |
| Inspection–Roll | images/day | 26,860 | 12k (26.86k) 60K |
| Fiche | images/day | 24,000 | |
| Aperture Card Mounting | images/day | 3320 | 2k (3.32k) 5.5k |
| Printout–Selective | images/day | 2150 | .96k (2.15k) 4.8k |
| Continuous Flow | images/day | 16,000 | |

### TABLE II.3.22.4. FILING SYSTEM CHARACTERISTICS FOR VARIOUS SYSTEM CAPACITIES

| | | Units | Filing Cabinet Letters | Filing Cabinet Cards | Microfilm | Microfiche | Magnetic Tape | Moving-Head File |
|---|---|---|---|---|---|---|---|---|
| 1. | System–Equipment | | 1 Cabinet | 1 Cabinet | 1 Viewer | 1 Viewer | 1 M.T.U. | 1 File |
| 2. | Operators | | 1 | 1 | 1 | 1 | 0 | 0 |
| 3. | Media | | 8.5x11 in. | 3x5 in. | Roll | Fiche | Tape | Disc |
| 4. | Added–Equipment | | Cabinets | Cabinets | - | - | - | - |
| 5. | Operators | | 0 | 0 | 0 | 0 | 1 | 1 |
| 6. | Media | | yes | yes | yes | yes | yes | yes |
| | Basic System | | | | | | | |
| 7. | Capacity–Char. | MBy | 48 | 42 | 19.5 | .468 | 23.5 | 100 |
| 8. | No. of Media | | 16k | 84k | 1 | 1 | 1 | 1 |
| 9. | Access Time | sec. | 5 | 5 | 3 | 0.5 | 90 | .038 |
| 10. | Add One Unit | | 1 Cab. | 1 Cab. | 1 Roll | 1 Fiche | 1 Tape | 1 Disc |
| 11. | Total Capacity | MBy | 96 | 84 | 39 | .936 | 47 | 200 |
| | Access Time | | | | | | | |
| 12. | Remove Media | sec. | - | - | 8 | 3 | 65 | 60 |
| 13. | Walk to Med. Stor. | sec. | 0.16 | 0.42 | - | - | - | - |
| 14. | Load Media | sec. | - | - | 5 | 1 | 5 | 30 |
| 15. | Unit Access | sec. | 5 | 5 | 3 | 0.5 | 90 | .038 |
| 16. | Total | sec. | 5.16 | 5.42 | 16 | 4.5 | 160 | 90 |
| | For n Units | | | | | | | |
| 17. | Total Capacity | MBy | 48n | 42n | 19.5n | .468n | 23.5n | 100n |
| 18. | Access Time | | | | | | | |
| 19. | Remove Media | sec. | - | - | 8 | 3 | 65 | 60 |
| 20. | Walk to Med. Stor. | sec. | 0.16n | 0.42n | - | - | - | - |
| 21. | Select Media | sec. | - | - | 5 | 5 | - | - |
| 22. | Load Media | sec. | - | - | 5 | 1 | 5 | 30 |
| 23. | Unit Access | sec. | 5 | 5 | 3 | 0.5 | 90 | 0.38 |
| 24. | Total | sec. | 5 + 0.16n | 5 + 0.42n | 21 | 9.5 | 160 | 90 |
| 25. | Equip./Media Cost | $/MBy | 2.33 | 24.43 | .31 + 15.38/n | .21 + 320.5/n | .47 + 327.7/n | 10 + 259.7/n |

**TABLE II.3.23.1 PRINTING SYSTEM COSTS**

| | Units | Microfilm | Line Printer | |
|---|---|---|---|---|
| **Hardware** | | Calcomp 2100 | IBM 1403-N1 | IBM 3203-2 |
| Print Speed | lpm | 15,000 | 1100 | 1200 |
| Rental | $/Mo. | 1300 | 900 | 1234 |
| Film Processor | $/Mo. | 200 | | |
| Duplicator | $/Mo. | 200 | | |
| Hardware Costs | $/Mo. | 1700 | 900 | 1234 |
| **Media** | | Microfiche 200 ft. | Continuous Forms 1000 sheets | |
| Cost | $ | 55.00 | 4.62 | 4.62 |
| Chemicals | $ | 7.20 | - | - |
| per 1000 pages | $ | 2.74 | 4.62 | 4.62 |
| Second Copy | | Duplicat'n | Two-Part Form | |
| per 1000 pages | $ | 3.69 | 13.90 | 13.90 |
| Third Copy | | Duplicat'n | Three-Part Form | |
| per 1000 pages | $ | 4.64 | 21.12 | 21.12 |
| **System** | | | | |
| Capacity | kpg./Mo. | 5400 | 396 | 432 |
| Cost of 300k pages | | | | |
| One Copy | $ | 2522 | 2286 | 2620 |
| Two Copies | $ | 2807 | 5070 | 5404 |
| Three Copies | $ | 3092 | 7236 | 7570 |

**TABLE II.3.24.1 DATA MANIPULATION COST FACTORS**

| | Units | Manual Operation | Using a Calculator Electromechanical | Electronic |
|---|---|---|---|---|
| **Calculations** | | | | |
| Addition | | | | |
| Copy n d-digit Operands | sec. | 0.6nd | 0.4nd | 0.3nd |
| Add n d-digit Operands | sec. | (n-1.6)d | 0.5 | 0 |
| Copy d-digit Result | sec. | 0.6d | 0.6d | 0.6d |
| Subtraction | | | | |
| Copy 2 d-digit Operands | sec. | 1.2d | 0.8d | 0.6d |
| Subtract one from the other | sec. | 0.4d | 0.5 | 0 |
| Copy d-digit Result | sec. | 0.6d | 0.6d | 0.6d |
| Multiplication | | | | |
| Copy 2 d-digit Operands | sec. | 1.2d | 0.8d | 0.6d |
| Multiply 2 d-digit Operands | sec. | $3.2d^2-3.2d+2$ | 2.5d | 0 |
| Copy d-digit Result | sec. | 0.6d | 0.6d | 0.6d |
| Division | | | | |
| Copy 2 d-digit Operands | sec. | 1.2d | 0.8d | 0.6d |
| Divide 2 d-digit Operands | sec. | $3.2d^2+d$ | 2.5d | 0 |
| Copy d-digit Result | sec. | 0.6d | 0.6d | 0.6d |
| **Sorting 3x5 in. Cards** | | | | |
| Sort a Batch of s Items | | | | |
| per Item | sec. | $1.8s^{0.236}$ | N.A. | N.A. |
| All s Items | sec. | $1.8s^{1.236}$ | N.A. | N.A. |

of capacity, equal to the sum of the two. From Tables 3.22.1-2 we find typewritten sheets cost $1.50 per MByte and typewritten cards $3; and cabinet costs, assuming full cabinets, are $0.83 and $21.43 per MByte, respectively. The sums are therefore $2.33 and $24.43—note how paper costs dominate the first, and cabinet costs the second. For each of the other systems, cost per megabyte is simply the media cost per MByte, plus the equipment cost per MByte divided by the number of media in the system.

## TABLE II.3.23.1 PRINTING SYSTEM COSTS—NOTES

This table compares printing costs of line printers and a microfilm system. Two IBM printers are shown, along with the cost of printing paper. They are compared with a CalComp 2100 computer output microfilm system, along with its film and copying costs.

Print speeds given are the manufacturers' nominal values. We have seen (Figure 2.12.17) that actual line printer speed is a complicated function of printed format. COM speed is an even more complex subject, with the complexity enhanced by the fact that the film processing system may not be able to keep up with the COM printer.

Printer rentals are from Table II.2.12.4. The COM unit rental is from the manufacturer (purchase price was $60,000; monthly maintenance $300) as of July, 1976. The microfilm unit requires a film processor to develop exposed microfilm, and a duplicator to make multiple copies. We assume that either the printer or the COM unit can be driven by the same controller.

The 1976 cost of a 200-foot roll of film of microfiche width was $55, and the chemicals necessary to process that roll cost $7.20. A roll potentially produces 400 fiche, but it is prudent to allow for 10% loss or waste, and assume 360 fiche per roll. The most conservative (lowest magnification) optics produces 63 pages, each continuous-form size (11 inches by 14 inches) on a fiche. There are thus 63 x 360 or 22,680 pages to a roll, and the cost per 1000 pages is ($55.00 + $7.20)/22.68. Duplicate copies of a fiche cost six cents each for materials, so 1000 duplicate pages cost (6 cents/63)x1000, or $0.95. Continuous form prices per 1000 sheets are from Table II.2.16.2.

Unit capacity is found from print speed by assuming there are 360 useful hours per month and that a page contains 60 lines. The cost of 300,000 pages is found by multiplying the media costs of 1000 pages by 300 and adding hardware costs.

## TABLE II.3.24.1 DATA MANIPULATION COST FACTORS—NOTES

**Calculations.** All the figures in this portion of the table are estimates on my part, based on a very modest amount of personal experimentation and a few calculations. The column labelled "manual operation" is intended to describe pencil-and-paper arithmetic; of the two "calculators" columns, the first envisions one of the older electromechanical machines having ten keys for each digit position, and the second a newer electronic machine having only ten numeric keys. In the "manual" column, addition and subtraction times were estimated after a few experiments. Multiplication time is based on an estimate of the time to perform a multiplication by one multiplier digit, and the earlier formula for additions. The division formula was computed in the same fashion.

The operating times shown for the calculators are similarly based on some simple experiments and estimates.

**Sorting.** The sorting formula, like the filing formula in Table II.3.22.3, comes from HayeR70, where it appeared in graphical form as a pair of parallel lines on a log-log scale. The coefficient 1.8 describes a line lying between those shown on the graph, whose coefficients are approximately 1.3 and 2.3. The time given is that required to sort a batch of 3x5 inch cards.

## TABLE 3.25.1 USER COSTS AS PERCENTAGE OF CENTRAL PROCESSOR SYSTEM HARDWARE COSTS — NOTES

The columns labelled "Estimated" are from Table II.3.25.5, and represent figures culled from various parts of this book. Those labelled "IDC" are based on Table II.3.25.1, that labelled "ICL" on Table II.3.25.2, those labelled "Japan" on Table II.3.25.3, and that labelled "Datamation" on Table II.3.25.4. For the ICL column, the basis of the ratio is the expense of Processor, Core, Memory Peripherals, I/O Peripherals, and Maintenance; and Personnel Salaries is taken to be the sum of System Analysts, Programmers, and "Operations" costs. For the Japan columns, the basis is the sum of machine rental, depreciation, and maintenance for the average system. For the *Datamation* columns, the basis is the sum of Central Site computers, Memory, Peripherals, COM gear, Communications gear, and other Hardware; and the "Salaries and Fringe Benefits" figure has been divided by 1.15 to remove the benefits.

The IDC data in Table II.3.25.1 presents some special problems. Obviously various changes have been made in the rules used to create the tables, year by year—one need only look at lines 12, 15, and 17 to realize that. Furthermore, the data on hardware expenditures does not seem to be consistent with the IDC figures (not shown here, but appearing in Table II.1.21) for the value of US GP systems in use. For example, if we convert that "value in use" to annual rental by dividing by 44 and then multiplying by 12, and compare the resulting "as if rented" figures to the sum of lines 1, 2, and 3 in Table II.3.25.1—the total lease payments actually made—we discover that about 80% of all equipment in use was leased in 1969, 1970, and 1971, and that that figure suddenly dropped to 60% in 1972 and 1973. Furthermore, if we accept these figures on the lease base and compute, by subtraction, the installed base of purchased equipment, we find (from line 5 in Table II.3.25.1) that IDC's estimate of maintenance cost per $100K ranges from $400/mo. to $500/mo.—more than twice as high as seems reasonable.

In choosing a basis for the IDC calculations in the present table, I therefore decided to ignore lines 1-6 of Table II.3.25.1, and to use as a basis 12/44 of the "US GP Value in Use" figures of Table II.1.21. The bases are $4773M for 1969 and $6873M for 1972.

## TABLE II.3.25.1 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS I

International Data Corporation, the publisher of *EDP/IR*, is the source of data in this table. The entries under "IDC Review" come from IDC's annual "briefing session" on the computer industry—a meeting held early every year by IDC to review the events of the previous year, and to forecast and speculate on the coming year. The two segments of data in the bottom half of the table come from two issues of *EDP/IR*, as is indicated by the boldface table entries. Incidentally, the data in top half of the table for the years 1972 and 1973 is consistent with information presented in February 27, 1974 issue of *EDP/IR*; and the 1974 data is consistent with information in the March 26, 1975, issue.

Although the data presented for the various years is ostensibly compatible, there are a variety of obvious discrepancies, many of them unexplained. In the next few paragraphs I will discuss the meaning of various line items, and will comment on the discrepancies.

**Hardware.** 1-6. System hardware costs include rentals paid to system manufacturers, rentals paid to peripheral equipment manufacturers, lease payments paid to leasing companies (third parties), equipment purchases (both from system manufacturers and from independent peripheral manufacturers), and the maintenance of purchased equipment. The basis for lines 4 and 5 is different for the years 1969 through 1971 from what it is for later years. For the former, it includes general purpose machines only; for the latter, both general purpose and mini systems.

7. Data entry equipment includes expenditures for keypunches, key-to-tape and key-to-disk equipment, and character reading equipment.

8-10. Communication equipment, on line 8, includes modems and multiplexors, but excludes terminals of all kinds. Communication line costs are those communication costs directly attributable to the transmission of data and included in the computer operators' budget. For the years 1972 and later, line 10 is the sum of lines 8 and 9. For the years 1969 to 1971, line 10 is supposed to include both line costs and equipment costs; however, the numbers given don't appear to be comparable to those for the years 1972 and 1973. Comparing 8 and 9 with the data in Table II.1.24, we find the "line costs" on line 9 substantially higher than the "carriage of data" expenses in the earlier table. No entry in Table II.1.24 is comparable to the "communications equipment" expense on line 8, for that expense includes multiplexors as well as modems, and represents a mixture of sale and rental or service expenditures.

11-13. It would appear that the data on these lines should correspond exactly to the "custom and standard" software industry revenue given in Table II.1.25. And in fact, the figures on line 12 for the years 1969 through 1971 do agree with data from the earlier table. However, all other entries on these lines differ substantially from Table II.1.25 (whose source is again IDC), and I have no explanation for the difference.

14. Service expenditures represent payments made by computer users for batch and time-sharing services provided by service companies. The service revenue data given in Table II.1.26 includes the cost of services provided to companies which have no computers themselves, and is thus not comparable with the figures here.

15. Expenses for computer-related supplies would seem to be exactly comparable to the data on total supply revenues as given in Table II.1.27. And in fact, the 1969 to 1971 data is reasonably similar to that in the earlier table. However, the 1972 and later figures seem not to be comparable with the earlier ones—and I have no explanation for this difference.

16. Total outside expenditures is the sum of hardware costs from line 6, data entry equipment costs from line 7, communications costs from line 10, software costs from line 13, and service and supplies cost from lines 14 and 15.

17. Salaries include the costs of system analysts, programmers, computer operators, and keypunch operators. It does not include salaries of people who enter data through remote terminals.

18. The grand total is the sum of lines 16 and 17.

**EDP/IR.** The data on lines 19 through 26 is comparable with that on lines 29 through 34, as is evident when one compares the 1971 figures in those two sections of the table. However, these entries are not in general comparable with corresponding entries in the first part of the table. (Keep in mind that the entries for the years 1972 and 1973 in lines 1 through 18 were published in *EDP/IR* of February 27, 1974—so there has obviously been a major change in the definition of terms that publication was using starting with the 1974 issue.) In general no explanation was given for the differences, though one can infer certain explanations as follows:

"Data entry and communications" on lines 20 and 28 should presumably be comparable to the sum of lines 7 and 10. One difference is that communication line costs were apparently not included in *EDP/IR's* earlier figures. In addition, the 1972 and 1973 figures on line 10 explicitly exclude terminals, while the figures on lines 20 and 28 would seem to include terminals—the definitions given are ambiguous. The software entries on lines 21 and 29 are comparable to the figures in Table II.1.25. The service expenses on lines 22 and 30 are stated to include the cost of education services. They appear to be consistent with Table II.1.26, being the sum of batch data processing, on-line processing, and a fraction of "other". Similarly, the supplies expenses on lines 23 and 31 seem consistent with the data in Table II.1.27. Finally, there was apparently a major revision in the way "internal salaries" were computed by IDC in preparing the *EDP/IR* data—compare the internal salary figure of $6.4B given on line 17 for the year 1972 with the $9.1B on line 25.

In short, starting in 1974 IDC made a major unexplained change in the basis for their calculations of users' costs, perhaps to eliminate expenditures by firms which require data processing services but do not operate their own computers.

## TABLE II.3.25.2 USERS' EXPENDITURES II—NOTES

In a memorandum submitted to the government's Select Committee on Science and Technology in 1970, Great Britain's ICL provided a table reproduced here, which purported to show computer users' expenditures in 1968. No detailed explanations, definitions, or discussion were included.

### TABLE II.3.25.1 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS I

| | | 1969 | | 1970 | | 1971 | | 1972 | | 1973 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M | % | $M | % | $M | % | $M | % | $M | % |
| | **IDC—Review** | | | | | | | | | | |
| 1. | System—Rentals | 3293 | 24.6 | 3902 | 25.7 | 4469 | 26.5 | 3382 | 21.7 | 3550 | 20.2 |
| 2. | Periph. Eq. Rentals | 17 | 0.1 | 53 | 0.3 | 106 | 0.6 | 159 | 1.0 | 203 | 1.2 |
| 3. | Third Party Lease Payments | 505 | 3.8 | 605 | 4.0 | 655 | 3.9 | 697 | 4.5 | 792 | 4.5 |
| 4. | Purchases | 832 | 6.2 | 501 | 3.3 | 300 | 1.8 | 1654 | 10.6 | 1973 | 11.2 |
| 5. | Maintenance of Purch. Eq. | 213 | 1.6 | 239 | 1.6 | 260 | 1.5 | 470 | 3.0 | 557 | 3.2 |
| 6. | Subtotal Hardware | 4860 | 36.3 | 5300 | 34.9 | 5790 | 34.4 | 6362 | 40.7 | 7075 | 40.2 |
| 7. | Data Entry Equipment | 320 | 2.4 | 385 | 2.5 | 415 | 2.5 | 383 | 2.5 | 441 | 2.5 |
| 8. | Communications—Equipment | | | | | | | 252 | 1.6 | 327 | 1.9 |
| 9. | Line Costs | | | | | | | 745 | 4.8 | 894 | 5.1 |
| 10. | Subtotal Commun. | 78 | 0.6 | 123 | 0.8 | 166 | 1.0 | 997 | 6.4 | 1221 | 6.9 |
| 11. | Software (outside)—Standard | 20 | 0.1 | 50 | 0.3 | 72 | 0.4 | 75 | 0.5 | 114 | 0.6 |
| 12. | Custom | 315 | 2.4 | 365 | 2.4 | 346 | 2.1 | 108 | 0.7 | 125 | 0.7 |
| 13. | Subtotal Software | 335 | 2.5 | 415 | 2.7 | 418 | 2.5 | 183 | 1.2 | 239 | 1.4 |
| 14. | Services | 375 | 2.8 | 538 | 3.5 | 646 | 3.8 | 590 | 3.8 | 696 | 4.0 |
| 15. | Supplies | 910 | 6.8 | 1020 | 6.7 | 1115 | 6.6 | 706 | 4.5 | 826 | 4.7 |
| 16. | Total Outside Expenditures | 6878 | 51.4 | 7781 | 51.3 | 8550 | 50.8 | 9221 | 59.0 | 10498 | 59.7 |
| 17. | Internal Salaries | 6500 | 48.6 | 7400 | 48.7 | 8290 | 49.2 | 6400 | 41.0 | 7100 | 40.3 |
| 18. | Grand Total Expenditures | 13378 | 100.0 | 15181 | 100.0 | 16840 | 100.0 | 15621 | 100.0 | 17598 | 100.0 |
| | **EDP/IR 4/27/73** | | | | | | | | | | |
| 19. | Subtotal Hardware | | | | | 6335 | 34.2 | 7155 | 34.7 | | |
| 20. | Data Entry & Commun. | | | | | 725 | 3.9 | 795 | 3.9 | | |
| 21. | Subtotal Software | | | | | 445 | 2.4 | 410 | 2.0 | | |
| 22. | Services | | | | | 1660 | 9.0 | 1985 | 9.6 | | |
| 23. | Supplies | | | | | 1075 | 5.8 | 1180 | 5.7 | | |
| 24. | Total Outside Expenditures | | | | | 10240 | 55.2 | 11525 | 55.9 | | |
| 25. | Internal Salaries | | | | | 8300 | 44.8 | 9100 | 44.1 | | |
| 26. | Grand Total Expenditures | | | | | 18540 | 100.0 | 20625 | 100.0 | | |
| | **EDP/IR 6/30/72** | | | | | | | | | | |
| 27. | Subtotal Hardware | | | 5930 | 35.0 | 6340 | 34.1 | | | | |
| 28. | Data Entry & Commun. | | | 720 | 4.3 | 760 | 4.1 | | | | |
| 29. | Subtotal Software | | | 440 | 2.6 | 450 | 2.4 | | | | |
| 30. | Services | | | 1430 | 8.4 | 1660 | 8.9 | | | | |
| 31. | Supplies | | | 1020 | 6.0 | 1080 | 5.8 | | | | |
| 32. | Total Outside Expenditures | | | 9540 | 56.3 | 10290 | 55.4 | | | | |
| 33. | Internal Salaries | | | 7400 | 43.7 | 8300 | 44.6 | | | | |
| 34. | Grand Total Expenditures | | | 16940 | 100.0 | 18590 | 100.0 | | | | |

### TABLE II.3.25.1 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS I

| | | 1974 | |
|---|---|---|---|
| | | $M | % |
| | **IDC—Review** | | |
| 1. | System—Rentals | 3905 | 19.2 |
| 2. | Periph. Eq. Rentals | 275 | 1.4 |
| 3. | Third Party Lease Payments | 870 | 4.3 |
| 4. | Purchases | 2314 | 11.4 |
| 5. | Maintenance of Purch. Eq. | 681 | 3.3 |
| 6. | Subtotal Hardware | 8045 | 39.6 |
| 7. | Data Entry Equipment | 503 | 2.5 |
| 8. | Communications—Equipment | 477 | 2.3 |
| 9. | Line Costs | 1091 | 5.4 |
| 10. | Subtotal Commun. | 1568 | 7.7 |
| 11. | Software (outside)—Standard | 177 | 0.9 |
| 12. | Custom | 175 | 0.9 |
| 13. | Subtotal Software | 352 | 1.7 |
| 14. | Services | 828 | 4.1 |
| 15. | Supplies | 991 | 4.9 |
| 16. | Total Outside Expenditures | 12287 | 60.4 |
| 17. | Internal Salaries | 8044 | 39.6 |
| 18. | Grand Total Expenditures | 20331 | 100.0 |

### TABLE II.3.25.2 USERS' EXPENDITURES II ICL ESTIMATE FOR 1968

| | Expense in Million Pounds Sterling | Percent of Total |
|---|---|---|
| Processor and Core | 48 | 14 |
| Memory Peripherals | 47 | 14 |
| I/O Peripherals | 25 | 7 |
| Subtotal Peripherals | 72 | 21 |
| Terminals | 5 | 1 |
| Subtotal Hardware | 125 | 36 |
| Communication Line Costs | 9 | 2 |
| Supplies | 30 | 9 |
| Maintenance | 20 | 6 |
| Operations | 60 | 17 |
| Syst. Anal./Prog. | 80 | 23 |
| Consultants | 6 | 1 |
| Service Bureaus | 20 | 6 |
| Grand Total | 350 | 100 |

The table also showed expected expenses in these same categories for the years 1975 and 1980.

### TABLE II.3.25.3 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS III

The 1970 edition of the Japanese "Computer White Paper" (JACUsag70) provides a table summarizing the results of a survey conducted in Japan regarding the state of computer usage at the end of September, 1969. One thousand questionaires were mailed, and the table presents the results of an analysis of 345 valid responses. The number of users surveyed having equipment in each of the price ranges shown in the table in the years 1968/1969 are as follows: over $61.8k, 13/28; $15.4k to $61.8k, 69/99; $2.4k to $15.4k, 114/148; $600 to $2400, 34/35; and less than $600, 5/2.

Entries in the table represent percentages of total expenses in each of various categories as shown. The top half of the table gives 1968 expenditures, from a previous survey, and the bottom half shows the same breakdown of 1969 expenses. Unfortunately, no explanations or definitions are given regarding the various terms used. In particular, there is no discussion of what is included in the "etc." with communication circuit fees, no definition of "punching and reading costs", and no explanation of exactly what is included in "labor costs". With regard to the latter item, a later section of the book lists keypunch operators, computer operators, system engineers, programmers, clerks, managers, and "related personnel" as major computer personnel categories, though no connection is made between those categories and the "labor costs" entry here.

In establishing the computer rental ranges in the table headings, I used a conversion rate of $2.778 per thousand Japanese yen.

### TABLE II.3.25.4 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS IV

This table presents the results of three surveys (McLaR74-2) by *Datamation* magazine. The first portion of the table shows a 1974 budget breakdown by system size. Three hundred data processing executives from large and small companies in the United States and Canada supplied confidential budget information in response to a four-page, 200-item questionaire. From these 300 responses, 181 "stable" U.S. installations were selected. Organizations which provided sketchy or ambiguous responses, and organizations whose 1974 budgets were very greatly different from their 1973 expenditures were arbitrarily excluded from the sample. The selected sites, by hardware expenditure size, were: less than $25k per year, 7; $25k to $100k, 67; $100k to $250k, 51; $250k to $500k, 24; $500k to $1M, 15; and over $1M, 10. These six expenditure categories (corresponding to the first six columns of figures in the table) represent annual expenditures on hardware, whether rented, purchased, or leased. For purchased equipment, it includes the annual amortization figures as well as the maintenance cost for those machines. The last two columns represent a projection of this small survey to all U.S. data processing shops "like those surveyed"—estimated to be about 34,500.

**TABLE II.3.25.3 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS III DISTRIBUTION OF TOTAL EXPENSES IN JAPAN**

| | Less Than $600 | $600 to $2400 | $2.4k to $15.4k | $15.4k to $61.8k | Over $61.8k | System |
|---|---|---|---|---|---|---|
| **1968** | | | | | | |
| Machine Rental | 30.1 | 43.7 | 45.3 | 46.2 | 55.8 | 48.8 |
| Machine Cost (Depreciation) | 6.6 | 9.5 | 3.7 | 6.4 | 10.3 | 7.1 |
| Maintenance and Insurance | 2.0 | 1.2 | 1.1 | 1.7 | 0.8 | 1.3 |
| Subtotal Hardware | 38.7 | 54.4 | 50.1 | 54.3 | 66.9 | 57.2 |
| Cards, Paper, and Tape | 3.4 | 3.7 | 2.8 | 3.0 | 2.3 | 2.8 |
| Magnetic Tape, Cards, and Disks | 0 | 0.8 | 3.5 | 3.9 | 3.6 | 3.7 |
| Printing Paper | 3.4 | 3.5 | 3.4 | 5.7 | 4.5 | 4.9 |
| Subtotal Supplies | 6.8 | 8.0 | 9.7 | 12.6 | 10.4 | 11.4 |
| Services (Outside Processing) | 0 | 0.2 | 2.7 | 1.7 | 1.8 | 1.9 |
| Communication Circuit Fees, etc. | 8.5 | 1.1 | 2.8 | 2.9 | 1.9 | 2.5 |
| Punching and Reading Cost | 0 | 2.4 | 1.8 | 3.5 | 1.8 | 2.6 |
| Total Outside Expenditures | 54.0 | 66.1 | 67.1 | 75.0 | 82.8 | 75.6 |
| Labor Cost | 46.0 | 33.8 | 33.0 | 24.9 | 17.1 | 24.4 |
| Grand Total Expenditures | 100.0 | 99.9 | 100.1 | 99.9 | 99.9 | 100.0 |
| **1969** | | | | | | |
| Machine Rental | 36.7 | 32.0 | 47.2 | 31.8 | 45.6 | 39.1 |
| Machine Cost (Depreciation) | 0 | 14.9 | 3.7 | 10.3 | 4.7 | 7.1 |
| Maintenance and Insurance | 0.7 | 2.6 | 3.2 | 4.0 | 1.3 | 3.6 |
| Subtotal Hardware | 37.4 | 49.5 | 54.1 | 46.1 | 51.6 | 49.8 |
| Cards, Paper, and Tape | 1.4 | 5.1 | 3.3 | 1.1 | 1.9 | 1.8 |
| Magnetic Tape, Cards, and Disks | 0 | 2.2 | 2.8 | 4.0 | 2.1 | 3.0 |
| Printing Paper | 2.4 | 5.7 | 5.3 | 4.8 | 5.1 | 4.8 |
| Subtotal Supplies | 3.8 | 13.0 | 11.4 | 9.9 | 9.1 | 9.6 |
| Services (Outside Processing) | 2.2 | 0.8 | 2.2 | 2.4 | 6.5 | 4.1 |
| Communication Circuit Fees, etc. | 1.9 | 3.6 | 3.1 | 10.4 | 3.7 | 6.6 |
| Punching and Reading Cost | 0 | 6.5 | 2.1 | 2.4 | 5.9 | 3.8 |
| Total Outside Expenditures | 45.3 | 73.4 | 72.9 | 71.2 | 76.8 | 73.9 |
| Labor Cost | 54.7 | 26.6 | 27.2 | 28.8 | 23.2 | 26.0 |
| Grand Total Expenditures | 100.0 | 100.0 | 100.1 | 100.0 | 100.0 | 99.9 |

## TABLE II.3.25.4 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS IV USER BUDGETS FOR 1974

| | Computer System Monthly Rental | | | | | | All Users' Expenditures | |
|---|---|---|---|---|---|---|---|---|
| | Less Than $2.1k (%) | $2.1k to $8.3k (%) | $8.3k to $20.8k (%) | $20.8k to $41.7k (%) | $41.7k to $83.3k (%) | Over $83.3k (%) | (%) | ($B) |
| Central Site Hardware–Total | 26.13 | 35.23 | 32.02 | 36.15 | 33.24 | 35.83 | | |
| Data Entry Equipment | 7.28 | 2.81 | 3.05 | 4.51 | 3.20 | 0.90 | | |
| Computers/Memory | 16.62 | 24.93 | 18.91 | 15.93 | 18.76 | 18.28 | | |
| Peripherals | 0 | 5.39 | 7.54 | 12.75 | 8.61 | 13.34 | | |
| COM | 0 | 0 | 0.36 | 0.18 | 0.29 | 0.66 | | |
| Film Readers, Printers, etc. | 0.88 | 0.18 | 0.12 | 0.12 | 0.12 | 0.07 | | |
| Auxiliary Equipment | 1.35 | 0.69 | 0.49 | 0.59 | 0.74 | 0.46 | | |
| Communications Gear | 0 | 0.32 | 0.98 | 1.95 | 1.36 | 1.20 | | |
| Other Hardware | 0 | 0.91 | 0.57 | 0.12 | 0.16 | 0.92 | | |
| Remote Site Hardware–Total | 0 | 1.08 | 2.50 | 3.33 | 2.97 | 10.51 | | |
| Computers/Memory | 0 | 0.05 | 0.92 | 0.59 | 1.63 | 6.47 | | |
| Terminals | 0 | 0.81 | 0.96 | 2.41 | 1.28 | 2.99 | | |
| Communications Gear | 0 | 0.15 | 0.23 | 0.23 | 0.06 | 0.82 | | |
| Other Hardware | 0 | 0.07 | 0.39 | 0.10 | 0 | 0.23 | | |
| Total Hardware | 26.13 | 36.31 | 34.52 | 39.48 | 36.21 | 46.34 | 39.1 | 11.0 |
| Communications Lines–Total | 0 | 0.17 | 0.56 | 1.77 | 0.84 | 2.85 | 0.9 | 0.3 |
| Data Lines | 0 | 0.14 | 0.44 | 1.58 | 0.38 | 1.57 | | |
| Voice Lines | 0 | 0.03 | 0.12 | 0.19 | 0.46 | 1.28 | | |
| Software | 0 | 0.46 | 0.79 | 0.94 | 0.81 | 1.05 | 0.8 | 0.2 |
| Supplies | 22.05 | 6.99 | 5.45 | 6.85 | 7.03 | 3.88 | 6.8 | 1.9 |
| Security | 0 | 0.24 | 0.17 | 0.10 | 0.54 | 0.25 | | |
| Outside Services–Total | 0 | 1.00 | 1.03 | 0.44 | 0.19 | 0.94 | 1.4 | 0.4 |
| Time-Sharing | 0 | 0.35 | 0.21 | 0.29 | 0.01 | 0.35 | 0.5 | 0.1 |
| Batch Processing | 0 | 0.12 | 0.19 | 0.05 | 0.02 | 0.55 | 0.6 | 0.2 |
| Remote Batch | 0 | 0.45 | 0.40 | 0 | 0 | 0 | 0.3 | 0.1 |
| Film Processing | 0 | 0.08 | 0.23 | 0.07 | 0.16 | 0.04 | | |
| Outside Personnel–Total | 0 | 1.38 | 1.19 | 0.44 | 1.28 | 4.56 | 1.4 | |
| Consultants | 0 | 0.23 | 0.45 | 0.17 | 0.95 | 3.08 | 1.1 | 0.3 |
| Contract Programmers | 0 | 0.92 | 0.19 | 0.02 | 0 | 0.86 | 0.3 | |
| Temporary Help | 0 | 0.23 | 0.55 | 0.25 | 0.33 | 0.62 | | |
| Miscellaneous | 0 | 0.66 | 0.45 | 0.41 | 0 | 0.70 | | |
| Internal Personnel–Total | 51.82 | 52.79 | 55.84 | 49.60 | 53.10 | 39.43 | 47.4 | |
| Salaries & Fringe Benefits | 50.92 | 52.13 | 54.91 | 48.73 | 52.03 | 38.87 | 46.9 | 13.2 |
| Training | 0.23 | 0.28 | 0.37 | 0.40 | 0.49 | 0.25 | 0.3 | |
| Conferences | 0.10 | 0.30 | 0.39 | 0.28 | 0.24 | 0.19 | 0.2 | |
| Travel, etc. | 1.57 | 0.08 | 0.17 | 0.19 | 0.34 | 0.12 | | |
| Grand Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 28.1 |

## TABLE II.3.25.4 EXPENDITURES BY ORGANIZATIONS HAVING COMPUTERS IV USER BUDGETS FOR 1972-1975

| | Percent of Total Budget | | | |
|---|---|---|---|---|
| | 1972 | 1973 | 1974 | 1975 |
| Central Site Hardware–Total | | | | 35.4 |
| Data Entry Equipment | | | | 2.9 |
| Computers/Memory | | | | 17.6 |
| Peripherals | | | | 12.7 |
| COM | | | | 0.1 |
| Film Readers, Printers, etc. | | | | |
| Auxiliary Equipment | | | | 0.5 |
| Communications Gear | | | | 1.2 |
| Other Hardware | | | | 0.4 |
| Remote Site Hardware–Total | | | | 2.4 |
| Computers/Memory | | | | 0.4 |
| Terminals | | | | 1.8 |
| Communications Gear | | | | 0.1 |
| Other Hardware | | | | 0.1 |
| Total Hardware | 39.2 | 40.0 | 39.1 | 37.8 |
| Communications Lines–Total | | | 0.9 | 0.7 |
| Data Lines | 5.2 | 5.9 | | 0.6 |
| Voice Lines | NI | NI | | 0.1 |

| | Percent of Total Budget | | | |
|---|---|---|---|---|
| | 1972 | 1973 | 1974 | 1975 |
| Software | 0.7 | 0.9 | 0.8 | 1.0 |
| Supplies | 5.9 | 5.9 | 6.8 | 7.3 |
| Security | NI | NI | | 0.1 |
| Outside Services–Total | 1.2 | 1.2 | 1.4 | 0.4 |
| Time-Sharing | 0.6 | 0.6 | 0.5 | 0.1 |
| Batch Processing | 0.4 | 0.4 | 0.6 | 0.1 |
| Remote Batch | 0.2 | 0.2 | 0.3 | |
| Film Processing | NI | NI | | 0.2 |
| Outside Personnel–Total | 1.2 | 1.0 | 1.4 | 0.7 |
| Consultants | 0.4 | 0.4 | 1.1 | 0.2 |
| Contract Programmers | 0.8 | 0.6 | 0.3 | 0.3 |
| Temporary Help | NI | NI | | 0.2 |
| Miscellaneous | NI | NI | | 0.2 |
| Internal Personnel–Total | 46.7 | 45.1 | 47.4 | 51.9 |
| Salaries & Fringe Benefits | 46.3 | 44.5 | 46.9 | 51.1 |
| Training | 0.3 | 0.4 | 0.3 | 0.5 |
| Conferences | 0.1 | 0.2 | 0.2 | 0.3 |

The second half of the table provides the same breakdown of expenses over the period since the first study was conducted, in 1972.

The papers provided no definitions or descriptions of the various line items in the table. They did warn that, because of the small size of the samples involved, single installations often biased the results. For example, the 1974 paper mentioned that installations spending $41.7k to $83.3k per month spend very little money on outside help, including consultants. But it added that the sample was biased by one particular installation which planned to spend $140k that year on outside consultants.

### TABLE II.3.25.5 CHRONOLOGY OF SYSTEM OPERATING COSTS—NOTES

**Overhead** 1-4. Line 1 is from Table II.4.11, line 2; line 2 from Table II.1.25, line 4; line 3 from Table 4.22.1; and line 4 from Table II.4.4.5, line 2.

5. Line 5 is new, and is derived from line 2 by adding 35% to that line. Line 2 represents direct salary overhead—salary of supervisors and secretaries, and their fringe benefits. It increases because of increases in fringe benefits. The additional 35% comes from office space (20%), telephone and office supplies (5%), depreciation of furniture and equipment (2%), and miscellaneous including other supervision, insurance, utilities, etc. (8%).

**Computer Facilities.** 6-9. The average price of a GP system in use in the US is from Table II.1.21. The room area occupied by that equipment is estimated from the average system price and Figure 3.25.5, taking into account roughly the relative proportion of different generations installed, and the fact that a relatively large *number* of systems are in the less expensive price range at any time. The average annual space rental, on line 8, is from UrbaL67, which gives charts on gross rental income for office space for the years 1925 to 1965. The figures since 1965 are my own extrapolation. Line 9 is the product of lines 7 and 8, divided by twelve to convert cost to a monthly figure.

10-13. Line 10 is derived from line 6 and Figure 3.25.8 in much the same way that line 7 was derived. System power usage on line 11 was computed from the heat dissipation on line 10 by noting that 1 KBTU/hr. is created by 0.293 Kwatts. To that figure we must add the power required for the air conditioner, taking into account the facts that one horsepower of motor capacity is required for each ton of air conditioning, and that a ton is defined as that capacity able to handle a load of 12,000 BTU/hr. (equivalent to the heat absorbed in melting a ton of ice per day). The total power requirement is therefore 0.355 times the heat load on line 10. Line 12 is my estimate of average system usage per month—I have not found a good source for that average, and it may be wildly wrong. Line 13 is the product of lines 11 and 12.

14-15. The average US price of electricity, in cents per kilowatt-hour, is from CenStatAb, and is computed by dividing the revenue from elecricity sold to all "ultimate customers" in the US by the total power sold to those customers. It thus excludes intra-utility power transfers, and averages residential and industrial usage. Line 15 is the product of lines 13 and 14.

16-20. The cost of the computer room "false floor" is estimated at $4 per square foot for the entire period—I have no historical figures, though I suspect costs have in fact dropped since the fifties. The capital cost of the air conditioning installation is estimated at $1000 per ton. In computing the tonnage required, I assumed the user bought 25% more capacity than he needed, to allow for growth, and that for safety he installed three separate units of equal capacity, any two of which would handle the load. The total cost, in thousands of dollars, is thus computed from the heat load on line 10, by dividing by 12 (to convert to tons of air conditioning capacity), and multiplying the result first by 1.25, then by 1.5. The monthly capital cost is then the sum of lines 16 and 17, divided by 120 to account for a ten-year depreciation period. Line 19 is the sum of lines 9, 15, and 18. The motor-generator set cost on line 20 is based on an estimated price of $350 per installed kva. With an assumed power factor of 0.8, the cost per killowatt of system power is $350/0.8 = $437.5, and the cost per KBTU/hr. is $437.5x0.293 = $128. If we add 25% for spare capacity, as we did for the air conditioning system, the cost is very nearly the same as the air conditioning capital cost—$156 times the heat load. Note there is no need to use MG set power to drive the air conditioning motor, though if we were providing an uninterrupted power source—batteries or a prime mover—it would be necessary to drive the air conditioner (and computer room lights) as well.

**User Cost Summary.** 21-34. The data in this portion of the table is simply copied from other tables. Lines 21, 22, 23, 26, and 28 come from Table II.1.20, lines 37, 34, 33, 36, and 35 respectively. Line 25 is line 15 from Table II.1.23. Lines 29 and 30 come from lines 34 and 35 of Table II.1.24. Lines 24 and 27 are the sums of preceding lines. Line 31 is line 7 from Table II.1.25, and line 32 is line 81 from Table II.1.27. Lines 33 and 34 are lines 2 and 9, respectively, from Table II.1.26.

35-40. Annual salaries were computed from the salary data in Table II.1.4.3 and the user personnel summary in Table II.1.4.2. The personnel counts were as of year-end, and I computed annual salaries by computing the average of two end-year counts and multiplying by the end-year salary, assuming a 52-week year.

41-44. The monthly personnel costs were computed from annual ones by dividing by twelve and applying the overhead rate of line 5 to the result.

## TABLE II.3.25.5 CHRONOLOGY OF SYSTEM OPERATING COSTS

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Overhead Rates** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Factory Assembly Lab. | 3.25.1 | % | 125 | | | | | 140 | | | | | 160 | | | | | 175 | 176 | 177 | | 180 |
| 2. | Basic Programmer/SA | 3.25.1 | % | 46 | 47 | 48 | 49 | 50 | 50 | 51 | 51 | 51 | 52 | 52 | 52 | 53 | 53 | 53 | 54 | 54 | 54 | 55 | 56 |
| 3. | Software Development | | % | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 | 78 | 81 | 84 | 87 | 90 | 93 | 97 | 98 | 98 |
| 4. | Maintenance C.E. | 3.25.1 | % | | 130 | | | | 150 | | | | | 165 | | | | | 175 | | | | 180 |
| 5. | Complete–Office Worker | 3.25.1 | % | 81 | 82 | 83 | 84 | 85 | 85 | 86 | 86 | 86 | 87 | 87 | 87 | 88 | 88 | 88 | 89 | 89 | 89 | 90 | 91 |
| | **Computer Facilities** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Av. U.S. GP System Value | | $k | 730 | 457 | 429 | 428 | 431 | 424 | 424 | 430 | 389 | 360 | 360 | 378 | 387 | 427 | 465 | 487 | 463 | 461 | 439 | 464 |
| 7. | Av. Area Required | | sq ft | 600 | 500 | 500 | 500 | 500 | 450 | 350 | 320 | 310 | 300 | 300 | 310 | 320 | 340 | 360 | 370 | 360 | 350 | 340 | 350 |
| 8. | Av. Annual Space Rental | | $psf | 3.50 | 3.60 | 3.80 | 3.90 | 4.00 | 4.00 | 4.10 | 4.20 | 4.30 | 4.50 | 4.45 | 4.50 | 4.55 | 4.60 | 4.65 | 4.70 | 4.80 | 5.00 | 5.20 | 5.40 |
| 9. | Tot. Monthly Space Cost | 3.25.9 | $k/mo | .18 | .15 | .16 | .16 | .17 | .15 | .12 | .11 | .11 | .11 | .11 | .12 | .12 | .13 | .14 | .15 | .14 | .15 | .15 | .16 |
| 10. | Heat Dissipation/System | | kB/hr | 90 | 70 | 60 | 60 | 60 | 55 | 47 | 40 | 35 | 32 | 30 | 31 | 32 | 33 | 34 | 35 | 34 | 34 | 33 | 34 |
| 11. | System Power Usage | | kw | 32.0 | 24.9 | 21.3 | 21.3 | 21.3 | 19.5 | 16.7 | 14.2 | 12.4 | 11.4 | 10.7 | 11.0 | 11.4 | 11.7 | 12.1 | 12.4 | 12.1 | 12.1 | 11.7 | 12.1 |
| 12. | Operating Time/Mo. | | hr | 300 | 300 | 300 | 300 | 300 | 300 | 305 | 310 | 315 | 320 | 325 | 330 | 335 | 340 | 345 | 350 | 355 | 360 | 365 | 370 |
| 13. | Monthly Power Usage | | Mwhr | 9.6 | 7.5 | 6.4 | 6.4 | 6.4 | 5.9 | 5.1 | 4.4 | 3.9 | 3.6 | 3.5 | 3.6 | 3.8 | 4.0 | 4.2 | 4.3 | 4.3 | 4.4 | 4.3 | 4.5 |
| 14. | Electricity Price | | cpkwh• | 1.67 | 1.64 | 1.67 | 1.71 | 1.69 | 1.69 | 1.69 | 1.68 | 1.65 | 1.62 | 1.59 | 1.57 | 1.56 | 1.55 | 1.54 | 1.59 | 1.69 | 1.58 | 1.86 | 2.30 |
| 15. | Monthly Elec. Cost | 3.25.9 | $k/mo | .16 | .12 | .11 | .11 | .11 | .10 | .09 | .07 | .06 | .06 | .06 | .06 | .06 | .06 | .06 | .07 | .07 | .07 | .08 | .10 |
| | Capital Expenditures | | | | | | | | | | | | | | | | | | | | | | |
| 16. | False Floor | | $k | 2.40 | 2.00 | 2.00 | 2.00 | 2.00 | 1.80 | 1.40 | 1.28 | 1.24 | 1.20 | 1.20 | 1.24 | 1.28 | 1.36 | 1.44 | 1.48 | 1.44 | 1.40 | 1.36 | 1.40 |
| 17. | Air Conditioning Cost | | $k | 14.04 | 10.92 | 9.36 | 9.36 | 9.36 | 8.58 | 7.33 | 6.24 | 5.46 | 4.99 | 4.68 | 4.84 | 4.99 | 5.14 | 5.30 | 5.46 | 5.30 | 5.30 | 5.15 | 5.30 |
| 18. | Monthly Cost | 3.25.9 | $k/mo | .14 | .11 | .09 | .09 | .09 | .09 | .07 | .06 | .06 | .05 | .05 | .05 | .05 | .05 | .06 | .06 | .06 | .06 | .05 | .06 |
| 19. | Tot. Facilities Costs | 3.25.9 | $k/mo | .48 | .38 | .36 | .36 | .37 | .34 | .28 | .24 | .23 | .22 | .22 | .23 | .23 | .24 | .26 | .28 | .27 | .28 | .28 | .32 |
| 20. | Optional MG Cost | 3.25.9 | $k/mo | .12 | .09 | .08 | .08 | .08 | .07 | .06 | .05 | .05 | .04 | .04 | .04 | .04 | .04 | .04 | .05 | .04 | .04 | .04 | .04 |
| | **Cost Summary** | | | | | | | | | | | | | | | | | | | | | | |
| | U.S. GP Users | | | | | | | | | | | | | | | | | | | | | | |
| 21. | In Use–Processors | | $B | .147 | .207 | .295 | .419 | .536 | .611 | .858 | 1.271 | 1.319 | 1.243 | 1.535 | 2.254 | 2.363 | 3.750 | 5.337 | 5.597 | 5.064 | 4.871 | 4.577 | 6.308 |
| 22. | Internal Memory | | $B | .012 | .042 | .082 | .157 | .259 | .400 | .548 | .626 | 1.018 | 1.450 | 1.749 | 2.144 | 3.154 | 4.051 | 4.767 | 5.451 | 6.228 | 6.844 | 7.179 | 7.286 |
| 23. | Peripherals & Controllers | | $B | .021 | .071 | .163 | .324 | .545 | .854 | 1.189 | 1.518 | 2.108 | 3.157 | 4.266 | 5.922 | 7.658 | 8.761 | 9.986 | 10.842 | 11.788 | 12.265 | 12.224 | 12.311 |
| 24. | CPU System | | $B | .180 | .320 | .540 | .900 | 1.340 | 1.865 | 2.595 | 3.415 | 4.445 | 5.850 | 7.550 | 10.320 | 13.175 | 16.562 | 20.090 | 21.890 | 23.080 | 23.980 | 23.980 | 25.905 |
| 25. | Keyboard DE | | $B | .005 | .015 | .027 | .046 | .067 | .095 | .136 | .179 | .258 | .374 | .483 | .637 | .811 | .975 | 1.193 | 1.445 | 1.775 | 2.045 | 2.422 | 2.538 |
| 26. | OCR & MICR | | $B | | | | | | | .010 | .030 | .050 | .070 | .110 | .150 | .215 | .308 | .410 | .490 | .570 | .650 | .720 | .825 |
| 27. | Data Entry Tot. | | $B | .005 | .015 | .027 | .046 | .067 | .095 | .146 | .209 | .308 | .444 | .593 | .787 | 1.026 | 1.273 | 1.603 | 1.935 | 2.345 | 2.695 | 3.142 | 3.363 |
| 28. | Terminals | | $B | | | | | | | | .040 | .055 | .080 | .140 | .230 | .410 | .630 | .900 | 1.220 | 1.550 | 1.970 | 2.600 | 3.470 |
| 29. | Annual Rev.–Data Sets | | $B | | | | | | .001 | .001 | .003 | .004 | .006 | .011 | .016 | .026 | .040 | .061 | .089 | .126 | .156 | .187 | .216 |
| 30. | Data Transmission | | $B | | | | | | | .004 | .009 | .014 | .023 | .035 | .053 | .085 | .135 | .200 | .280 | .405 | .500 | .590 | .675 |
| 31. | Software–Standard | | $B | | | | | | | | | | | | | .010 | .025 | .045 | .075 | .100 | .281 | .395 | .500 |
| 32. | Supplies | | $B | .003 | .009 | .019 | .034 | .055 | .085 | .134 | .182 | .268 | .354 | .444 | .578 | .713 | .781 | .897 | .967 | .999 | 1.087 | 1.289 | 1.876 |
| 33. | Services–Batch DP | | $B | .015 | .020 | .025 | .040 | .090 | .125 | .180 | .220 | .260 | .285 | .340 | .410 | .480 | .600 | .740 | .930 | 1.060 | 1.230 | 1.400 | 1.580 |
| 34. | Other | | $B | | | | | | | | | | .002 | .005 | .010 | .030 | .050 | .150 | .200 | .400 | .500 | .600 | .700 |
| 35. | Annual Salaries–SA | | $M | 5.0 | 9.6 | 17.0 | 29.8 | 48.0 | 71.8 | 107.2 | 151.5 | 214.0 | 299.5 | 410.6 | 581.3 | 830.8 | 1114 | 1475 | 1794 | 1968 | 2180 | 2434 | 2712 |
| 36. | Programmers | | $M | 5.5 | 10.9 | 19.2 | 32.5 | 51.3 | 76.3 | 110.5 | 159.6 | 217.3 | 298.8 | 422.4 | 609.2 | 846.5 | 1150 | 1537 | 1860 | 2096 | 2345 | 2520 | 2847 |
| 37. | SA & P | | $M | 10.5 | 20.5 | 36.2 | 62.3 | 99.3 | 148.1 | 217.7 | 311.1 | 431.3 | 598.3 | 833.0 | 1190.5 | 1677.3 | 2264 | 3012 | 3654 | 4064 | 4525 | 4954 | 5559 |
| 38. | Comp. Operators | | $M | 2.5 | 5.3 | 9.5 | 16.7 | 27.3 | 41.8 | 62.9 | 89.7 | 122.7 | 170.3 | 236.7 | 331.1 | 457.6 | 612.3 | 813.8 | 1036 | 1251 | 1459 | 1690 | 1929 |
| 39. | Keypunch Op. | | $M | 6.0 | 11.7 | 24.7 | 43.9 | 71.6 | 106.4 | 155.6 | 216.0 | 308.3 | 456.8 | 642.4 | 867.8 | 1165 | 1443 | 1742 | 2108 | 2467 | 3023 | 3658 | 4076 |
| 40. | Total Salaries | | $M | 19.0 | 37.5 | 70.4 | 122.9 | 198.2 | 296.3 | 436.2 | 616.8 | 862.3 | 1225.4 | 712.1 | 2389.4 | 3300 | 4319 | 5568 | 6798 | 7782 | 9007 | 10302 | 11564 |
| | Monthly Sal. incl. OH | | | | | | | | | | | | | | | | | | | | | | |
| 41. | SA & P | | $M/mo | 1.58 | 3.11 | 5.52 | 9.55 | 15.31 | 22.83 | 33.74 | 48.22 | 66.9 | 93.2 | 129.8 | 185.5 | 262.8 | 355 | 472 | 576 | 640 | 713 | 784 | 885 |
| 42. | Comp. Operators | | $M/mo | .38 | .80 | 1.45 | 2.56 | 4.21 | 6.44 | 9.75 | 13.90 | 19.0 | 26.5 | 36.9 | 51.6 | 71.7 | 96 | 127 | 163 | 197 | 230 | 268 | 307 |
| 43. | Keypunch Operators | | $M/mo | .90 | 1.77 | 3.77 | 6.73 | 11.04 | 16.40 | 24.12 | 33.48 | 47.8 | 71.2 | 100.1 | 135.2 | 182.5 | 226 | 273 | 332 | 389 | 476 | 579 | 649 |
| 44. | Total | | $M/mo | 2.87 | 5.69 | 10.74 | 18.84 | 30.56 | 45.68 | 67.61 | 95.60 | 133.7 | 191.0 | 266.8 | 372.3 | 517.0 | 677 | 872 | 1071 | 1226 | 1419 | 1631 | 1841 |

## TABLE II.3.25.5 CHRONOLOGY OF SYSTEM OPERATING COSTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Monthly Hardware Cost | | | | | | | | | | | | | | | | | | | | | | |
| 45. | Processors | | $M/mo | 3.34 | 4.70 | 6.70 | 9.52 | 12.18 | 13.89 | 19.5 | 28.9 | 30.0 | 28.3 | 34.9 | 51.2 | 53.7 | 85.2 | 121.3 | 127.2 | 115.1 | 110.7 | 104.0 | 143.4 |
| 46. | Internal Memory | | $M/mo | .27 | .95 | 1.86 | 3.57 | 5.89 | 9.09 | 12.5 | 14.2 | 23.1 | 33.0 | 39.8 | 48.7 | 71.7 | 92.1 | 108.3 | 123.9 | 141.5 | 155.5 | 163.1 | 165.6 |
| 47. | Peripherals & Controllers | | $M/mo | .48 | 1.61 | 3.70 | 7.36 | 12.39 | 19.41 | 27.0 | 34.5 | 47.9 | 71.8 | 97.0 | 134.6 | 174.0 | 199.1 | 227.0 | 246.4 | 267.9 | 278.8 | 277.8 | 279.8 |
| 48. | CPU Systems | | $M/mo | 4.09 | 7.27 | 12.27 | 20.45 | 30.45 | 42.39 | 59.0 | 77.6 | 101.0 | 133.0 | 171.6 | 234.5 | 299.4 | 376.4 | 456.6 | 497.5 | 524.5 | 545.0 | 545.0 | 588.8 |
| 49. | Keyboard Data Entry | | $M/mo | .09 | .26 | .48 | .81 | 1.18 | 1.68 | 2.4 | 3.2 | 4.6 | 6.6 | 8.5 | 11.3 | 14.4 | 17.3 | 21.3 | 26.2 | 32.9 | 38.7 | 46.3 | 49.4 |
| 50. | OCR & MICR | | $M/mo | | | | | | | .2 | .7 | 1.1 | 1.6 | 2.5 | 3.4 | 4.9 | 7.0 | 9.3 | 11.1 | 13.0 | 14.8 | 16.4 | 18.8 |
| 51. | Total Data Entry | | $M/mo | .09 | .26 | .48 | .81 | 1.18 | 1.68 | 2.6 | 3.9 | 5.7 | 8.2 | 11.0 | 14.7 | 19.3 | 24.3 | 30.6 | 37.3 | 45.9 | 53.5 | 62.7 | 68.2 |
| 52. | Terminals | | $M/mo | | | | | | | | .9 | 1.3 | 1.8 | 3.2 | 5.2 | 9.3 | 14.3 | 20.5 | 27.7 | 35.2 | 44.8 | 59.1 | 78.9 |
| | Monthly Expenses | | | | | | | | | | | | | | | | | | | | | | |
| 53. | Data Sets | | $M/mo | | | | | | .08 | .1 | .3 | .3 | .5 | .9 | 1.3 | 2.2 | 3.3 | 5.1 | 7.4 | 10.5 | 13.0 | 15.6 | 18.0 |
| 54. | Data Transmission | | $M/mo | | | | | | | .3 | .8 | 1.2 | 1.9 | 2.9 | 4.4 | 7.1 | 11.3 | 16.7 | 23.3 | 33.8 | 41.7 | 49.2 | 56.3 |
| 55. | Software–Standard | | $M/mo | | | | | | | | | | | | | .8 | 2.1 | 3.8 | 6.3 | 8.3 | 23.4 | 32.9 | 41.7 |
| 56. | Supplies | | $M/mo | .25 | .75 | 1.58 | 2.83 | 4.58 | 7.08 | 11.2 | 15.2 | 22.3 | 29.5 | 37.0 | 48.2 | 59.4 | 65.1 | 74.8 | 80.6 | 83.3 | 90.6 | 107.4 | 156.3 |
| 57. | Services–Batch DP | | $M/mo | .13 | .17 | .21 | .33 | .75 | 1.04 | 1.5 | 1.8 | 2.2 | 2.4 | 2.8 | 3.4 | 4.0 | 5.0 | 6.2 | 7.8 | 8.8 | 10.3 | 11.7 | 13.2 |
| 58. | Other | | $M/mo | | | | | | | | | | .2 | .4 | .8 | 2.5 | 4.2 | 12.5 | 16.7 | 33.3 | 41.7 | 50.0 | 58.3 |
| 59. | Total | | $M/mo | .13 | .17 | .21 | .33 | .75 | 1.04 | 1.5 | 1.8 | 2.2 | 2.6 | 3.2 | 4.2 | 6.5 | 9.2 | 18.7 | 24.5 | 42.1 | 52.0 | 61.7 | 71.5 |
| 59a. | Facilities | | $M/mo | .12 | .27 | .45 | .76 | 1.15 | 1.50 | 1.7 | 1.9 | 2.7 | 3.7 | 4.8 | 6.5 | 8.2 | 9.8 | 12.0 | 13.1 | 14.7 | 16.2 | 17.4 | 20.8 |
| | **Summary** | | | | | | | | | | | | | | | | | | | | | | |
| 60. | Total User Costs | | $M/mo | 7.55 | 14.41 | 25.73 | 44.02 | 68.67 | 99.45 | 144.0 | 198.0 | 270.4 | 372.2 | 501.4 | 691.3 | 929.2 | 1193 | 1511 | 1789 | 2024 | 2299 | 2582 | 2942 |
| 61. | Number of GP Systems | | k | .240 | .700 | 1.260 | 2.100 | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 28.300 | 35.600 | 41.000 | 46.000 | 48.500 | 54.400 | 57.730 | 62.250 | 65.040 |
| 62. | Cost per System | | $k/mo | 31.46 | 20.59 | 20.42 | 20.96 | 22.08 | 22.60 | 23.41 | 24.44 | 23.11 | 22.29 | 23.21 | 24.43 | 26.10 | 29.10 | 32.85 | 36.89 | 37.21 | 39.82 | 41.48 | 45.23 |
| | Cost Breakdown I | | | | | | | | | | | | | | | | | | | | | | |
| 63. | Hardware–CPU Syst. | | % | 54.2 | 50.5 | 47.7 | 46.5 | 44.3 | 42.6 | 41.0 | 39.2 | 37.4 | 35.7 | 34.2 | 33.9 | 32.2 | 31.6 | 30.2 | 27.8 | 25.9 | 23.7 | 21.1 | 20.0 |
| 64. | Data Entry | | % | 1.2 | 1.8 | 1.9 | 1.8 | 1.7 | 1.7 | 1.8 | 2.0 | 2.1 | 2.2 | 2.2 | 2.1 | 2.1 | 2.0 | 2.0 | 2.1 | 2.3 | 2.3 | 2.4 | 2.3 |
| 65. | Terminals & Data Sets | | % | | | | | | 0.1 | 0.1 | 0.6 | 0.6 | 0.6 | 0.8 | 0.9 | 1.2 | 1.5 | 1.7 | 2.0 | 2.3 | 2.5 | 2.9 | 3.3 |
| 66. | Total Hardware | 3.25.11 | % | 55.4 | 52.3 | 49.6 | 48.3 | 46.0 | 44.4 | 42.9 | 41.8 | 40.1 | 38.5 | 37.2 | 36.9 | 35.5 | 35.1 | 33.9 | 31.9 | 30.5 | 28.5 | 26.4 | 25.6 |
| 67. | Data Transmission | | % | | | | | | | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 0.6 | 0.8 | 0.9 | 1.1 | 1.3 | 1.7 | 1.8 | 1.9 | 1.9 |
| 68. | Software | | % | | | | | | | | | | | | | 0.1 | 0.2 | 0.3 | 0.4 | 0.4 | 1.0 | 1.3 | 1.4 |
| 69. | Supplies | 3.25.11 | % | 3.3 | 5.2 | 6.1 | 6.4 | 6.7 | 7.1 | 7.8 | 7.7 | 8.2 | 7.9 | 7.4 | 7.0 | 6.4 | 5.5 | 5.0 | 4.5 | 4.1 | 3.9 | 4.2 | 5.3 |
| 70. | Services | | % | 1.7 | 1.2 | 0.8 | 0.7 | 1.1 | 1.0 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.6 | 0.7 | 0.8 | 1.2 | 1.4 | 2.1 | 2.3 | 2.4 | 2.4 |
| 71. | Personnel–Total | 3.25.11 | % | 38.0 | 39.5 | 41.7 | 42.8 | 44.5 | 45.9 | 46.9 | 48.3 | 49.4 | 51.3 | 53.2 | 53.9 | 55.6 | 56.7 | 57.7 | 59.9 | 60.6 | 61.7 | 63.2 | 62.6 |
| 72. | Salaries | | % | 21.0 | 21.7 | 22.8 | 23.3 | 24.1 | 24.8 | 25.2 | 26.0 | 26.6 | 27.4 | 28.4 | 28.8 | 29.6 | 30.2 | 30.7 | 31.7 | 32.1 | 32.6 | 33.3 | 32.8 |
| 73. | Overhead | | % | 17.0 | 17.8 | 18.9 | 19.5 | 20.4 | 21.1 | 21.7 | 22.3 | 22.8 | 23.9 | 24.8 | 25.1 | 26.0 | 26.5 | 27.0 | 28.2 | 28.5 | 29.1 | 29.9 | 29.8 |
| 74. | Personnel–SA & P | | % | 20.9 | 21.6 | 21.5 | 21.7 | 22.3 | 23.0 | 23.4 | 24.4 | 24.7 | 25.0 | 25.9 | 26.8 | 28.3 | 29.8 | 31.2 | 32.2 | 31.6 | 31.0 | 30.4 | 30.1 |
| 75. | Computer Oper. | | % | 5.0 | 5.6 | 5.6 | 5.8 | 6.1 | 6.5 | 6.8 | 7.0 | 7.0 | 7.1 | 7.4 | 7.5 | 7.7 | 8.0 | 8.4 | 9.1 | 9.7 | 10.0 | 10.4 | 10.4 |
| 76. | Keyboard Op. | | % | 11.9 | 12.3 | 14.7 | 15.3 | 16.1 | 16.5 | 16.8 | 16.9 | 17.7 | 19.1 | 20.0 | 19.6 | 19.6 | 18.9 | 18.1 | 18.6 | 19.2 | 20.7 | 22.4 | 22.1 |
| 77. | Facilities | | % | 1.6 | 1.9 | 1.7 | 1.7 | 1.7 | 1.5 | 1.2 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| | Cost Breakdown II | | | | | | | | | | | | | | | | | | | | | | |
| 78. | Operations–CPU Syst. | | % | 54.2 | 50.5 | 47.7 | 46.5 | 44.3 | 42.6 | 41.0 | 39.2 | 37.4 | 35.7 | 34.2 | 33.9 | 32.2 | 31.6 | 30.2 | 27.8 | 25.9 | 23.7 | 21.1 | 20.0 |
| 79. | Supplies | | % | 3.3 | 5.2 | 6.1 | 6.4 | 6.7 | 7.1 | 7.8 | 7.7 | 8.2 | 7.9 | 7.4 | 7.0 | 6.4 | 5.5 | 5.0 | 4.5 | 4.1 | 3.9 | 4.2 | 5.3 |
| 80. | Comp. Operators | | % | 5.0 | 5.6 | 5.6 | 5.8 | 6.1 | 6.5 | 6.8 | 7.0 | 7.0 | 7.1 | 7.4 | 7.5 | 7.7 | 8.0 | 8.4 | 9.1 | 9.7 | 10.0 | 10.4 | 10.4 |
| 81. | Facilities | | % | 1.6 | 1.9 | 1.7 | 1.7 | 1.7 | 1.5 | 1.2 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| 82. | Total | 3.25.13 | % | 64.1 | 63.2 | 61.1 | 60.4 | 58.8 | 57.7 | 56.8 | 54.9 | 53.6 | 51.7 | 50.0 | 49.3 | 47.2 | 45.9 | 44.4 | 42.1 | 40.4 | 38.3 | 36.4 | 36.4 |
| 83. | Data Entry–Equipment | | % | 1.2 | 1.8 | 1.9 | 1.8 | 1.7 | 1.7 | 1.8 | 2.0 | 2.1 | 2.2 | 2.2 | 2.1 | 2.1 | 2.0 | 2.0 | 2.1 | 2.3 | 2.3 | 2.4 | 2.3 |
| 84. | Operators | | % | 11.9 | 12.3 | 14.7 | 15.3 | 16.1 | 16.5 | 16.8 | 16.9 | 17.7 | 19.1 | 20.0 | 19.6 | 19.6 | 18.9 | 18.1 | 18.6 | 19.2 | 20.7 | 22.4 | 22.1 |
| 85. | Total | 3.25.13 | % | 13.1 | 14.1 | 16.6 | 17.1 | 17.8 | 18.2 | 18.6 | 18.9 | 19.8 | 21.3 | 22.2 | 21.7 | 21.7 | 20.9 | 20.1 | 20.7 | 21.5 | 23.0 | 24.8 | 24.4 |
| 86. | Communications–Lines | | % | | | | | | | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 0.6 | 0.8 | 0.9 | 1.1 | 1.3 | 1.7 | 1.8 | 1.9 | 1.9 |
| 87. | Data Sets | | % | | | | | | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.5 | 0.6 | 0.6 | 0.6 |
| 88. | Terminals | | % | | | | | | | | 0.5 | 0.5 | 0.5 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.5 | 1.7 | 1.9 | 2.3 | 2.7 |
| 89. | Total | 3.25.13 | % | | | | | | 0.1 | 0.3 | 1.0 | 1.0 | 1.1 | 1.4 | 1.6 | 2.0 | 2.4 | 2.8 | 3.3 | 3.9 | 4.3 | 4.8 | 5.2 |
| 90. | Syst Analysts & Prog. | 3.25.13 | % | 20.9 | 21.6 | 21.5 | 21.7 | 22.3 | 23.0 | 23.4 | 24.4 | 24.7 | 25.0 | 25.9 | 26.8 | 28.3 | 29.8 | 31.2 | 32.2 | 31.6 | 31.0 | 30.4 | 30.1 |

## TABLE II.3.25.5 CHRONOLOGY OF SYSTEM OPERATING COSTS ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91. | Software & Services | | % | 1.7 | 1.2 | 0.8 | 0.7 | 1.1 | 1.0 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.6 | 0.8 | 0.9 | 1.5 | 1.8 | 2.5 | 3.3 | 3.7 | 3.8 |
| | Per-System Costs | | | | | | | | | | | | | | | | | | | | | | |
| 92. | Total Cost | 3.25.10 | $k/mo | 31.46 | 20.59 | 20.42 | 20.96 | 22.08 | 22.60 | 23.41 | 24.44 | 23.11 | 22.29 | 23.21 | 24.43 | 26.10 | 29.10 | 32.85 | 36.89 | 37.21 | 39.82 | 41.48 | 45.23 |
| | Cost Breakdown I | | | | | | | | | | | | | | | | | | | | | | |
| 93. | Total Hardware | 3.25.10 | $k/mo | 17.43 | 10.77 | 10.13 | 10.12 | 10.16 | 10.03 | 10.04 | 10.22 | 9.27 | 8.58 | 8.63 | 9.01 | 9.27 | 10.21 | 11.14 | 11.77 | 11.35 | 11.35 | 10.95 | 11.58 |
| 94. | Supplies | 3.25.10 | $k/mo | 1.04 | 1.07 | 1.25 | 1.34 | 1.48 | 1.60 | 1.83 | 1.88 | 1.90 | 1.76 | 1.72 | 1.71 | 1.67 | 1.60 | 1.64 | 1.66 | 1.53 | 1.55 | 1.74 | 2.40 |
| 95. | Personnel—Total | | $k/mo | 11.95 | 8.13 | 8.52 | 8.97 | 9.83 | 10.37 | 10.98 | 11.80 | 11.42 | 11.43 | 12.35 | 13.17 | 14.51 | 16.50 | 18.95 | 22.10 | 22.55 | 24.57 | 26.22 | 28.31 |
| 96. | Salaries | 3.25.10 | $k/mo | 6.61 | 4.47 | 4.66 | 4.88 | 5.32 | 5.60 | 5.90 | 6.35 | 6.15 | 6.11 | 6.59 | 7.04 | 7.73 | 8.79 | 10.08 | 11.69 | 11.94 | 12.98 | 13.81 | 14.84 |
| 97. | Overhead | 3.25.10 | $k/mo | 5.35 | 3.67 | 3.86 | 4.09 | 4.50 | 4.77 | 5.08 | 5.45 | 5.27 | 5.33 | 5.76 | 6.13 | 6.79 | 7.71 | 8.87 | 10.40 | 10.60 | 11.59 | 12.40 | 13.48 |
| 98. | Other Costs | | $k/mo | 1.04 | 0.62 | 0.52 | 0.53 | 0.61 | 0.60 | 0.56 | 0.54 | 0.52 | 0.52 | 0.51 | 0.54 | 0.65 | 0.79 | 1.12 | 1.36 | 1.78 | 2.35 | 2.57 | 2.94 |
| | Cost Breakdown II | | | | | | | | | | | | | | | | | | | | | | |
| 99. | Operations Total | 3.25.12 | $k/mo | 20.17 | 13.01 | 12.48 | 12.66 | 12.98 | 13.04 | 13.30 | 13.42 | 12.39 | 11.52 | 11.61 | 12.04 | 12.32 | 13.36 | 14.59 | 15.53 | 15.03 | 15.25 | 15.10 | 16.46 |
| 100. | Data Entry Total | 3.25.17 | $k/mo | 4.12 | 2.90 | 3.39 | 3.58 | 3.93 | 4.11 | 4.35 | 4.62 | 4.58 | 4.75 | 5.15 | 5.30 | 5.66 | 6.08 | 6.60 | 7.64 | 8.00 | 9.16 | 10.29 | 11.04 |
| 101. | Communications Total | 3.25.12 | $k/mo | | | | | | 0.02 | 0.07 | 0.24 | 0.23 | 0.25 | 0.32 | 0.39 | 0.52 | 0.70 | 0.92 | 1.22 | 1.45 | 1.71 | 1.99 | 2.35 |
| 102. | Syst. Analysts & Prog. | 3.25.12 | $k/mo | 6.58 | 4.45 | 4.39 | 4.55 | 4.92 | 5.20 | 5.48 | 5.96 | 5.71 | 5.57 | 6.01 | 6.55 | 7.39 | 8.67 | 10.25 | 11.88 | 11.76 | 12.31 | 12.61 | 13.61 |
| 103. | Other Costs | | $k/mo | 0.59 | 0.23 | 0.16 | 0.17 | 0.25 | 0.23 | 0.21 | 0.20 | 0.20 | 0.20 | 0.12 | 0.15 | 0.21 | 0.29 | 0.49 | 0.62 | 0.97 | 1.39 | 1.49 | 1.72 |
| 104. | CPU System Costs | | $k/mo | 17.05 | 10.40 | 9.74 | 9.75 | 9.78 | 9.63 | 9.60 | 9.58 | 8.64 | 7.96 | 7.94 | 8.28 | 8.40 | 9.20 | 9.92 | 10.26 | 9.64 | 9.36 | 8.84 | 9.27 |
| | % of CPU/System Costs | | | | | | | | | | | | | | | | | | | | | | |
| 105. | Total Costs | 3.25.14 | % | 184.6 | 198.2 | 209.7 | 215.3 | 225.5 | 234.6 | 244.1 | 255.2 | 267.7 | 279.8 | 292.2 | 294.8 | 310.4 | 317.0 | 330.9 | 359.6 | 385.9 | 421.8 | 473.8 | 499.7 |
| 106. | Software Purchases | | % | | | | | | | | | | | | | 0.3 | 0.6 | 0.8 | 1.3 | 1.6 | 4.3 | 6.0 | 7.1 |
| 107. | Services | | % | 2.9 | 2.3 | 1.7 | 1.6 | 2.5 | 2.5 | 2.5 | 2.3 | 2.2 | 2.0 | 1.9 | 1.8 | 2.2 | 2.4 | 4.1 | 4.9 | 8.0 | 9.5 | 11.3 | 12.1 |
| 108. | Personnel—Total | 3.25.14 | % | 70.2 | 78.3 | 87.5 | 92.1 | 100.4 | 107.8 | 114.6 | 123.2 | 132.4 | 143.6 | 155.5 | 158.8 | 172.7 | 179.9 | 191.0 | 215.3 | 233.7 | 260.4 | 299.3 | 312.7 |
| 109. | Salaries | 3.25.14 | % | 38.8 | 43.0 | 47.8 | 50.1 | 54.3 | 58.3 | 61.6 | 66.2 | 71.2 | 76.8 | 83.2 | 84.9 | 91.9 | 95.7 | 101.6 | 113.9 | 123.7 | 137.8 | 157.5 | 163.7 |
| 110. | Overhead | | % | 31.4 | 35.3 | 39.6 | 42.0 | 46.1 | 49.5 | 53.0 | 57.0 | 61.2 | 66.8 | 72.3 | 73.9 | 80.8 | 84.2 | 89.4 | 101.4 | 110.0 | 122.6 | 141.8 | 149.0 |
| 111. | Operations—CPU Syst. | 3.25.15 | % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 111a. | Supplies | 3.25.15 | % | 6.1 | 10.3 | 12.9 | 13.8 | 15.0 | 16.7 | 19.0 | 19.6 | 22.1 | 22.2 | 21.6 | 20.6 | 19.8 | 17.3 | 16.4 | 16.2 | 15.9 | 16.6 | 19.7 | 26.5 |
| 112. | Computer Operators | 3.25.15 | % | 9.3 | 11.0 | 11.8 | 12.5 | 13.8 | 15.2 | 16.5 | 17.9 | 18.8 | 19.9 | 21.5 | 22.0 | 23.9 | 25.5 | 27.8 | 32.8 | 37.6 | 42.2 | 49.2 | 52.1 |
| 113. | Facilities | 3.25.15 | % | 2.9 | 3.7 | 3.7 | 3.7 | 3.8 | 3.5 | 2.9 | 2.4 | 2.7 | 2.8 | 2.8 | 2.8 | 2.7 | 2.6 | 2.6 | 2.6 | 2.8 | 3.0 | 3.2 | 3.5 |
| 114. | Total | 3.25.15 | % | 118.3 | 125.1 | 128.4 | 130.0 | 132.6 | 135.4 | 138.4 | 139.9 | 143.6 | 144.9 | 145.9 | 145.4 | 146.4 | 145.3 | 146.8 | 151.6 | 156.3 | 161.8 | 172.1 | 182.1 |
| 115. | Data Entry—Equipment | 3.25.16 | % | 2.2 | 3.6 | 3.9 | 4.0 | 3.9 | 4.0 | 4.4 | 5.0 | 5.6 | 6.2 | 6.4 | 6.3 | 6.4 | 6.5 | 6.7 | 7.5 | 8.8 | 9.8 | 11.5 | 11.6 |
| 116. | Operators | 3.25.16 | % | 22.0 | 24.3 | 30.7 | 32.9 | 36.3 | 38.7 | 40.9 | 43.1 | 47.3 | 53.5 | 58.3 | 57.7 | 61.0 | 60.0 | 59.8 | 66.7 | 74.2 | 87.3 | 106.2 | 110.2 |
| 117. | Total | 3.25.16 | % | 24.2 | 27.9 | 34.6 | 36.8 | 40.2 | 42.7 | 45.3 | 48.1 | 52.9 | 59.7 | 64.7 | 64.0 | 67.4 | 66.1 | 66.5 | 74.2 | 83.0 | 97.1 | 117.7 | 121.8 |
| 118. | Communications—Lines | | % | | | | | | | 0.5 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | 2.4 | 3.0 | 3.7 | 4.7 | 6.4 | 7.7 | 9.0 | 9.6 |
| 119. | Data Sets | | % | | | | | | 0.2 | 0.2 | 0.4 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.9 | 1.1 | 1.5 | 2.0 | 2.4 | 2.9 | 3.1 |
| 120. | Terminals | 3.25.16 | % | | | | | | | | 1.2 | 1.3 | 1.4 | 1.9 | 2.2 | 3.1 | 3.8 | 4.5 | 5.6 | 6.7 | 8.2 | 10.8 | 13.4 |
| 121. | Total | 3.25.16 | % | | | | | | 0.2 | 0.7 | 2.6 | 2.8 | 3.2 | 4.1 | 4.7 | 6.2 | 7.7 | 9.3 | 11.8 | 15.1 | 18.3 | 22.7 | 26.1 |
| | **Supplies Expenses per Peripheral** | | | | | | | | | | | | | | | | | | | | | | |
| 122. | Cont. Forms per L.P. | 3.25.17 | $k/yr | 16.4 | 16.2 | 16.0 | 15.8 | 15.6 | 15.3 | 15.1 | 14.8 | 14.6 | 11.9 | 11.4 | 10.5 | 10.0 | 9.9 | 10.3 | 10.7 | 9.8 | 10.2 | 10.8 | 12.1 |
| 123. | Cards per Punch | 3.25.17 | $k/yr | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.9 | 7.3 | 14.6 |
| 124. | Tape Reels per MTU | 3.25.17 | $k/yr | | 1.0 | 1.3 | 1.3 | 1.5 | 1.8 | 2.2 | 2.1 | 2.2 | 2.2 | 1.9 | 1.9 | 1.6 | 0.8 | 0.6 | 0.6 | 0.7 | 0.6 | 0.6 | 0.5 |
| 125. | Disc Packs per Spindle | 3.25.17 | $k/yr | | | | | | | | | | | 0.8 | 1.0 | 1.1 | 1.5 | 1.1 | 0.7 | 0.2 | 0.3 | 0.2 | 0.3 |
| 126. | Cards per Keypunch | 3.25.17 | $k/yr | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.5 |

45-52. These lines are computed from lines 21 to 28, generally using the ratio 44:1 of purchase price to monthly rental. Table II.4.4.2 provides some data justifying the number 44, which is intended to include maintenance costs. For keyboard data entry equipment the ratio seems too low. Table II.2.13.1 provides prices of various keypunches and related equipment, and the IBM 24, 26, 29, and 59 keypunches have an average ratio of about 56.7:1. For the years up to and including 1965, I used that ratio. Starting in 1966, I used a varying ratio which took into account the increasing proportions of key-to-tape keyboards (estimated ratio 51.7:1, from the Mohawk unit) and buffered units (estimated at 45.2 from the IBM 129, 5496, 3741, and 3742). The resulting ratios, using the proportions of units from Table II.1.27, were 56.6, 56.5, 56.4, 56.1, 55.1, 54.0, 52.8, 52.3, and 51.4 for the years 1966 to 1974.

53-59. These monthly costs were computed from lines 29 through 34. In computing the money spent by end users on services, I arbitrarily decided to include *all* the "other" services, which includes facilities management and third-party maintenance, among other things, and 10% of batch data processing, on the grounds that some users do buy a small amount of such services to handle peak workloads. I excluded any time-sharing service costs, though the recent data shown in Table II.3.25.4 indicates that users' time-sharing expenditures are high, presumably for company employees who have special computations to perform. With regard to software expenses, note (line 55) I have included all of standard software revenues and none of the custom software. Again my choice is arbitrary—a comparison if IDC's estimates in Table II.3.25.1 with annual revenues from Table II.1.25 leaves one with the uncomfortable impression that IDC's view of these costs has been changing. Most standard software must surely be purchased by end users. Some custom software is also; but most of it is designed for users with large special jobs—like the Off-Track Betting System designed by Computer Sciences Corporation for New York. Line 59a is computed from line 19 by multiplying by the number of systems in use, from line 61.

60-91. Line 60 is the sum of lines 44, 48, 51 to 56, 59, and 59a. Line 61 is from Table II.1.21, and line 62 is the quotient of 60 and 61. Lines 63 to 91 were computed by dividing appropriate selections from lines 45-59a by line 60.

92-104. These figures were computed by applying the percentages of lines 63-91 to the per-system cost of line 62 (or 92).

105-121. These lines are the ratios of various items on lines 42 to 59 to the CPU-system figure on line 48.

122-126. Lines 122 and 123 are from Table II.1.27 directly. Line 124 is computed by dividing annual tape shipments, from Table II.1.27, by the number of tape units in use from Table II.1.22. Line 125 was computed in the same way, using the number of spindles given in Table II.1.27 as the divisor (i.e. 360/370, S/3, 1130, and non-IBM spindles). The card expense per keypunch was derived from the data in the notes to line 9 of Table II.1.27: 1.2 operators per keypunch times 100 cards per hour per operator, times the card prices from the same table.

## TABLE II.3.25.6 INSTALLATION CHARACTERISTICS OF VARIOUS SYSTEMS—NOTES

This table summarizes the cost of various systems, each approximating a standard Auerbach configuration (see Table II.2.23.2) identified in this table by parenthetic Roman numerals. The first column indicates the number of units included in the configuration, or the memory size in thousands of bytes. The other columns are self-explanatory. All the data is from Tables II.2.11.1, II.2.12.1, and II.2.12.3-5. A "totals" row appears for each configuration, and below it is shown the computer room area required, computed at 7.5 times the equipment area.

At the end of the table a **Summary** section repeats the system total price, and shows required area, power, and heat per $M price, and price, power, and heat dissipation per 100 square feet of required area.

## TABLE II.3.25.7 USERS' COSTS VS. SYSTEM RENTAL—NOTES

This table summarizes the results of five studies each of which gathered data, from at least several hundred sites, on the cost of operating a computer as a function of processor rental.

**Business Automation Study.** This study reported in *Business Automation* magazine in July of 1966, was analyzed by Solomon (SoloM70). Manpower counts and salaries were collected and summarized for over 2200 computer sites in all size ranges. The jobs counted included managers, systems analysts and programmers, operators, keypunch supervisors and operators, tabulating machine operators and supervisors, schedulers, record control clerks, and others. Solomon computed the average salary, but did not explain his procedure. The line "Salary/Equipment Rent" in the table is computed by multiplying the average (weekly) salary by the average number of employees, multiplying the result by 4.33 to convert it to a monthly expense, and dividing the product by the average equipment rental.

**Research Institute of America.** This study reported median costs for three small and three medium or large systems. The data for the three small systems is based on reports from 100 installations of each system. Only 141 users of larger systems took part in the study, so the sample for those machines is smaller. The categories shown in the report (RIASurv69) were identified as "Equipment Costs" and "Personnel Costs", and the latter included managers and supervisors. No other definition or description of the costs was provided.

**Government Installations.** Selwyn (SelwL70) analyzed the operating costs of 1039 Federal Government installations, as obtained from the Automatic Data Processing Management Information System file. Operating costs include salaries and overtime (but not fringe benefits), keypunch equipment rentals, supplies, parts for in-house maintenance of computer equipment, and some other expenses not classified. Unfortunately, Selwyn's report is ambiguous about one key point: whether rental itself is included in total expenses. I assume that is is, though at one point (p. 82) he writes, "the...file contains breakdown of operating costs of installations other than the actual hardware rental of the computer(s) present."

I present the data in three segments, the first two of which appeared as shown in Selwyn's paper, and the third of

TABLE II.3.25.6 INSTALLATION CHARACTERISTICS OF VARIOUS SYSTEMS

| No. of Units | Type of Unit | Unit Designation | Purchase ($k) | Total Prices Rent ($k/mo) | Maint. ($k/mo) | Area (sq. ft.) | Power (kva) | Heat (KBTU/hr.) |
|---|---|---|---|---|---|---|---|---|
| | **IBM 650 (II)** | | | | | | | |
| 1 | CPU | 650,655 | 122.4 | 2.35 | 122 | 25.8 | 16.8 | 35.1 |
| 4kby | Memory | | 17.5 | .43 | 97 | | | |
| 4 | Tape Units | 727 | 72.8 | 2.20 | 476 | 24.0 | 8.8 | 16.4 |
| 1 | Controller | 652 | 50.4 | 1.05 | 58 | | | |
| 1 | Printer | 407 | 51.0 | 1.00 | 132 | 12.3 | 3.1 | 7.85 |
| 1 | Card Unit | 533 | 25.0 | .55 | 53 | 10.2 | 1.1 | 2.5 |
| | Totals | | 339.1 | 7.58 | 538 | 72.3 | 29.8 | 61.85 |
| | Required Area | | | | | 542.3 | | |
| | **IBM 1401** | | | | | | | |
| 1 | CPU | 1401 | 62.68 | 1.181 | 42 | 6.24 | 1.0 | 3.0 |
| 4kby | Memory | | 22.35 | .625 | 16 | | | |
| 4 | Tape Units | 729-2 | 110.00 | 2.80 | 540 | 25.0 | 6.4 | 15.6 |
| 1 | Controller | | 11.25 | .245 | 4 | | | |
| 1 | Printer | 1403-2 | 34.00 | .775 | 131 | 9.3 | 1.0 | 3.0 |
| 1 | Card Unit | 1402-2 | 32.70 | .615 | 69 | 12.1 | 2.1 | 6.2 |
| 1 | Printer Contr. | 5540 | 2.45 | .06 | 1 | | | |
| | Totals | | 275.43 | 6.301 | 803 | 52.6 | 10.5 | 27.8 |
| | Required Area | | | | | 394.5 | | |
| | **IBM 1401** Card (I) | | | | | | | |
| 1 | CPU | 1401 | 62.68 | 1.181 | 42 | 6.24 | 1.0 | 3.0 |
| 4kby | Memory | | 22.35 | .625 | 16 | | | |
| 1 | Printer | 1403-2 | 34.00 | .775 | 131 | 9.3 | 1.0 | 3.0 |
| 1 | Controller | 5540 | 2.45 | .060 | 1 | | | |
| 1 | Card Reader/Punch | 1402-N1 | 35.00 | .660 | 90 | 12.1 | 2.1 | 6.2 |
| | Totals | | 156.48 | 3.301 | 280 | 27.6 | 4.1 | 12.2 |
| | Required Area | | | | | 207.0 | | |
| | **IBM 360/30** | | | | | | | |
| 1 | CPU | | 60.14 | 1.275 | 90 | 12.9 | 2.5 | 7.0 |
| 8kby | Memory, incl. | | | | | | | |
| 4 | Tape Units | 2401-1 | 64.4 | 1.340 | 248 | 24.16 | 6.4 | 14.0 |
| 1 | Controller | 2803-1 | 32.6 | .650 | 20 | | | |
| 1 | Printer | 1403-1 | 30.3 | .725 | 172 | 9.3 | 1.0 | 3.0 |
| 1 | Card Unit | 2520-B1 | 42.0 | .875 | 128 | 7.2 | 1.6 | 4.0 |
| | Totals | | 229.44 | 4.865 | 658 | 53.56 | 11.5 | 28.0 |
| | Required Area | | | | | 401.7 | | |
| | **IBM 360/30** Card (I) | | | | | | | |
| 1 | CPU | | 60.14 | 1.275 | 90 | 12.9 | 2.5 | 7.0 |
| 8kby | Memory incl. | | | | | | | |
| 1 | Printer | 1403-N1 | 41.2 | .900 | 133 | 11.5 | 1.5 | 4.5 |
| 1 | Controller | 2821-2 | 28.8 | .600 | 32 | | | |
| 1 | Card Read/Punch | 2540-1 | 34.0 | .660 | 115 | 11.7 | 1.2 | 3.0 |
| | Totals | | 164.14 | 3.435 | 370 | 36.1 | 5.2 | 14.5 |
| | Required Area | | | | | 270.1 | | |
| | **IBM 370/135** | | | | | | | |
| 1 | CPU | | 281.2 | 5.670 | 460 | 14.9 | 9.46 | 28.88 |
| 96k | Memory incl. | | | | | | | |
| 4 | Tape Units | 3410-1 | 30.8 | .740 | 180 | 23.2 | 1.6 | 4.6 |
| 1 | Tape Contr. | 3411-1 | 17.0 | .405 | 70 | | | |
| 1 | Printer | 1403-1 | 30.3 | .725 | 172 | 9.3 | 1.0 | 3.0 |
| 1 | Card Unit | 2596 | 29.6 | .845 | 330 | 9.0 | 1.7 | 4.5 |
| | Totals | | 388.9 | 8.385 | 1212 | 56.4 | 13.8 | 41.0 |
| | Required Area | | | | | 423.0 | | |
| | **IBM 704** 10-Tape (VII A) | | | | | | | |
| 1 | CPU | 704 | 450.0 | 9.7 | 1007 | 18.5 | 40.3 | 109.8 |
| 32k | Memory | | 940.0 | 19.7 | 640 | 104.9 | 23.4 | 60.5 |
| 10 | Tape Units | 727 | 182.0 | 5.5 | 1190 | 60.0 | 22.0 | 41.0 |
| 1 | Printer | 720-2 | 93.0 | 1.9 | 503 | 24.8 | 3.9 | 11.32 |
| 1 | Print Contr. | 760 | 111.0 | 2.5 | 486 | | | |
| 1 | Card Reader | 711-2 | 32.0 | .8 | 63 | 6.7 | 0.7 | 1.7 |
| 1 | Card Punch | 721 | 25.0 | .6 | 62 | 7.2 | 3.5 | 9.0 |
| | Totals | | 1833.0 | 40.7 | 3951 | 222.1 | 93.8 | 233.32 |
| | Required Area | | | | | 1665.8 | | |

**TABLE II.3.25.6 INSTALLATION CHARACTERISTICS OF VARIOUS SYSTEMS (continued)**

| No. of Units | Type of Unit | Unit Desig- nation | Total Prices Purchase ($k) | Rent ($k/mo) | Maint. ($k/mo) | Area (sq. ft.) | Power (kva) | Heat (KBTU/hr.) |
|---|---|---|---|---|---|---|---|---|
| | **IBM 7090** | | | | | | | |
| | 10-Tape (VII A) | | | | | | | |
| 1 | CPU | 7090 | 817.5 | 19.275 | 1008 | 23.3 | 3.18 | 7.24 |
| 196k | Memory | | 840.0 | 17.500 | 580 | 11.7 | 8.03 | 19.40 |
| 10 | Tape Units | 729-4 | 485.0 | 9.000 | 1280 | 62.4 | 16.0 | 39.0 |
| 1 | Printer | 1403-2 | 34.0 | .775 | 131 | 9.3 | 1.0 | 3.0 |
| 1 | Card Reader | 7500-1 | 18.0 | .400 | 45 | 7.0 | 1.5 | 4.4 |
| 1 | Card Punch | 7550-1 | 24.6 | .550 | 37 | 7.0 | 1.5 | 4.8 |
| | Totals | | 2219.1 | 47.500 | 3081 | 120.7 | 31.21 | 77.84 |
| | Required Area | | | | | 905.3 | | |
| | **IBM 360/65** | | | | | | | |
| | 100 MBy (VIII R) | | | | | | | |
| 1 | CPU | | 760.5 | 18.100 | 698 | 22.8 | 5.4 | 15.8 |
| 256k | Memory | | 399.6 | 9.300 | 575 | 17.2 | 7.4 | 25.3 |
| 8 | Discs (240 MBy) | 2314-1 | 244.4 | 5.408 | 615 | 40.6 | 7.4 | 20.4 |
| 4 | Tape Units | 2401-6 | 156.4 | 3.440 | 392 | 24.2 | 6.4 | 14.0 |
| 1 | Tape Contr. | 2803-2 | 38.9 | .825 | 25 | | | |
| 1 | Printer | 1403-N1 | 41.2 | .900 | 138 | 11.5 | 1.5 | 4.5 |
| 1 | Printer Contr. | 2821-2 | 28.8 | .600 | 32 | | | |
| 1 | Card Read/Punch | 2540-1 | 34.0 | .660 | 115 | 11.7 | 1.2 | 3.0 |
| | Totals | | 1703.8 | 39.233 | 2590 | 128.0 | 29.3 | 83.0 |
| | Required Area | | | | | 960.0 | | |
| | **IBM 370/165** | | | | | | | |
| | 100 MBy (VIII R) | | | | | | | |
| 1 | CPU | | 1705.6 | 35.53 | 2960 | 32.7 | 56.4 | 163.5 |
| 1024k | Memory | | 538.2 | 12.22 | 1180 | 55.2 | 18.4 | 54.6 |
| 2 | Discs (200 MBy) | 3330-1 | 51.9 | 1.30 | 170 | 9.2 | 3.4 | 9.4 |
| 1 | Disc Controller | 3830 | 95.9 | 2.40 | 145 | | | |
| 4 | Tape Units | 3420-3 | 54.3 | 1.42 | 200 | 25.0 | 7.2 | 16.0 |
| 1 | Printer | 3211 | 69.4 | 1.70 | 365 | 11.5 | 4.9 | 12.2 |
| 1 | Card Read/Punch | 2540-1 | 34.0 | .66 | 115 | 11.7 | 1.2 | 3.0 |
| | Totals | | 2549.3 | 55.23 | 5135 | 145.3 | 91.5 | 258.7 |
| | Required Area | | | | | 1089.8 | | |
| | **Summary** | | | | | | | |
| | IBM 650 (11/54) | | 339.1 | | | | | |
| | Per $M Price | | | | | 1599.2 | 87.87 | 182.4 |
| | Per 100 sq. ft. | | 62.52 | | | | 5.50 | 11.41 |
| | IBM 704 (12/55) | | 1833.0 | | | | | |
| | Per $M Price | | | | | 908.8 | 51.2 | 127.3 |
| | Per 100 sq. ft. | | 110.0 | | | | 5.63 | 14.01 |
| | IBM 1401 (9/60) | | 275.43 | | | | | |
| | Per $M Price | | | | | 1432.3 | 38.1 | 100.9 |
| | Per 100 sq. ft. | | 69.82 | | | | 2.66 | 7.05 |
| | IBM 1401 | | 156.48 | | | | | |
| | Per $M Price | | | | | 1322.9 | 26.20 | 77.97 |
| | Per 100 sq. ft. | | 75.59 | | | | 1.98 | 5.89 |
| | IBM 7090 (11/59) | | 2219.1 | | | | | |
| | Per $M Price | | | | | 408.0 | 14.06 | 35.08 |
| | Per 100 sq. ft. | | 245.1 | | | | 3.45 | 8.60 |
| | IBM 360/30 (5/65) | | 229.44 | | | | | |
| | Per $M Price | | | | | 1750.8 | 50.1 | 122.0 |
| | Per 100 sq. ft. | | 57.12 | | | | 2.86 | 6.97 |
| | IBM 360/30 | | 164.14 | | | | | |
| | Per $M Price | | | | | 1645.5 | 31.7 | 88.33 |
| | Per 100 sq. ft. | | 60.77 | | | | 1.93 | 5.37 |
| | IBM 360/65 (11/65) | | 1703.8 | | | | | |
| | Per $M Price | | | | | 563.7 | 17.20 | 48.74 |
| | Per 100 sq. ft. | | 177.5 | | | | 3.05 | 8.65 |
| | IBM 370/165 (6/71) | | 2549.3 | | | | | |
| | Per $M Price | | | | | 427.5 | 35.9 | 101.5 |
| | Per 100 sq. ft. | | 233.9 | | | | 8.40 | 23.74 |
| | IBM 370/135 | | 388.9 | | | | | |
| | Per $M Price | | | | | 1087.7 | 35.5 | 105.4 |
| | Per 100 sq. ft. | | 91.9 | | | | 3.26 | 9.69 |

**TABLE II.3.25.7 USERS' COSTS VS. SYSTEM RENTAL ●**

| | Units | Costs and Cost Factors for Various Rental Ranges | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Bus. Auto., 1966** | | | | | | | | | |
| Rental Range | $k/mo | 0-3 | 3-6 | 6-12 | 12-25 | 25-50 | 50-75 | 75-150 | 150-300 |
| Average Rental | $k/mo | 2 | 4.5 | 9 | 18.5 | 37.5 | 62.5 | 112.5 | 225 |
| No. Computers | | 201 | 437 | 590 | 462 | 277 | 104 | 75 | 30 |
| No. Employees | | 1903 | 5811 | 13444 | 17950 | 19402 | 11120 | 11375 | 6273 |
| Av. Employees | | 9.46 | 13.30 | 22.79 | 38.85 | 70.04 | 106.9 | 151.7 | 209.1 |
| Employees/Rent $k | no/$k | 4.7 | 3.0 | 2.5 | 2.1 | 1.9 | 1.7 | 1.3 | 0.93 |
| Av. Salary | $/wk | 155 | 156 | 160 | 167 | 173 | 178 | 184 | 174 |
| Salary/Equipment Rent | % | 317.7 | 199.8 | 175.6 | 152.0 | 140.0 | 131.9 | 107.5 | 70.1 |
| **RIA, 1968** | | | | | | | | | |
| Computer | | 360/20 | 1401 | 360/30 | | | | | |
| Median Rental | $k/mo | 3 | 4.75 | 10 | 16.67 | 20.83 | 36.92 | | |
| Median Employees | | 7 | 8 | 16 | 34 | 50 | 71 | | |
| Employees/Rent $k | no/$k | 2.33 | 1.68 | 1.60 | 2.04 | 2.40 | 1.92 | | |
| Av. Salary | $/wk | 134 | 134 | 140 | 141 | 138 | 149 | | |
| Salary/Equipment Rent | % | 135.5 | 97.8 | 97.2 | 100.1 | 143.3 | 124.3 | | |
| **Selwyn, 1968** | | | | | | | | | |
| **Govt. Instalns. with** | | | | | | | | | |
| *2 or Fewer Computers* | | 104 | 219 | 107 | 127 | 59 | 27 | 9 | 5 |
| Rental Range | $k/mo | 0-2 | 2-5 | 5-10 | 10-20 | 20-40 | 40-70 | 70-100 | 100- |
| Mean Rental | $k/mo | 1.381 | 3.270 | 7.386 | 13.201 | 28.751 | 52.213 | 86.287 | 227.367 |
| Mean Total Exp. | $k/mo | 7.383 | 17.263 | 29.659 | 45.643 | 76.501 | 109.929 | 179.861 | 271.767 |
| Mn. (Exp./Rent) | % | 313.5 | 334.4 | 262.5 | 259.1 | 225.7 | 191.2 | 165.3 | 127.3 |
| Mn. Exp./Mn. Rent | % | 534.6 | 527.9 | 401.6 | 345.8 | 266.1 | 210.5 | 208.4 | 119.5 |
| *All Govt. Installations* | | | | | | | | | |
| Number of Instalns | | 113 | 227 | 126 | 185 | 134 | 96 | 38 | 120 |
| Rental Range | $k | 0-2 | 2-5 | 5-10 | 10-20 | 20-40 | 40-70 | 70-100 | 100- |
| Mean Rental | $k | 1.373 | 3.291 | 7.365 | 14.065 | 28.433 | 52.745 | 85.125 | 268.226 |
| Mean Total Exp. | $k | 8.232 | 17.904 | 30.749 | 45.795 | 97.422 | 135.200 | 198.998 | 483.989 |
| Mn. (Exp./Rent) | % | 315.4 | 339.0 | 262.5 | 259.7 | 245.1 | 222.2 | 198.4 | 176.1 |
| Mn. Exp./Mn. Rent | % | 599.6 | 544.0 | 417.5 | 325.6 | 342.6 | 256.3 | 233.8 | 180.4 |
| *3 or More Computers* | | 9 | 8 | 19 | 58 | 75 | 69 | 29 | 115 |
| Rental Range | $k | 0-2 | 2-5 | 5-10 | 10-20 | 20-40 | 40-70 | 70-100 | 100- |
| Mean Rental | $k | 1.281 | 3.866 | 7.247 | 15.957 | 28.183 | 52.953 | 84.764 | 270.002 |
| Mean Total Exp. | $k | 18.043 | 35.451 | 36.887 | 46.128 | 113.880 | 145.089 | 204.937 | 493.216 |
| Mn. Exp./Mn. Rent | % | 1408.5 | 917.0 | 509.0 | 289.1 | 404.1 | 274.0 | 241.8 | 182.7 |
| **Japan** | | | | | | | | | |
| Rental Range | $k | 0-0.6 | .6-2.4 | 2.4-15.4 | 15.4-61.8 | 61.8- | Average | | |
| Exp./Rent Ratios—1968 | | | | | | | | | |
| Supplies | % | 17.5 | 14.7 | 19.4 | 23.2 | 15.5 | 19.9 | | |
| Services | % | 0 | .4 | 5.4 | 3.1 | 2.7 | 3.3 | | |
| Data Trans. | % | 22.0 | 2.0 | 5.6 | 5.3 | 2.8 | 4.4 | | |
| Punch/Read | % | 0 | 4.4 | 3.6 | 6.4 | 2.7 | 4.5 | | |
| Labor | % | 118.9 | 62.1 | 65.9 | 45.9 | 25.6 | 42.7 | | |
| Total | % | 258.4 | 183.6 | 199.8 | 184.0 | 149.3 | 174.8 | | |
| Exp./Rent Ratios—1969 | | | | | | | | | |
| Supplies | % | 10.2 | 26.3 | 21.1 | 21.5 | 17.6 | 19.3 | | |
| Services | % | 5.9 | 1.6 | 4.1 | 5.2 | 12.6 | 8.2 | | |
| Data Trans | % | 5.1 | 7.3 | 5.7 | 22.6 | 7.2 | 13.3 | | |
| Punch/Read | % | 0 | 13.1 | 3.9 | 5.2 | 11.4 | 7.6 | | |
| Labor | % | 146.3 | 53.7 | 50.3 | 62.5 | 45.0 | 52.2 | | |
| Total | % | 267.4 | 202.0 | 184.8 | 217.1 | 193.8 | 200.6 | | |
| **D'mation, 1974** | | | | | | | | | |
| Budgets: Exp./Rent Ratios | | | | | | | | | |
| Rental Range | $k/mo | 0-2.1 | 2.1-8.3 | 8.3-20.8 | 20.8-41.7 | 41.7-83.3 | 83.3- | | |
| Data Entry | % | 43.8 | 8.9 | 10.8 | 14.6 | 11.0 | 2.6 | | |
| Terminals | % | 0 | 2.6 | 3.4 | 7.8 | 4.4 | 8.7 | | |
| Data Trans. Lines | % | 0 | 0.4 | 1.6 | 5.1 | 1.3 | 4.6 | | |
| Software | % | 0 | 1.5 | 2.8 | 3.0 | 2.8 | 3.1 | | |
| Supplies | % | 132.7 | 22.2 | 19.2 | 22.1 | 24.1 | 11.3 | | |
| Outside Services | % | 0 | 3.2 | 3.6 | 1.4 | .7 | 2.7 | | |
| Time-Sharing | % | 0 | 1.1 | 0.7 | 0.9 | 0 | 1.0 | | |
| Batch | % | 0 | 0.4 | 0.7 | 0.2 | 0 | 1.6 | | |
| Remote Batch | % | 0 | 1.4 | 1.4 | 0 | 0 | 0 | | |
| Salaries & Fringe Ben. | % | 306.4 | 165.2 | 196.9 | 157.5 | 178.3 | 113.0 | | |
| Total | % | 601.7 | 317.0 | 352.6 | 323.3 | 342.7 | 290.7 | | |

**TABLE II.3.26.1 CLERICAL DATA PROCESSING SYSTEM COSTS**

| Function | Comments | Requirements Minimum | Requirements Maximum |
|---|---|---|---|
| **File Processing** | Each 108-byte record is stored on a 3x5 inch card. A batch of transactions arrives, pre-sorted to the same order as the file, and is to be processed. | | |
| Clerical Operations: | | | |
| 1. Find Master Record | A clerk retrieves a batch of file records. Time per record (Fig. 3.22.6) is 5 seconds, assuming batch size is at least .01% of file size. | 5 sec. | 5 sec. |
| 2. Perform Updating Calculation | Minimum time occurs when no calculation is required. Maximum allows time for 3 or 4 5-digit multiplications and additions, by hand. Electronic calculator time would be 50 sec. | 0 | 450 sec. |
| 3. Create a 120-byte Report | Minimum time is for typing, maximum for hand copying. (Table II.3.21.1) | 22 sec. | 100 sec. |
| 4. Update Master | Minimum time is for typing 10 bytes, maximum for hand copying 50. (Table II.3.21.1) | 6 sec. | 42 sec. |
| 5. Create New Master | Five percent of the time the master card is full and a new card must be created. Minimum and maximum times are for typing and hand copying. | 1 sec. | 4 sec. |
| 6. File Master Record | Same as for 1 above | 5 sec. | 5 sec. |
| Total Time | | 39 sec. | 606 sec. |
| Monthly Cost of File Clerk (1971) | File clerk wage $93/week (Table II.1.4.3), overhead rate 89% (Table II.3.25.5) | $762 | $762 |
| Per Transaction | | $.0476 | $.740 |
| Monthly Transactions Per Clerk | Assumes a 40-hour week, 173.3-hour month. | 16,000 | 1,030 |
| Cost of File: Monthly Depreciation | At 108 bytes/card, a large card file cabinet with 84,000 cards, holds 9.07 Mbytes. We require 3 cabinets for 20 Mbytes, and 11 for 100 Mbytes. One cabinet cost $900, and 11 $9900. (Table II.3.22.2) Depreciation is over 10 years. | $8 | $83 |
| —Space cost/month | Each cabinet occupies 10.7 sq. ft. Floor space in 1971 cost $4.80 per square foot per year. (Table II.3.25.5) | $4 | $47 |
| Monthly Cost of File | Depreciation plus space | $12 | $130 |
| Total Monthly Transaction Cost | Fixed file cost plus clerical cost per transaction for n transactions/mo. | $12+.048n | $130+.74n |
| **Random Access File Processing** | Each 108-byte record is stored on a 3x5 inch card. A single transaction is to be processed by the clerk | | |
| 1. Find Master Record | A 5 Mbyte file fits in a single cabinet and requires only a 5 sec. access time. A 100 Mbyte file, in 11 cabinets, requires 10 seconds. (Table II.3.22.4) | 5 sec. | 10 sec. |
| 2. Calculate, Update and Create Report | Same as for Batch File Processing. | 29 sec. | 596 sec. |
| 3. File Master Record | Same as for 1 above | 5 sec. | 10 sec. |
| Total Time | | 39 sec. | 608 sec. |
| Clerical Cost Per Transaction | Based on 1971 salary and overhead data | $.0476 | $.742 |
| Peak Transaction/hour | For one clerk. | 92 | 5.9 |
| Monthly Cost of File | Same as for Batch File Processing | $12 | $130 |
| Total Monthly Transaction Cost | Fixed file cost plus clerical cost per transaction for m transactions/hr. | $12+8.25m | $130+ 128.6m |
| **Math Problem** | A series of floating-point arithmetic operations are to be performed on 8-digit numbers. | | |
| Clerical Operations | | | |
| 1. Copy 10 Operands | Each operand has 8 digits. Minimum time is to enter on 10-key electronic keyboard, maximum uses electro-mechanical machine (Table II.3.24.1). | 24 sec. | 32 sec. |
| 2. Perform "Standard Calculation" | Using floating-point operations, evaluate 5 fifth-order polynomials (five additions and five multiplications each), perform five divisions, and evaluate one square root. Minimum time uses electronic calculator with enough internal storage that no intermediate result need be copied. Maximum time uses electromechanical calculator with 11 results copied by hand. Assume floating-point times are same as fixed-point. (Table II.3.24.1) Also assume each result computed twice as a check and 5% repeated a third time to correct an error. Finally, assume square root takes the same time as division. | 330 sec. | 1845 sec. |

TABLE II.3.26.1 CLERICAL DATA PROCESSING SYSTEM COSTS (continued)

| Function | Comments | Requirements Minimum | Requirements Maximum |
|---|---|---|---|
| 3. Create Output Record | Record consists of 10 8-digit numbers, and is formed once for every ten inputs (step 1). We therefore include only 10% of the output time here. Minimum time is for typing, maximum for hand copying. | 1 sec. | 5 sec. |
| Totals | The sum of items 1-3 comprises a complete calculation | 355 sec. | 1882 sec. |
| | One alternative repeats step 2 ten times for each step 1 and 3 | 3325 sec. | 18487 sec |
| | A final alternative repeats step 2 100 times for each step 1 and 3 | 33025 sec. | 184.5ksec |
| Monthly Input Records Per Clerk | Assumes 40-hour week, 173.3-hour month | | |
| | Computation Factor 1 | 1758 | 332 |
| | Computation Factor 10 | 188 | 33.8 |
| | Computation Factor 100 | 18.9 | 3.4 |
| Costs per Input Record | Based on 1971 salary and overhead data | | |
| | Computation Factor 1 | $.43 | $2.30 |
| | Computation Factor 10 | $4.06 | $22.57 |
| | Computation Factor 100 | $40.31 | $225.20 |
| **Sorting** | Sort 10,000 cards according to an 8-digit key | | |
| Clerical Time | Estimated from two formulas given in Figure 3.24.5 | 31.78 hrs | 43.90 hrs |
| Monthly Sorts per Clerk | Assumes 40-hour week, 173.3-hour month | 5.45 | 3.95 |
| Cost per Sort | Based on 1971 Salary and Overhead Data | $139.65 | $192.91 |

which I calculated from the first two. Segment 1 describes the installations having two or fewer computers, Segment 2 describes all installations, and Segment 3 the installations with three or more computers. For all three segments the number of systems included, mean rent, mean total expenses, and the ratio of mean total expenses to mean rental are given. For the first two segments, Selwyn also showed the mean value of the ratio of total expenses to rent—which is generally lower than the ratio of mean expenses to mean rent, presumably because of a few high-expense installations in each price range. Since it is not possible to compute this latter ratio for the third segment, I am unable to show it.

Two other important questions are raised by an examination of Selwyn's data (in addition to the question of whether rental is included in total expenses). First, in installations with more than one computer, does the rental figure include all computers, or is it a per-computer figure? Looking at Segment 3, we see there are 9 government installations in the under-$2K/month rental range with an average rental of $1.28K/month and at least three computers per installation. Three computers averaging $1.28K/month, or $420/month? Presumably the latter, though Selwyn does not say. The other question has to do with the equations Selwyn developed to fit the data (see Figure 3.25.18). Do his equations attempt to fit the mean (expense/rental) data, or the mean expense/mean rental data? Again he doesn't say, though it appears they fit the latter.

**Japan.** The figures in this portion of the table are derived in the obvious way from data in Table II.3.25.3. Machine rental plus machine depreciation plus maintenance and insurance was the "rental" figure used as a base.

**1974 Budgets.** This data is derived from Table II.3.25.4. The rental base used in computing the ratios was Central Site Computers, Memory, Peripherals, COM gear, Communication gear (assuming it is the computer's communication interface), and "other hardware". I do not use the remote site CPU/memory as part of the basic system, though it of course appears in the total expenses.

### TABLE II.3.26.1 CLERICAL DATA PROCESSING SYSTEM COSTS—NOTES

The descriptions in the table should be self-explanatory, except perhaps for that leading to the time for a "Standard Calculation" in the Math Problem. Here the estimate was based on evaluating a fifth-order polynomial by repeating the sequence "enter-multiply-enter-add" five times. This was followed by six repetitions of "enter-enter-divide" operations—the sixth representing the square rooting operation. To these times were added eleven "copy" operations (to note the results of the five polynomial evaluations and the six divisions). The resulting times were multiplied by 2.05 to include the checking and correcting functions.

### TABLE II.3.26.2 COMPUTER DATA PROCESSING SYSTEM COSTS (1971)—NOTES

The configurations, parameters, and operating times come from AuerCTR71. The systems shown were chosen on the following basis. The lowest-rent system is the cheapest system for which AuerCTR71 showed a performance measure. Having identified that system, I scanned the Auerbach table for entries having performance significantly better than the cheapest one, and chose the cheapest of those. The other entries were chosen using the same procedure.

The formula for total expenses is from Figure 3.25.23.

### TABLE 3.27.1 DATA BASE SYSTEM OPERATING COSTS—NOTES

The top portion of this table is from GoldR75, a paper which gives data on one batch and four on-line systems, each of which allows certain users access to a large data base containing personnel records of various kinds. The hospital system contains patient records, the insurance system policyholder records, the personnel system employee records, the credit system individual credit reports, and the law enforcement system records on outstanding warrants and stolen cars.

The number of subjects covered by each system, the total number of characters in the data base, the number of users requiring access to the data, the number of requests (transactions) made per year, and the total annual costs were all given in the paper. Characters per subject is the quotient of number of characters and number of subjects. Transactions per hour are computed assuming each system operates only 40 hours per week, 52 weeks per year—the volume would obviously be even lower if the systems operate more hours per year. Volume per user per hour is the quotient of volume per hour and number of users.

Annual costs are said to include the costs of "programming, computer processing, information storage, data communications, administration, and capital equipment". Costs per transaction is the quotient of annual costs and annual transactions, and cost per kilobyte is the quotient of cost per transaction and characters per subject.

The alternative systems are drawn from Tables II.3.26.1 and II.3.26.2. The "one-clerk" systems for the personnel and law enforcement applications are drawn from the former table, and seem appropriate for applications where the average inquiry rate is around 25 per hour. The figures for "potential volume" were derived assuming that a transaction, consisting of finding and modifying a record on one or more three-inch by five-inch cards in a file cabinet, might take sixty seconds. The cost per transaction is based on the annual clerical costs computed from Table II.3.26.1 (1971 salary and overhead figures), and on the "assumed" transaction volume copied from the upper portion of the table.

The Honeywell and IBM system costs and capacities are drawn from Table II.3.26.2. Annual costs are twelve times the "total monthly expense" from that table, and potential transaction volume was found by multiplying hourly volume by 2080—the number of hours in 52, 40-hour weeks. Note that, while the potential annual transaction volume for the on-line IBM systems is well above the volume required, *the file capacity of 100 million bytes is much lower than the required capacities of around 3.5 billion bytes. It is therefore not fair to compare directly the per-transaction of these alternative systems with those of the actual described system.*

The Honeywell 1200 system, however, seems well suited to process the medical transactions, which are required weekly. It must process 48,100 (2.5 million/52) transactions per week against a one-million subject file, with each subject record containing 3500 bytes. According to Table II.3.26.2, the HIS 1200 can read (without processing) 10,000 108-byte records from magnetic tape in 0.39 minutes, for an average data rate of 46,154 bytes per second. It thus should be able to read (without processing) the 3500 million bytes in the data base in 75,800 seconds (3500 million/46,154). If it took a full second to process each of the 48,000 records which must be handled in a week, the total time per week would only be 123,900 seconds or about 34 hours. In a 40-hour week, then, its potential transaction volume would be 68,200 records, on that same basis; in a 52-week year that would amount to over 3.5 million transactions.

**TABLE II.3.26.2 COMPUTER DATA PROCESSING SYSTEM COSTS (1971)**

| | Configurations, Costs, and Running Times | | | |
|---|---|---|---|---|
| **File Processing** | | | | |
| Computer | IBM 360/20 | | Uni 9200 | HIS 1200 |
| Auerbach Configuration | I | II | I | VII B |
| Monthly Rental | $2.6k | $3.452k | $1.085k | $15.995k |
| Tot. Monthly Expense ($T=5R^{0.8}$) | $10.7k | $13.5k | $5.34k | $45.9k |
| Time to Process 10k Records | | | | |
| 10k Transactions | 67 min. | 21 min. | 206 min. | 2 min. |
| 1k Transactions | - | 7.0 min. | - | 0.50 min. |
| 1 Transaction | - | 6.0 min. | - | 0.39 min. |
| Transactions/355-hr. month | | | | |
| Every Record Processed | 3.18M | 10.14M | 1.03M | 106.5M |
| 10% Processed | - | 3.04M | - | 42.6M |
| .01% Processed | - | 3.55k | - | 54.6k |
| **Random Access File Processing** | | | | |
| Computer | IBM 360/50 | HIS 115 | NCR 100 | NCR 200 |
| Auerbach Configuration | VIII R | III R | III R | VIII R |
| File Size | 100 Mbytes | 5 Mbytes | 5 Mbytes | 100 Mbytes |
| Monthly Rental | $26.117k | $4.043k | $2.70k | $11.825k |
| Tot. Monthly Expense ($T=5R^{0.8}$) | $68.1k | $15.3k | $11.1k | $36.1k |
| Transaction Time | 117ms | 136.2ms | 198.0ms | 306ms |
| Peak Transactions/hr. | 30,769 | 26,432 | 18,182 | 11,765 |
| **Math Problem** | | | | |
| Computer | IBM 360/25 | IBM 360/44 | NCR 100 | NCR 200 |
| Auerbach Configuration | I | XI | III C | III C |
| Monthly Rental | $3.415k | $9.43k | $3.075k | $4.80k |
| Tot. Monthly Expense ($T=5R^{0.8}$) | $13.4k | $30.1k | $12.3k | $17.5k |
| Time per Input Record | | | | |
| Comp. Factor 1 | 130ms | 100ms | 400ms | 210ms |
| Comp. Factor 10 | 1.2 sec. | 100ms | 2.7 sec. | 210ms |
| Comp. Factor 100 | 12.0 sec. | 280ms | 27.0 sec. | 2.0 sec. |
| Input Rec./355-hr. month | | | | |
| Comp. Factor 1 | 9.83M | 12.78M | 3.20M | 6.09M |
| Comp. Factor 10 | 1.07M | 12.78M | 473k | 6.09M |
| Comp. Factor 100 | 107k | 4.56M | 47.3k | 639k |
| **Sorting** | | | | |
| Computer | | RCA 70/25 | Uni 9300 | Uni 1106 |
| Auerbach Configuration | | IV | II | VIII A |
| Monthly Rental | | $10.746k | $2.9k | $36.72k |
| Tot. Monthly Expense ($T=5R^{0.8}$) | | $33.4k | $11.7k | $89.3k |
| Time per Sort | | 2.5 min. | 6.5 min. | 0.95 min. |
| Sorts/355-hr. month | | 8520 | 3277 | 22,421 |

## II.4.1 Manufacturing Costs

### TABLE II.4.10.1 U.S. DEPARTMENT OF COMMERCE MANUFACTURING COST DATA—NOTES

As has been stated previously, the U.S. Department of Commerce collects and publishes statistics on most segments of American industry. The electronic computer industry was placed in a separate classification (SIC Code 3573) starting in 1967; and at the same time the related calculating and accounting machine industry was given SIC Code 3574. Before 1967, statistics for these two industries were lumped together in a category called Computing and Related Industries (SIC Code 3571). This table presents Department of Commerce data on these three industries, particularly with regard to manufacturing costs. Sources for the data are ComIndOut and ComCenMan.

1-15. These lines give the Department of Commerce figure on the value of shipments, wages paid to production workers, and material costs for establishments classified in groups 3571, 3573, and 3574. Some of these establishments (i.e. plants) ship products which should properly be assigned to other SIC Codes. Such products amounted to about 7% of 1967 shipments from establishments classified under SIC Code 3573, for example. (See discussion on lines 16 to 18 below.) Shipments are net selling values at the plant after discounts, and include products shipped from one establishment to another which then become input materials for the second establishment. For example, if Control Data Corporation ships a magnetic tape unit to NCR and NCR subsequently incorporates it in a system and ships the system to a customer, the value of the tape unit will be counted twice in the census figures.

Production wages are the wages paid to workers (up to and including working foremen) engaged in "fabricating, processing, assembling, inspecting, receiving, storing, handling, packaging, warehousing, shipping", etc. Material costs include the cost of "materials, supplies, semi-finished goods, fuel, and electric energy used during the year." It includes the cost of products purchased for resale, and even the cost of systems received from other establishments of the same company–thus contributing additional "double counting". Lines 4, 5, 9, 10, 14, and 15 show the percentages which shipments and materials represent of total shipment value.

16-18. As described above, the "industry" figures of lines 1 through 15 refer to the operation of all establishments whose principal products are classified according to the given SIC Code. If we subtract out the products which these establishments produced but which are classified under some other code (for example, cash register shipments from a plant whose primary product is computers), and add in products properly classified under the given SIC Code, though they were made by establishments with some other classification (for example, computer terminals manufactured by an aerospace corporation), the result is the shipment value of all *equipment* classified under the given code. Lines 16 through 18 provide data on these equipment shipments for the three pertinent SIC Codes.

## II.4.11 Logic Costs

In attempting to establish a simple model for electronic manufacturing costs, the author has had to rely heavily on personal experience, discussion with friends in the industry, recollections of sales personnel and distributors of some types of component and subassembly, and reviews of trade literature and brochures. Figures on the size, complexity, power requirements, and component count of modules, for example, were established after a review of data sheets on a collection of commercially available digital modules spanning the years 1957 to 1973. An estimate of IC complexity was arrived at by examining advertisements in *Datamation* and *Computer Design* magazine for the years since 1960. The resulting model is thus to a large extent a subjective thing, not well documented with references to thorough and scholarly analyses. I hope we will see such analyses in the technical literature in the future.

### TABLE II.4.11.1 LOGIC COST—NOTES

1. Factory assembly cost per hour is the average rate for computer manufacturing direct labor, as discussed in Section 1.4.
2. The factory overhead rates shown are the author's best guess as to what has happened to this important cost parameter. The principal components of overhead are salaries and wages of "indirect" personnel (supervisors, along with personnel involved in such functions as production planning, manufacturing engineering, quality control, and purchasing), and the depreciation and maintenance cost for facilities and production equipment. The ratio of indirect to direct people has increased as productivity has gone up. And the improvements which led to reduced printed circuit board costs and reduced labor content in backwiring and module testing, for example, were achieved in part through the acquisition of new capital equipment—materials handling equipment, sophisticated inspection and testing devices and instruments, special equipment for automatic soldering, wire preparation, and wire wrapping, and of course data processing equipment to help keep track of inventories, expedite purchasing, and manage production control.

When I explicitly include the depreciation cost of some piece of production equipment in my cost analysis—as I do, for example, for wire-wrap machines—it can be argued I am charging depreciaton costs twice: once explicitly, and once as a part of a growing overhead burden. I will not argue the point, except to say that my explicit costs by no means include all the costs of the new equipment (for example, I ignore interest costs, utilities cost, maintenance cost, and floor space cost in evaluating the automatic wire wrap machine). And that the cost of an item of capital equipment as big as an automatic wire wrap machine is often separated from overhead in order to remind everyone of the importance of keeping it fully occupied.

3-5. Line 3 is the labor cost of line 1 with the overhead burden of line 2. The module test labor rate of line 4 is calculated by assuming testers earn 20% more than assemblers; and the system assembly and test salary rate on line 5 assume a 50% increase over factory assemblers.

6. The labor cost ratio is the ratio of burdened labor rates in a given year to the rate in 1955. It is used below to calculate some costs which are presumed to be proportional to labor rates.

7-18. For the most part, these average prices are from EIAYrbk. As usual figures in light type are extrapolations by the author. EIA figures are averages for the year, found by dividing dollar volume sales by units sold for the year. Lines 7, 8, and 9 are for fixed composition

## II.4.10.1 U.S. DEPARTMENT OF COMMERCE MANUFACTURING COST DATA ●

| Line | Item | Figure | Units | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Computing & Related Ind.(3571) | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Shipment Value | | $B | | | | 1.104 | 1.302 | 1.556 | 1.677 | 1.833 | 2.740 | 3.011 | 3.352 | 4.833 | 4.479 | | | | | | | |
| 2. | Production Wages | | $B | | | | .269 | .275 | .354 | .366 | .365 | .369 | .395 | .459 | .540 | .534 | | | | | | | |
| 3. | Material Costs | | $B | | | | | | | | | | 1.569 | 1.793 | 2.735 | 2.074 | | | | | | | |
| 4. | Percent of Shipments–Wages | | % | | | | 24.4 | 21.1 | 22.7 | 21.9 | 19.9 | 19.3 | 13.1 | 13.4 | 11.2 | 11.9 | | | | | | | |
| 5. | Materials | | % | | | | | | | | | | 52.1 | 53.1 | 56.6 | 46.3 | | | | | | | |
| | Electronic Compt'ng Ind.(3573) | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Shipment Value | | $B | | | | | | | | | | | | | 3.771 | 4.163 | 5.112 | 5.232 | 5.700 | 6.387 | | |
| 7. | Production Wages | | $B | | | | | | | | | | | | | .315 | .379 | .503 | .499 | .541 | .546 | | |
| 8. | Material Costs | | $B | | | | | | | | | | | | | 1.876 | 1.993 | 2.609 | 2.520 | 2.631 | 2.979 | | |
| 9. | Percent of Shipments–Wages | | % | 20. | 19. | 18. | 17.1 | 14.8 | 15.9 | 15.3 | 13.9 | 13.5 | 9.2 | 9.4 | 7.8 | 8.3 | 9.1 | 9.8 | 9.5 | 9.5 | 8.5 | | |
| 10. | Materials | | % | | | | | | | | | | | | | 49.7 | 47.9 | 51.0 | 48.2 | 46.2 | 46.6 | | |
| | Calc & Acctg Mach Ind.(3574) | | | | | | | | | | | | | | | | | | | | | | |
| 11. | Shipment Value | | $B | | | | | | | | | | | | | .708 | .773 | .893 | .589 | .530 | .637 | | |
| 12. | Production Wages | | $B | | | | | | | | | | | | | .220 | .202 | .203 | .182 | .134 | .152 | | |
| 13. | Material Costs | | $B | | | | | | | | | | | | | .198 | .227 | .256 | .184 | .176 | .257 | | |
| 14. | Percent of Shipments–Wages | | % | | | | | | | | | | | | | 31.1 | 26.1 | 22.7 | 30.9 | 25.3 | 23.9 | | |
| 15. | Materials | | % | | | | | | | | | | | | | 28.0 | 29.4 | 28.7 | 31.2 | 33.2 | 40.3 | | |
| | Shipment Value of All Equip. | | | | | | | | | | | | | | | | | | | | | | |
| 16. | Compt'ng & Related (3571) | | $B | | | | | | | | | 2.468 | 2.734 | 2.964 | 4.156 | 4.680 | | | | | | | |
| 17. | Electronic Compt'ng (3573) | | $B | | | | | | | | | | | | | 4.049 | 4.329 | 5.213 | 5.641 | 5.169 | 6.108 | | |
| 18. | Calc & Acctg Mach. (3574) | | $B | | | | | | | | | | | | | .631 | .609 | .577 | .525 | .447 | .694 | | |

## TABLE II.4.11.1 LOGIC TECHNOLOGY COST PARAMETERS

| Line | Item | Figure | Units | 1955 | 1960 | 1962.5 | 1965 | 1967.5 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Labor Costs** | | | | | | | | | | |
| 1. | Factory Assembly | | $/hr. | 2.50 | 2.80 | 2.85 | 3.00 | 3.15 | 3.75 | 4.19 | 4.45 |
| 2. | Overhead Rates | | % | 125 | 140 | 150 | 160 | 170 | 175 | 177 | 180 |
| | Burdened Cost | | | | | | | | | | |
| 3. | Factory Assembly | | $/hr. | 5.63 | 6.72 | 7.13 | 7.80 | 8.51 | 10.31 | 11.61 | 12.46 |
| 4. | Module Test | | $/hr. | 6.75 | 8.06 | 8.55 | 9.36 | 10.21 | 12.37 | 13.93 | 14.95 |
| 5. | System Test | | $/hr. | 8.44 | 10.08 | 10.69 | 11.70 | 12.76 | 15.47 | 17.42 | 18.69 |
| 6. | Labor Cost Ratio | | | 1.00 | 1.19 | 1.27 | 1.39 | 1.51 | 1.83 | 2.06 | 2.21 |

resistors, ceramic dielectric capacitors, and receiving tubes, respectively. The digital IC average price on line 14 includes both monolithic and multiple-chip IC's, bipolar and MOS, for the period 1965-1968. However, EIAYrbk72 provided enough information to compute the average price of monolithic bipolar IC's for 1970 and later. Lines 15-17 represent the author's best guess as to the average selling price of general purpose logic IC's containing one, two, and four flip-flops. The estimates are based in part upon the average IC value from line 14, and in part on a review of semiconductor advertisements in computer trade publications over the past ten years.

19-25. The cost of components in the flip-flops of lines 19-21 are computed on the assumption that a flip-flop contains nine resistors, three capacitors, and two active elements—vacuum tubes or transistors. The component cost per flip-flop in an integrated circuit is the cost of the IC divided by the number of flip-flops it contains. Lines 22-24 are thus easily explained. Line 25 must be derived from line 18 with some estimate of the average number of flip-flops, or equivalent flip-flops, in an MOS IC. 1972 costs for a four-function, eight digit calculator chip were about \$10.00. (Electronic News, February 19, 1973.) Such an integrated circuit must contain at least sixty-four register flip-flops plus control flip-flops and necessary gating. Assuming that each flip-flop requires roughly fifteen gates, and that two gates are equivalent to a flip-flop, these calculator chips must have a complexity of roughly 500 flip-flops, and therefore a cost of about 2 cents per flip-flop. The average MOS IC was less complex, inasmuch as its price was less than \$10.00, and therefore the equivalent cost per flip-flop must be somewhat higher. I therefore assumed a 2.5 cents per flip-flop cost for 1972, deduced that the equivalent number of flip-flops must have been 243, and computed the other entries on line 25 based on seemingly reasonable assumptions about the way MOS complexity has increased with time.

26-29. These printed circuit board costs were estimated after consultation with representatives of a PCB manufacturer. The reductions shown are principally due to improvements in yield, along with reductions in direct labor time caused by improvements in material handling—notably the use of facilities which have made it possible to manufacture two or more boards at one time on a single sheet of material, cutting them apart only at the very end of the process. The costs shown do not include General and Administrative costs or a profit, and therefore assume that the printed circuit manufacturing operation is a subsidiary part of the main manufacturing operation. See the discussion in connection with Table 4.11.1 in Part I for more information.

30-34. The labor costs per pin for various backwiring techniques are computed using the labor times given in Table 4.11.3 and the labor rates in line 3 of this table. The labor cost for the automatic wire wrap machine assumes two operators for every three machines. Note the costs shown here are per pin, while the times given in Table 4.11.3 are per wire.

35. It is assumed that wire costs 1 cent per foot and that the average wire connecting two pins is two feet long. I also assume wire costs have not changed over the past 20 years. Copper costs have increased substantially in that time, but wire manufacturing techniques have greatly improved.

36. Taper pin technology required that a pin be crimped on each end of each wire. The cost of that pin is estimated at 1.5 cents each, in large quantities.

37. The figure for automatic wire wrap depreciation is derived in Table 4.11.4 in Part I, and assumes three shift operation for the machines.

38-42. Total backwiring costs are computed from the data in lines 30-37 by adding together labor, material, and depreciation costs as appropriate.

43-44. The simple linear model for connector costs is based on an analysis of prices for typical connectors in 1973, and an estimate that connector costs have steadily increased by a total of about 46% between 1955 and 1974. In fact, there is of course a price differential between connectors designed for wire wrap, for soldering, and for taper pin connections—the last being the most expensive and the first being the least. Furthermore, because connectors are purchased in very large quantities, prices are determined by competitive bidding and negotiation, and are anything but firm and standard at any given time. I therefore used a formula whose coefficients were about 60% of the coefficients which were derived from the raw data, in an attempt to allow for large purchase quantities and a nogotiated price.

45-47. Labor costs are based on the data in Table 4.11.3 and the labor rates in line 3 above. A wire cost of 1 cent per foot is again assumed, with an average wire length of three feet to account for the runs from a power supply located in the base of the cabinet to connectors at all levels in the cabinet.

48-56. These figures are based on an analysis of commercially available power supplies and packaging equipment in the period 1970-72, along with an assumption that the costs of these components have generally followed labor costs and therefore should be proportionate to the labor cost ratio of line 6 above.

## TABLE II.4.11.1 LOGIC TECHNOLOGY COST PARAMETERS (continued) ●

| Line | Item | Figure | Units | 1955 | 1960 | 1962.5 | 1965 | 1967.5 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Component Costs** | | | | | | | | | | |
| 7. | Av. Price–Resistors | 4.11.2 | cents | *2.2* | *2.2* | *2.2* | *2.2* | 2.2 | 2.5 | 2.2 | 1.9 |
| 8. | Capacitors | 4.11.2 | cents | *3.2* | *3.2* | *3.2* | *3.2* | 3.2 | 5.4 | 4.9 | 7.9 |
| 9. | Vacuum Tubes | 4.11.2 | $ | .75 | .84 | .75 | .71 | .65 | 1.12 | 1.21 | 1.33 |
| 10. | Ge Diodes | 4.11.3 | $ | *.90* | .38 | .15 | .08 | .06 | .05 | .04 | |
| 11. | Ge Transistors | 4.11.3 | $ | 2.88 | 1.70 | .69 | .50 | .42 | .41 | .52 | |
| 12. | Si Diodes | 4.11.3 | $ | | 1.26 | .44 | .26 | .13 | .08 | .05 | |
| 13. | Si Transistors | 4.11.3 | $ | 20.44 | 11.27 | 2.65 | .86 | .51 | .38 | .27 | |
| 14. | Digital IC's | 4.11.4 | $ | | | | 7.28 | 2.58 | 1.19 | .70 | |
| 15. | One-Flip-Flop IC | 4.11.4 | $ | | | | 6.4 | 1.85 | .7 | .7 | |
| 16. | Two-Flip-Flop IC | 4.11.4 | $ | | | | 20. | 4.0 | 1.2 | .7 | |
| 17. | Four-Flip-Flop IC | 4.11.4 | $ | | | | | 15. | 2.4 | 1.0 | .7 |
| 18. | MOS IC | 4.11.4 | $ | | | | | | 7.15 | 6.07 | |
| | **Component Cost of F/F's** | | | | | | | | | | |
| 19. | Vacuum Tube | 4.11.5 | $ | 1.80 | 1.98 | 1.80 | 1.72 | 1.62 | 2.63 | | |
| 20. | Ge Transistor | 4.11.5 | $ | 6.06 | 3.70 | 1.68 | 1.30 | 1.16 | 1.21 | | |
| 21. | Si Transistor | 4.11.5 | $ | 41.18 | 22.84 | 5.60 | 2.02 | 1.33 | 1.15 | | |
| 22. | One-Flip-Flop IC | 4.11.5 | $ | | | | 6.40 | 1.85 | .70 | | |
| 23. | Two-Flip-Flop IC | 4.11.5 | $ | | | | 10.00 | 2.00 | .60 | .35 | |
| 24. | Four-Flip-Flop IC | 4.11.5 | $ | | | | | 3.75 | .60 | .25 | .18 |
| 25. | MOS IC | 4.11.5 | cents | | | | | | 4.5 | 2.5 | |
| | **PCB Costs** | | | | | | | | | | |
| 26. | One-Sided 4x5 | 4.11.6 | $ | 4.60 | 3.40 | 3.00 | 2.50 | 2.10 | 1.70 | 1.50 | 1.50 |
| 27. | Two-Sided 4x5, .030in. | 4.11.6 | $ | 9.20 | 6.60 | 5.80 | 5.00 | 4.20 | 3.40 | 3.00 | 3.00 |
| 28. | Two-Sided 4x5, .015in. | 4.11.6 | $ | | | | 12.50 | 7.90 | 5.00 | 4.00 | 3.50 |
| 29. | Four-Layer 10x10, .015in. | 4.11.6 | $ | | | | | 83.00 | 45.00 | 38.00 | 35.00 |
| | **Backwiring Costs** | | | | | | | | | | |
| | Labor Cost Per Pin | | | | | | | | | | |
| 30. | Soldering, Hand Prep. | | cents | 4.5 | 5.3 | 5.6 | 6.2 | 6.7 | 8.2 | 9.2 | 9.9 |
| 31. | Soldering, Machine Prep. | | cents | 3.0 | 2.6 | 3.9 | 4.2 | 4.6 | 5.6 | 6.3 | 6.7 |
| 32. | Taper Pin | | cents | 2.3 | 2.8 | 3.0 | 3.2 | 3.5 | 4.3 | 4.8 | 5.2 |
| 33. | Manual Wire-Wrap | | cents | 1.4 | 1.7 | 1.8 | 2.0 | 2.1 | 2.6 | 2.9 | 3.1 |
| 34. | Auto. Wire-Wrap | | cents | .38 | .45 | .48 | .52 | .57 | .69 | .77 | .83 |
| 35. | Wire Cost Per Pin | | cents | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 36. | Taper Pin Cost | | cents | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| 37. | AWW Depreciation Per Pin | | cents | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| | Total Cost Per Pin | | | | | | | | | | |
| 38. | Soldering, Hand Prep. | 4.11.8 | cents | 5.5 | 6.3 | 6.6 | 7.2 | 7.7 | 9.2 | 10.2 | 10.9 |
| 39. | Soldering, Machine Prep. | 4.11.8 | cents | 4.0 | 4.6 | 4.9 | 5.2 | 5.6 | 6.6 | 7.3 | 7.7 |
| 40. | Taper Pin | 4.11.8 | cents | 4.8 | 5.3 | 5.5 | 5.7 | 6.0 | 6.8 | 7.3 | 7.7 |
| 41. | Manual Wire-Wrap | 4.11.8 | cents | | | 2.8 | 3.0 | 3.1 | 3.6 | 3.9 | 4.1 |
| 42. | Auto. Wire-Wrap | 4.11.8 | cents | | | 2.6 | 2.6 | 2.7 | 2.8 | 2.9 | 2.9 |
| | **Connector Cost** | | | | | | | | | | |
| 43. | Fixed Cost | 4.11.7 | cents | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 19 |
| 44. | Per Pin | 4.11.7 | cents | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 | 1.6 | 1.7 | 1.9 |
| | **Power Wiring** | | | | | | | | | | |
| 45. | Labor Cost Per Wire | | cents | 15.0 | 17.9 | 19.0 | 20.8 | 22.7 | 27.5 | 31.0 | 33.2 |
| 46. | Material Cost Per Wire | | cents | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 47. | Total Cost | | cents | 18 | 20.9 | 22.0 | 23.8 | 25.7 | 30.5 | 34.0 | 36.2 |
| | **Power Supply Costs** | | | | | | | | | | |
| 48. | Fixed Cost | 4.11.9 | $ | 50 | 60 | 62 | 67 | 73 | 90 | 100 | 107 |
| 49. | Incremental Cost | 4.11.9 | $/watt | .25 | .30 | .31 | .34 | .37 | .45 | .50 | .54 |
| 50. | Volume Occupied | | $in.^3/w$ | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| | **Packaging Costs** | | | | | | | | | | |
| | Module Mount Cost | | | | | | | | | | |
| 51. | Fixed Cost | 4.11.10 | $ | 6 | 7 | 7.5 | 8.1 | 8.9 | 10.7 | 12.1 | 13.0 |
| 52. | Incremental Cost | 4.11.10 | $\$/in.^3$ | .07 | .09 | .09 | .10 | .11 | .13 | .15 | .16 |
| | Cabinet Cost | | | | | | | | | | |
| 53. | Fixed Cost | 4.11.11 | $ | 48 | 58 | 62 | 67 | 73 | 89 | 100 | 107 |
| 54. | Incremental Cost | 4.11.11 | $\$/ft.^3$ | 1.45 | 1.75 | 1.85 | 2.00 | 2.20 | 2.65 | 3.00 | 3.20 |
| | Cooling System | | | | | | | | | | |
| 55. | Cost | | $/watt | .05 | .05 | .06 | .06 | .07 | .08 | .09 | .10 |
| 56. | Volume | | $in.^3/w.$ | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

## TABLE II.4.11.2 SYSTEM AND TECHNOLOGY CHARACTERISTICS—NOTES

**Components.** 1. The components shown were assumed to be typical of large scale production in the years shown.

2. Early integrated circuits were packaged in the TO-5 can; by 1970 the dual inline package was common.

3-4. The earliest integrated circuits were packaged one flip-flop and two gates to a package. The increases in density shown seem typical of higher production quantities in the years shown.

**Interconnect.** 5-9. These printed circuit boards are the same technologies described in connection with Table 4.11.1, and the same board ID is used.

10. The number of pins per printed circuit board is a critical parameter, and limits the number of components which can be mounted on a printed circuit card. The author reviewed advertising literature on digital modules for sale over the period since 1955 and concluded that the pin numbers shown were typical of the indicated years. Note that pin density and printed circuit board complexity go together: to increase the number of components on a board, and make better use of the available pins, it was necessary that the printed circuit board itself provide denser interconnections, by increasing the number of circuit layers and reducing line width and spacing.

11-12. The number of flip-flops packaged on a complete module is assumed and is consistent with commercially available module families over the years. The number of gates packaged on an average gate module is derived from layout considerations which are discussed in connection with lines 17-25 below.

13. Test time for the increasingly complex modules is assumed as shown. To achieve these times, increasingly sophisticated module test equipment had to be designed and made available to manufacturers as the generations of technology progressed. The increase in test time of only 50% from the 20 square inch module in 1970 to the 100 square inch module in 1972 is particularly vulnerable to criticism. For the most part, modules in use in technologies up to and including 1970 were general purpose modules, with small arrays of gates most of whose pins were brought out on the connector and could be interconnected using backwiring technology. The very large printed circuit boards of the 1972 and later technology, on the other hand, were each individual, specially designed, and very complex modules performing a variety of different functions. The problem of designing test equipment for these large modules is obviously both difficult and important.

14. This line identifies the backwiring technology assumed used in each indicated year.

**Power** 15-16. Power requirements for both flip-flops and gates were established by surveying typical medium-performance technologies at each of the indicated times.

**System.** The rest of this table shows the calculations employed to determine the characteristics and costs of a one-cabinet system manufactured in each technology. A system is assumed to consist of flip-flops and gates, with an average of seventeen gates for each flip-flop and an average of 2.7 inputs per gate. The general approach is first to determine the average power required by a single module, then the volume occupied by the module and by the power and cooling system which supports it. Given these volumes we determine how many modules fit in a 24-cubic-foot cabinet, and then compute characteristics of the power supply and packaging system. Subsequently we find the number of components required, the time necessary to fabricate and test the modules, the time required to wire the back panels, and the time necessary for final assembly and test. These various figures are then used in computing costs in Tables II.4.11.3 to II.4.11.6.

17-25. We begin by determining the module content of a 100 flip-flop system. The number of printed circuit boards required per system is a critically important parameter, and was derived as follows. For the four technologies up to and including mid-1967, the required number of flip-flop modules (line 22) was computed based on the assumption in line 11 above. Next, a specific set of quite general gating cards was assumed, having the property that each card required two pins for power and ground, and had other pins available for signals. A suitable combination of these cards was then postulated, which together provided a total of 1700 gates and an average of 2.7 inputs per gate. For example, the 1955 system required two types of gating card, used in equal quantities. The first contained three independent gates, two with two inputs each and the other with three inputs. The second card contained four three-input gates, with the outputs of the first three driving the fourth. The two cards thus contained a total of seven gates having a total of 19 inputs—the average then being 2.7 inputs per gate. Each card required 10 signal pins for inputs to and outputs from the gates, so no more components could be added without exceeding the 12 pin limitation. The total number of gating cards required was then 1700 divided by 3.5, the average number of gates per card. To these 486 gating cards must be added the 100 flip-flop cards, for a total of 586.

The card requirements for 1970 to 1974 technologies were calculated in a different fashion. For 1970, I assumed that 16 of the 100 flip-flops, along with all their gating, were part of a regular structure which could be implemented using four MSI integrated circuits mounted on a single printed circuit card. The other 84 flip-flops, along with their gates, were implemented with 46 general gating cards each containing 31 gates. Finally, six cards were necessary for the 100 flip-flops—thus a total of $1+46+6 = 53$ cards were required altogether. For 1972, I assumed that 32 of the 100 flip-flops were implemented in MSI in four dual inline packages. The other 68 flip-flops along with their gates require 162 dual inline packages, using the assumptions of lines 3 and 4 above regarding the number of flip-flops and gates per package. The total of 166 DIPs could physically be located on two 10-inch by 10-inch cards. The problem of laying out logic on cards to achieve high density is, however, a difficult one, and I arbitrarily assume a density of 0.8 IC's per square inch is feasible, so that 2.1 modules are required for the 166 IC's.

For 1974, I assume 48% of the logic resides in four MSI IC's (an average of 12 flip-flops and 204 gates per IC, in some suitable combination of standard parts). The remaining 52 flip-flops and 884 gates require 13 and 111 IC's, respectively, based on the assumptions of lines 3 and 4. This time I assume 0.9 IC's per square inch is achievable, so that 1.4 10-inch by 10-inch modules are necessary.

26. Total power is computed from the data on lines 15 and

## TABLE II 4.11.2 SYSTEM AND TECHNOLOGY CHARACTERISTICS ●

| | | Units | 1955 | 1960 | 1965 | 1967.5 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **Components** | | Vacuum Tubes, Ge Diodes | Ge Trans., Ge Diodes | Si Trans., Si Diodes | Bipolar IC's SSI | Bipolar IC's SMSI | Bipolar IC's MSI | Bipolar IC's MSI |
| 2. | Package | | | | | TO-5 | DIP | DIP | DIP |
| 3. | Flip-Flops/Pack. | | | | | 1 | 2 | 4 | 4 |
| 4. | Gates/Pack. | | | | | 2 | 4 | 8 | 8 |
| | **Interconnect** | | | | | | | | |
| 5. | Printed Circuit Boards | | A | A | B | B | C | D | D |
| 6. | Size | in. | 4x5 | 4x5 | 4x5 | 4x5 | 4x5 | 10x10 | 10x10 |
| 7. | Spacing | in. | 1.2,.75 | .75 | .5 | .5 | .5 | .5 | .5 |
| 8. | Layers | | 1 | 1 | 2 | 2 | 2 | 4 | 4 |
| 9. | Line Width | in. | .030 | .030 | .030 | .030 | .015 | .015 | .015 |
| 10. | Pins | | 12 | 22 | 34 | 50 | 70 | 150 | 150 |
| | Modules | | | | | | | | |
| 11. | No. of Flip-Flops | | 1 | 2 | 4 | 8 | 16 | - | - |
| 12. | No. of Gates | | 3.5 | 7 | 13 | 19 | 31 | - | - |
| 13. | Test Time | hrs. | 0.1 | 0.1 | 0.12 | 0.16 | 0.2 | 0.3 | 0.3 |
| 14. | Wiring | | Hand Solder | Hand Solder | Taper Pins | Manual Wire-Wrap | AWW | AWW | AWW |
| | **Power** | | | | | | | | |
| 15. | Per Flip-Flop | mw. | 5000 | 300 | 150 | 100 | 50 | 50 | 50 |
| 16. | Per Gate | mw. | 400 | 175 | 40 | 30 | 15 | 10 | 6 |
| | **System** | | | | | | | | |
| | Module Layout for 100-Flip-Flop System | | | | | | | | |
| 17. | Logic in Special IC's | % | 0 | 0 | 0 | 0 | 16 | 32 | 48 |
| 18. | Number of Special IC's | | 0 | 0 | 0 | 0 | 4 | 4 | 4 |
| 19. | Number of Flip-Flop IC's | | 0 | 0 | 0 | 100 | 42 | 17 | 13 |
| 20. | Number of Gate IC's | | 0 | 0 | 0 | 850 | 357 | 145 | 111 |
| 21. | Total IC's | | | | | 950 | 403 | 166 | 128 |
| 22. | Flip-Flop Modules | | 100 | 50 | 25 | 13 | 6 | - | - |
| 23. | Gate Modules | | 486 | 243 | 131 | 90 | 46 | - | - |
| 24. | Special Modules | | 0 | 0 | 0 | 0 | 1 | 2.1 | 1.4 |
| 25. | Total Modules | | 586 | 293 | 156 | 103 | 53 | 2.1 | 1.4 |
| 26. | Total Power | watts | 1180 | 328 | 83.0 | 61.0 | 30.5 | 22.0 | 15.2 |
| | Per Module | | | | | | | | |
| 27. | Power | mw. | 2014 | 1119 | 532 | 592 | 575 | 10480 | 10860 |
| 28. | Module Volume | $in.^3$ | 16.54 | 15 | 10 | 10 | 10 | 50 | 50 |
| 29. | Power and Cooling Volume | $in.^3$ | 9.06 | 5.04 | 2.39 | 2.66 | 2.59 | 47.16 | 48.87 |
| 30. | Total Volume | $in.^3$ | 25.60 | 20.04 | 12.39 | 12.66 | 12.59 | 97.16 | 98.87 |
| | System Power & Packaging | | | | | | | | |
| 31. | Cabinet Volume | $ft.^3$ | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| 32. | Available | $in.^3$ | 8640 | 8640 | 8640 | 8640 | 8640 | 8640 | 8640 |
| 33. | Number of Modules | | 337 | 431 | 697 | 682 | 686 | 89 | 87 |
| 34. | Number of Flip-Flops | | 58 | 147 | 447 | 662 | 1294 | 4238 | 6214 |
| 35. | Total Power | kw | .679 | .482 | .371 | .404 | .394 | .933 | .945 |
| 36. | Power Density | wpcf | 28.3 | 20.1 | 15.5 | 16.8 | 16.4 | 38.9 | 39.4 |
| 37. | Power Supplies—Capacity | watts | 340 | 482 | 371 | 404 | 394 | 467 | 473 |
| 38. | Numbers | | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| 39. | Module Mounts—Volume | $in.^3$ | 697 | 646 | 697 | 682 | 686 | 636 | 621 |
| 40. | Number | | 8 | 10 | 10 | 10 | 10 | 7 | 7 |
| | Number of Components | | | | | | | | |
| 41. | Vacuum Tubes | | 116 | - | - | - | - | | |
| 42. | Transistors | | - | 294 | 894 | - | - | | |
| 43. | Diodes | | 2662 | 6747 | 20517 | - | - | | |
| 44. | R, C | | 1682 | 4263 | 12963 | - | - | | |
| 45. | IC's—TO-5 | | - | - | - | 6289 | - | | |
| 46. | 16-Pin DIP | | - | - | - | - | 5163 | 6865 | 7705 |
| 47. | 24-Pin DIP | | - | - | - | - | 52 | 170 | 249 |
| 48. | Total Components | | 4460 | 11304 | 34374 | 6289 | 5215 | 7035 | 7954 |

16. For example, 100 vacuum-tube flip-flops require 500 watts of power, and 1700 gates 680 watts for a total of 1180 watts.
27. Power per module is the quotient of lines 26 and 25.
28. Module volume is computed from the data on lines 6 and 7. For the vacuum-tube flip-flop, spacing is 1.2 inches, and the relative number of flip-flop and gating modules (lines 22 and 23) are used to determine average module volume.
29. Power and cooling volume per module is computed from the power requirement on line 27 and the volume requirements on lines 50 and 56 of Table II.4.11.1.
30. Total volume is the sum of lines 28 and 29.
31-32. Cabinet volume is assumed fixed at 24 cubic feet—e.g. a cabinet whose outside dimensions are 2x2x6. The volume available for hardware is computed assuming that only 25% of the total volume is usable for modules, power supplies, and cooling fans, and further *that* 17% *of available space in the cabinet is empty when the system is shipped.* This space may subsequently be employed to add on new features ordered by the customer.
33-34. The number of modules which fit in the cabinet is the quotient of lines 32 and 30.
35-38. Total power is the product of lines 33 and 27, and power density is the quotient of lines 35 and 31. The number and capacity of power supplies is computed from line 35 assuming that the maximum practical power supply size is 500 watts.
39-40. The number and size of module mounts is computed from the product of lines 33 and 28, assuming that maximum module mount size is 700 cubic inches.
41-48. Component counts are derived from the data of lines 18-21 and the flip-flop count of line 34. For the discrete-element (vacuum tube and transistor) systems I assume each flip-flop requires two active elements (tubes or transistors), nine resistors, and three capacitors, and a gate requires one resistor and an average of 2.7 diodes. The IC counts assume that the "special" IC's are 24-pin devices, the remainder 16-pin. Line 48 is the sum of lines 41 to 47.
49-58. Component insertion time is computed from the component counts of lines 41-48, and the module fabrication labor requirements of Table 4.11.2. Module soldering and inspection/repair times are also computed from the data on Table 4.11.2, taking into account the number of modules on line 33 and the printed circuit board type from Table II.4.11.1. Line 57 is the sum of lines 54-56. Test time, on line 58, is the product of module count on line 33 and test time per module on line 13.
59-62. The number of signal pins per flip-flop module is assumed to be four times the number of flip-flops on those modules. The number of pins on gate modules is computed from the proportion of gate modules in the system (the ratio of line 23 to 25) multiplied by the total number of modules on line 33, and assuming all but two of the module pins (line 10) are signal pins. The number of pins on "special" modules is computed in the same way, using line 24 instead of line 23. Line 62 is the sum of lines 59-61.
63-66. Wiring time, and material and depreciation costs, are computed from line 62 using the information on line 14 and the parameters in Table 4.11.3. (Note the table is on a *per wire* basis—assume two pins per wire). The number of power wires, on line 66, is twice the number of modules, assuming one power and one ground wire is brought to each module.
67-71. Assembly time is derived from the connector (i.e. module) count of line 33, the power supply and module mount counts of lines 38 and 40, and the timing data of Table 4.11.6. Line 71 is the sum of lines 67 to 70.
72-78. Test time likewise is computed from Table 4.11.6, taking into account pin counts and component counts on lines 48 and 62 and assuming two pins per wire. Wiring errors were such a serious problem with early technology that special testers were designed to detect such errors before system test. I assume such testers were in use starting with taper pin wiring technology in 1965.

## TABLES II.4.11.3 to II.4.11.6 TECHNOLOGY COSTS—NOTES

These four tables take the cost parameters of Table II.4.11.1 and the technology characteristics of Table II.4.11.2 and derive a cost history for each technology over a span of years during which that technology was important. Table II.4.11.3 covers vacuum-tube technology, Table II.4.11.4 transistor technology, and the last two tables, integrated circuit technology.

For a given line pertaining to a given technology there is typically a "factor" entry copied from Table II.4.11.2, and three or four cost entries (for three or four different years) computed from the factor entry and from cost items in Table II.4.11.1. Subtotals are provided for each of the major categories of cost.

In the paragraphs which follow, I shall discuss the cost factors used, referring to source line numbers in Table II.4.11.1—inasmuch as the factor entry is given explicitly, I assume its source in Table II.4.11.2 is obvious.

**Components.** 1-5. Component unit costs are from lines 7-13 and 15-17. The TO-5 and 16-pin DIP IC's are the one-, two-, or four-flip-flop IC's, with the understanding that a flip-flop IC costs the same as a gating IC. The 24-pin DIP's are assumed to cost twice the price of a 16-pin IC.

**Power.** 6-8. Power supply costs are computed from the factors on lines 48 and 49. Power wiring costs are based on line 47.

**Packaging.** These costs are calculated from the parameters given in lines 51-55.

**Interconnects.** 13-16. Printed circuit board unit costs come from lines 26-29. Assembly labor is based on the burdened labor cost of line 3, and test labor on line 4.

17-19. Connector costs are computed using lines 43-44. Backwiring labor is based on line 3. (Backwiring materials include depreciation and come directly from lines 64-65 of Table II.4.11.2.)

20. Cable costs are estimated at five percent of the other interconnect costs.

**Assembly and Test.** Assembly burdened rates are from line 3, and System Test from line 5.

**Summary.** 25-30. Total costs are the sum of lines 5, 8, 12, 21, and 24, and the major categories of cost are shown as percentages of the total.

31. Cost per flip-flop is the quotient of line 25 and the number of flip-flops, in the "factor" column.

**TABLE II 4.11.2 SYSTEM AND TECHNOLOGY CHARACTERISTICS (continued)** ●

| | | Units | 1955 | 1960 | 1965 | 1967.5 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|
| | Module Fabrication Time | | | | | | | | |
| 49. | Vacuum Tubes | min. | 40 | | | | | | |
| 50. | Diodes, Trans., R.C. | min. | 434 | 1130 | 3437 | | | | |
| 51. | IC's—TO-5 | min. | | | | 3145 | | | |
| 52. | 16-Pin DIP | min. | | | | | 1291 | 1717 | 1926 |
| 53. | 24-Pin DIP | min. | | | | | 26 | 85 | 125 |
| 54. | Total Insertion Time | min. | 474 | 1130 | 3437 | 3145 | 1317 | 1802 | 2051 |
| 55. | Soldering Time | min. | 236 | 302 | 279 | 273 | 274 | 89 | 87 |
| 56. | Inspection/Repair Time | min. | 607 | 776 | 1812 | 1773 | 2470 | 979 | 957 |
| 57. | Total Assembly Time | min. | 1317 | 2208 | 5528 | 5191 | 4061 | 2870 | 3095 |
| 58.. | Test Time | min. | 2022 | 2586 | 5018 | 6547 | 8232 | 1602 | 1566 |
| | Wiring Time and Cost | | | | | | | | |
| | Number of Signal Pins | | | | | | | | |
| 59. | Flip-Flop Modules | | 232 | 588 | 1788 | 2648 | 4348 | - | - |
| 60. | Gate Modules | | 2795 | 7149 | 18730 | 28604 | 40486 | - | - |
| 61. | Special Modules | | - | - | - | - | 880 | 13172 | 12876 |
| 62. | Total Signal Pins | | 3027 | 7737 | 20518 | 31252 | 45714 | 13172 | 12876 |
| 63. | Labor Time | min. | 1438 | 2514 | 5130 | 4688 | 1829 | 527 | 515 |
| 64. | Material Cost | $ | 30.27 | 77.37 | 513.0 | 312.5 | 457.1 | 131.7 | 128.8 |
| 65. | Depreciation | $ | - | - | - | - | 251.4 | 72.45 | 70.82 |
| 66. | Power Wiring Wires | | 674 | 862 | 1394 | 1364 | 1372 | 178 | 174 |
| | Assembly Time | | | | | | | | |
| 67. | Install—Connectors | min. | 112 | 144 | 232 | 228 | 229 | 30 | 29 |
| 68. | Module Mounts | min. | 16 | 20 | 20 | 20 | 20 | 14 | 14 |
| 69. | Power Supplies | min. | 10 | 5 | 5 | 5 | 5 | 10 | 10 |
| 70. | Modules | min. | 84 | 108 | 174 | 171 | 172 | 22 | 22 |
| 71. | Total | min. | 222 | 277 | 431 | 424 | 426 | 76 | 75 |
| | Test Time | | | | | | | | |
| 72. | Number of—Wiring Errors | | 8 | 19 | 0 | 0 | 0 | 0 | 0 |
| 73. | Bad Solder Joints | | 2 | 4 | 0 | 0 | 0 | 0 | 0 |
| 74. | Bad Components | | 2 | 6 | 17 | 3 | 3 | 4 | 4 |
| 75. | Total | | 12 | 29 | 17 | 3 | 3 | 4 | 4 |
| 76. | Time to Locate & Correct | hrs. | 12.0 | 70.1 | 24.1 | 0.75 | 0.75 | 1.33 | 1.33 |
| 77. | System Exercise Time | hrs. | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| 78. | Total Test Time | hrs. | 20.0 | 78.1 | 32.1 | 8.75 | 8.75 | 9.33 | 9.33 |

## TABLE II.4.11.3 VACUUM-TUBE TECHNOLOGY COSTS

| Item | Factors | Units | 1955 | 1960 | 1962.5 | 1965 |
|---|---|---|---|---|---|---|
| **Components** | | | | | | |
| 1. Vacuum Tubes | 116 | $ | 87 | 97 | 87 | 82 |
| 2. Diodes | 2662 | $ | 2396 | 1012 | 399 | 213 |
| 3. Resistors | 1508 | $ | 33 | 33 | 33 | 33 |
| 4. Capacitors | 174 | $ | 6 | 6 | 6 | 6 |
| 5. Total Components | 4460 | | 2522 | 1148 | 525 | 334 |
| **Power** | | | | | | |
| 6. Supply | 2-340 watt | $ | 270 | 324 | 335 | 365 |
| 7. Wiring | 674 wires | $ | 121 | 141 | 148 | 160 |
| 8. Total Power | | $ | 391 | 465 | 483 | 525 |
| **Packaging** | | | | | | |
| 9. Module Mounts | 8-697 cu.in. | $ | 438 | 558 | 562 | 622 |
| 10. Cabinet | 1-24 cu.ft. | $ | 83 | 100 | 106 | 115 |
| 11. Cooling System | 679 watts | $ | 34 | 34 | 41 | 41 |
| 12. Total Packaging | | $ | 555 | 692 | 709 | 778 |
| **Interconnects** | | | | | | |
| 13. Printed Circuit Boards | 337 | $ | 1550 | 1146 | 1011 | 843 |
| 14. Module Assembly Labor | 1317 min. | $ | 124 | 148 | 157 | 171 |
| 15. Module Test Labor | 2022 min. | $ | 227 | 272 | 288 | 315 |
| 16. Subtotal Modules | | $ | 1901 | 1566 | 1456 | 1329 |
| 17. Connectors | 337-12 pin | $ | 96 | 104 | 104 | 111 |
| 18. Backwiring Labor | 1438 min. | $ | 135 | 161 | 171 | 187 |
| 19. Materials | $30 | $ | 30 | 30 | 30 | 30 |
| 20. Cables | | $ | 108 | 93 | 88 | 83 |
| 21. Total Interconnects | | $ | 2270 | 1954 | 1849 | 1740 |
| **Assembly & Test** | | | | | | |
| 22. Assembly Labor | 222 min. | $ | 21 | 25 | 26 | 29 |
| 23. Test Labor | 20.0 hrs. | $ | 169 | 202 | 214 | 234 |
| 24. Total System Assy./test | | $ | 190 | 227 | 240 | 263 |
| **Summary** | | | | | | |
| 25. Total Costs | | $ | 5928 | 4486 | 3806 | 3640 |
| Distribution | | | | | | |
| 26. Components | | % | 42.5 | 25.6 | 13.8 | 9.2 |
| 27. Power | | % | 6.6 | 10.4 | 12.7 | 14.4 |
| 28. Packaging | | % | 9.4 | 15.4 | 18.6 | 21.4 |
| 29. Interconnects | | % | 38.3 | 43.6 | 48.6 | 47.8 |
| 30. Assembly & Test | | % | 3.2 | 5.1 | 6.3 | 7.2 |
| 31. Cost per Flip-Flop | 58 | $ | 102 | 77.3 | 65.6 | 62.8 |

## TABLE II.4.11.4 TRANSISTOR TECHNOLOGY COSTS

| | | | Germanium Transistors | | | | | Silicon Transistors | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Units | Factors | 1955 | 1960 | 1962+ | 1965 | Factors | 1960 | 1962+ | 1965 | 1967+ |
| **Components** | | | | | | | | | | | |
| 1. Transistors | $ | 294 | 847 | 500 | 203 | 147 | 894 | 10,075 | 2369 | 769 | 456 |
| 2. Diodes | $ | 6747 | 6072 | 2564 | 1012 | 540 | 20,517 | 25,851 | 9027 | 5334 | 2667 |
| 3. Resistors | $ | 3822 | 84 | 84 | 84 | 84 | 11,622 | 256 | 256 | 256 | 256 |
| 4. Capacitors | $ | 441 | 14 | 14 | 14 | 14 | 1341 | 43 | 43 | 43 | 43 |
| 5. Tot.Components | $ | 11,304 | 7017 | 3162 | 1313 | 785 | 34,374 | 36,225 | 11695 | 6402 | 3422 |
| **Power** | | | | | | | | | | | |
| 6. Supply | $ | 1-482 watt | 170 | 205 | 211 | 231 | 1-371 watt | 171 | 177 | 193 | 210 |
| 7. Wiring | $ | 862 wires | 155 | 180 | 190 | 205 | 1394 wires | 291 | 307 | 332 | 358 |
| 8. Total Power | $ | | 325 | 385 | 401 | 436 | | 462 | 484 | 525 | 568 |
| **Packaging** | | | | | | | | | | | |
| 9. Module Mounts | $ | 10-646 cu.in. | 512 | 651 | 656 | 727 | 10-699 cu.in. | 697 | 702 | 778 | 856 |
| 10. Cabinet | $ | 1-24 cu.ft. | 83 | 100 | 106 | 115 | 1-24cu.ft. | 100 | 106 | 115 | 126 |
| 11. Cooling System | $ | 482 watts | 24 | 24 | 29 | 29 | 371 watts | 19 | 22 | 22 | 26 |
| 12. Tot. Packaging | $ | | 619 | 775 | 791 | 871 | | 816 | 830 | 915 | 1008 |
| **Interconnects** | | | | | | | | | | | |
| 13. PCB's | $ | 431 | 1982 | 1465 | 1293 | 1078 | 697 | 4600 | 4043 | 3485 | 2927 |
| 14. Mod. Assy. Lab. | $ | 2208 min. | 207 | 247 | 262 | 287 | 5528 min. | 619 | 657 | 719 | 784 |
| 15. Mod. Test Labor | $ | 2586 min. | 291 | 347 | 369 | 403 | 5018 min. | 674 | 715 | 783 | 854 |
| 16. Sbtot. Modules | $ | | 2480 | 2059 | 1924 | 1768 | | 5893 | 5415 | 4987 | 4565 |
| 17. Connectors | $ | 431-22 pin | 179 | 193 | 193 | 207 | 697-34 pin | 429 | 429 | 460 | 491 |
| 18. Backwiring Lbr. | $ | 2514 min. | 236 | 282 | 299 | 327 | 5130 min. | 575 | 610 | 667 | 728 |

## TABLE II.4.11.4 TRANSISTOR TECHNOLOGY COSTS (continued)

| Item | Units | Germanium Transistors Factors | 1955 | 1960 | 1962+ | 1965 | Silicon Transistors Factors | 1960 | 1962+ | 1965 | 1967+ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19. Matls/Deprn. | $ | $77 | 77 | 77 | 77 | 77 | $513 | 513 | 513 | 513 | 513 |
| 20. Cables | $ | | 149 | 131 | 125 | 119 | | 371 | 348 | 331 | 315 |
| 21. Tot.Interconn. | $ | | 3121 | 2742 | 2618 | 2498 | | 7781 | 7315 | 6958 | 6612 |
| **Assembly & Test** | | | | | | | | | | | |
| 22. Assembly Labor | $ | 277 min. | 26 | 31 | 33 | 36 | 431 min. | 48 | 51 | 56 | 61 |
| 23. Test Labor | $ | 78.1 hrs. | 659 | 787 | 835 | 914 | 32.1 hrs. | 324 | 343 | 376 | 410 |
| 24. Total System | $ | | 685 | 818 | 868 | 950 | | 372 | 394 | 432 | 471 |
| **Summary** | | | | | | | | | | | |
| 25. Total Costs | $ | | 11767 | 7882 | 5991 | 5540 | | 45656 | 20718 | 15232 | 12081 |
| Distribution | | | | | | | | | | | |
| 26. Components | % | | 59.6 | 40.1 | 21.9 | 14.2 | | 79.3 | 56.4 | 42.0 | 28.3 |
| 27. Power | % | | 2.8 | 4.9 | 6.7 | 7.9 | | 1.0 | 2.3 | 3.4 | 4.7 |
| 28. Packaging | % | | 5.3 | 9.8 | 13.2 | 15.7 | | 1.8 | 4.0 | 6.0 | 8.3 |
| 29. Interconnects | % | | 26.5 | 34.8 | 43.7 | 45.1 | | 17.0 | 35.3 | 45.7 | 54.7 |
| 30. Asmbly. & Test | % | | 5.8 | 10.4 | 14.5 | 17.1 | | 0.8 | 1.9 | 2.8 | 3.9 |
| 31. Cost/Flip-Flop | $ | 147 | 80.0 | 53.6 | 40.8 | 37.7 | 447 | 102.1 | 46.3 | 34.1 | 27.0 |

## TABLE II.4.11.5 INTEGRATED CIRCUIT TECHNOLOGY COSTS I

| | Units | Small-Scale Integration Factors | 1965 | 1967+ | 1970 | 1972 | SMSI Factors | 1965 | 1967+ | 1970 | 1972 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Components** | | | | | | | | | | | |
| 1. TO-5 IC's | $ | 6289 | 40250 | 11635 | 4402 | 4402 | - | | | | |
| 2. 16-Pin DIP's | $ | - | | | | | 5163 | 103260 | 20652 | 6196 | 3614 |
| 3. 24-Pin DIP's | $ | - | | | | | 52 | 2080 | 416 | 125 | 73 |
| 5. Tot.Components | $ | 6289 | 40250 | 11635 | 4402 | 4402 | 5215 | 105340 | 21068 | 6321 | 3687 |
| **Power** | | | | | | | | | | | |
| 6. Supply | $ | 1-404 watt | 204 | 222 | 272 | 302 | 1-394 watt | 201 | 219 | 267 | 297 |
| 7. Wiring | $ | 1364 wires | 325 | 351 | 416 | 464 | 1372 wires | 327 | 353 | 418 | 466 |
| 8. Total Power | $ | | 529 | 573 | 688 | 766 | | 528 | 572 | 685 | 763 |
| **Packaging** | | | | | | | | | | | |
| 9. Module Mounts | $ | 10-682 cu.in. | 763 | 839 | 994 | 1144 | 10-686 cu.in. | 767 | 844 | 999 | 1150 |
| 10. Cabinet | $ | 1-24 cu.ft. | 115 | 126 | 153 | 172 | 1-24 cu.ft. | 115 | 126 | 153 | 172 |
| 11. Cooling System | $ | 404 watts | 24 | 28 | 32 | 36 | 394 watts | 24 | 28 | 32 | 35 |
| 12. Tot. Packaging | $ | | 902 | 993 | 1179 | 1352 | | 906 | 998 | 1184 | 1357 |
| **Interconnects** | | | | | | | | | | | |
| 13. PCB's | $ | 682 | 3410 | 2864 | 2319 | 2046 | 686 | 8575 | 5419 | 3430 | 2744 |
| 14. Mod. Assy. Lab. | $ | 5191 min. | 675 | 736 | 892 | 1004 | 4061 min. | 528 | 576 | 698 | 786 |
| 15. Mod. Test Labor | $ | 6547 min. | 1021 | 1114 | 1350 | 1520 | 8232 min. | 1284 | 1401 | 1697 | 1911 |
| 16. Sbtot. Modules | $ | | 5106 | 4714 | 4561 | 4570 | | 10387 | 7396 | 5825 | 5441 |
| 17. Connectors | $ | 682-50 pin | 614 | 655 | 655 | 696 | 686-70 pin | 823 | 878 | 878 | 933 |
| 18. Backwiring Lbr. | $ | 4688 min. | 609 | 665 | 806 | 907 | 1829 min. | 238 | 259 | 314 | 354 |
| 19. Matls/Deprn. | $ | $313 | 313 | 313 | 313 | 313 | $709 | 709 | 709 | 709 | 709 |
| 20. Cables | $ | | 332 | 317 | 317 | 324 | | 608 | 462 | 386 | 372 |
| 21. Tot.Interconn. | $ | | 6974 | 6664 | 6652 | 6810 | | 12765 | 9704 | 8112 | 7809 |
| **Assembly & Test** | | | | | | | | | | | |
| 22. Assembly Labor | $ | 424 min. | 55 | 60 | 73 | 82 | 426 min. | 55 | 60 | 73 | 82 |
| 23. Test Labor | $ | 8.75 hrs. | 102 | 112 | 135 | 152 | 8.75 hrs. | 102 | 112 | 135 | 152 |
| 24. Total System | $ | | 157 | 172 | 208 | 234 | | 157 | 172 | 208 | 234 |
| **Summary** | | | | | | | | | | | |
| 25. Total Costs | $ | | 48812 | 20037 | 13120 | 13564 | | 119696 | 32514 | 16510 | 13850 |
| Distribution | | | | | | | | | | | |
| 26. Components | % | | 82.5 | 58.1 | 33.6 | 32.5 | | 88.0 | 64.8 | 38.3 | 26.6 |
| 27. Power | % | | 1.1 | 2.9 | 5.2 | 5.6 | | 0.4 | 1.8 | 4.1 | 5.5 |
| 28. Packaging | % | | 1.8 | 5.0 | 9.0 | 10.0 | | 0.8 | 3.1 | 7.2 | 9.8 |
| 29. Interconnects | % | | 14.3 | 33.3 | 50.7 | 50.2 | | 10.7 | 29.8 | 49.1 | 56.4 |
| 30. Asmbly. & Test | % | | 0.3 | 0.9 | 1.6 | 1.7 | | 0.1 | 0.5 | 1.3 | 1.7 |
| 31. Cost/Flip-Flop | $ | 662 | 73.7 | 30.3 | 19.8 | 20.5 | 1294 | 92.5 | 25.1 | 12.8 | 10.7 |

## TABLE II.4.11.6 INTEGRATED CIRCUIT TECHNOLOGY COSTS II ●

| | | Medium-Scale Integration I | | | | | Medium-Scale Integration II | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Units | Factors | 1967+ | 1970 | 1972 | 1974 | Factors | 1970 | 1972 | 1974 |
| **Components** | | | | | | | | | | |
| 1. TO-5 IC's | $ | - | | | | | - | | | |
| 2. 16-Pin DIP's | $ | 6865 | 102,975 | 16,476 | 6865 | 4806 | 7705 | 18492 | 7705 | 5394 |
| 3. 24-Pin DIP's | $ | 170 | 5100 | 816 | 340 | 238 | 249 | 1195 | 498 | 349 |
| 5. Tot.Components | $ | 7035 | 108,075 | 17,292 | 7205 | 5044 | 7954 | 19687 | 8203 | 5743 |
| **Power** | | | | | | | | | | |
| 6. Supply | $ | 2-467 watt | 492 | 600 | 667 | 718 | 2-473 watt | 606 | 673 | 725 |
| 7. Wiring | $ | 178 wires | 46 | 54 | 61 | 64 | 174 wires | 53 | 59 | 63 |
| 8. Total Power | $ | | 538 | 654 | 728 | 782 | | 659 | 732 | 788 |
| **Packaging** | | | | | | | | | | |
| 9. Module Mounts | $ | 7-636 cu.in. | 552 | 654 | 753 | 803 | 7-621 cu.in. | 640 | 737 | 787 |
| 10. Cabinet | $ | 1-24 cu.ft. | 126 | 153 | 172 | 184 | 1-24 cu.ft. | 153 | 172 | 184 |
| 11. Cooling System | $ | 933 watts | 65 | 75 | 84 | 93 | 945 watts | 76 | 85 | 95 |
| 12. Tot. Packaging | $ | | 743 | 882 | 1009 | 1080 | | 869 | 994 | 1066 |
| **Interconnects** | | | | | | | | | | |
| 13. PCB's | $ | 89 | 7387 | 4005 | 3382 | 3115 | 87 | 3915 | 3306 | 3045 |
| 14. Mod. Assy. Lab. | $ | 2870 min. | 407 | 493 | 555 | 596 | 3095 min. | 532 | 599 | 643 |
| 15. Mod. Test Labor | $ | 1602 min. | 273 | 330 | 372 | 399 | 1566 min. | 323 | 364 | 390 |
| 16. Sbtot. Modules | $ | | 8067 | 4828 | 4309 | 4110 | | 4770 | 4269 | 4078 |
| 17. Connectors | $ | 89-150 pin | 228 | 228 | 242 | 271 | 87-150 pin | 223 | 237 | 264 |
| 18. Backwiring Lbr. | $ | 527 min. | 75 | 91 | 102 | 109 | 515 min. | 88 | 100 | 107 |
| 19. Matls/Deprn. | $ | $204 | 204 | 204 | 204 | 204 | $200 | 200 | 200 | 200 |
| 20. Cables | $ | | 429 | 268 | 243 | 235 | | 264 | 240 | 232 |
| 21. Tot.Interconn. | $ | | 9003 | 5619 | 5100 | 4929 | | 5545 | 5046 | 4881 |
| **Assembly & Test** | | | | | | | | | | |
| 22. Assembly Labor | $ | 76 min. | 11 | 13 | 15 | 16 | 75 min. | 13 | 15 | 16 |
| 23. Test Labor | $ | 9.33 hrs. | 119 | 144 | 163 | 174 | 9.33 hrs. | 144 | 163 | 174 |
| 24. Total System | $ | | 130 | 157 | 178 | 190 | | 157 | 178 | 190 |
| **Summary** | | | | | | | | | | |
| 25. Total Costs | $ | | 118,489 | 24,604 | 14220 | 12025 | | 26917 | 15153 | 12668 |
| Distribution | | | | | | | | | | |
| 26. Components | % | | 91.2 | 70.3 | 50.7 | 41.9 | | 73.1 | 54.1 | 45.3 |
| 27. Power | % | | 0.5 | 2.7 | 5.1 | 6.5 | | 2.4 | 4.8 | 6.2 |
| 28. Packaging | % | | 0.6 | 3.6 | 7.1 | 9.0 | | 3.2 | 6.6 | 8.4 |
| 29. Interconnects | % | | 7.6 | 22.8 | 35.9 | 41.0 | | 20.6 | 33.3 | 38.5 |
| 30. Asmbly. & Test | % | | 0.1 | 0.6 | 1.3 | 1.6 | | 0.6 | 1.2 | 1.5 |
| 31. Cost/Flip-Flop | $ | 4238 | 28.0 | 5.81 | 3.35 | 2.84 | 6214 | 4.33 | 2.44 | 2.04 |

## TABLE II.4.12.1 INTEGRATED CIRCUIT TECHNOLOGY—NOTES

Much of the data in this section evolved from a series of discussions between the author and representatives of various IC manufacturers. Where no source is given for an item of data, the data was a result of these discussions.

**IC Geometry.** 1. In the late fifties, transistors were manufactured on one-half inch wafers. The subsequent changes in wafer size shown here took place at different times in different organizations.

2-6. Lines 2 and 3 are from a graph in PhilC67, and line 4 from another in CallM69. Both refer to bipolar technology. The more conservative figures I use on line 5 are based on my discussions with industry people, and on fragmentary data from a variety of sources. For example, Pitritz lists almost 30 bipolar IC's in the 54/74 TTL family, available in 1967. Half represented small scale integration (SSI) and averaged 104 square mils per component. The other half represented medium scale integration (MSI), averaging 56 square mils per component. (See Table II.4.12.2). Assuming a stacking factor of 24% (see line 7 below), the actual chip area per component is 25 for SSI and 13 for MSI. I am thus accepting Phillip's stacking factor, while rejecting his data on component areas on the ground that it probably represents best practice in the years shown where my figures are intended to represent typical practice.

The MOS areas shown on line 6 are based on even more fragmentary data. For example, Madland (MadlG69) plots the dimensions of a number of MOS components, showing that components lie in the range 7.5 to 100 square mils per gate, with 24 given as a "typical" figure. The typical bipolar figure was 100. Assuming that a gate required 4 components (see below), and that the stacking factor was 30%, we compute 7.5 square mils for the typical bipolar component and 1.8 square mils for MOS. Rhodes, on the other hand, quotes 80 square mils as a typical MOS gate size in 1968 (RhoaW68). He counts five components per gate, which at 30% stacking factor gives 4.8 square mils per MOS component.

7. The stacking factor is the ratio of the actual component area, computed from its dimensions, to the effective area, computed by dividing chip area by the number of components per chip. It is thus a measure of how effectively the designer was able to use the silicon real estate at his disposal, and gives an indirect measure of the area wasted and of the area taken up by conductors, isolating regions between components, and terminating pads. The figures given on line 7 are from a graph in PhilC67. Both average component area and stacking factor may, of course, vary considerably from IC to IC at any given time depending on how easy it is to lay out the particular circuits, on the relative numbers of different kinds of components, and on the power which must be dissipated in those components.

8-9. The effective component area is found by dividing the actual area on lines 5 and 6 by the stacking factors on line 7.

10-16. The number of components required for each of several kinds of logical and memory devices is given on these lines. The reduction in components per gate shown on line 10 has come about partly because of circuit inventions and partly because greater numbers of logic elements per chip makes it feasible to use expander gates to replace OR gates, and eliminates the need for providing high driving capabilities necessary when signals pass from chip to chip. (See PetrR67 and the Notes to Table II.4.12.1.) Component counts for early IC's were verified by examining sample circuits in GibsR66. The other figures, for flip-flops, shift registers, and memory elements, come from various sources including GibsB66, PetrR67, BrocL70, MotoMem72, MotoTo72, and BellC72.

17-25. The figures on these lines are computed from data on lines 8-16. For example, the first entry on line 17, showing the number of bipolar gates per square inch of silicon typical in 1962, was found by multiplying the number of components per gate on line 10 by the area per component in line 8, dividing the result into 1,000,000 (the number of square mils in a square inch), and then dividing by 1000.

26-27. Wafer cost figures were estimated after discussion with some industry representatives. Noyce (NoycR68) uses a silicon cost *per unit area* of \$20, \$15 and \$10 per square inch for 1968, 1970, and 1974. He does not mention a wafer size. My assumed wafer costs correspond to the cost per square inch figures shown in line 27 (assuming the wafer diameters of line 1). Note they are substantially lower than Noyce's figures. But Noyce's estimate of \$10 per square inch for 1974 would give a cost of over \$70 for a three-inch wafer, which is unreasonably high according to the other data I have.

28. The defect density coefficient for the formula given in Figure 4.12.11 was estimated after a discussion with various industry representatives. The late R. Seeds estimated that $k = 18.4$ in 1972, and that it decreased by roughly 20% per year. However, that value of k led to yield and cost figures somewhat higher and lower (respectively) than seemed reasonable. I therefore postulated a 1974 value of $k = 20.0$, and assumed it has fallen by 15% per year since 1962.

29. Packaging and test yields are typical values estimated after consultation with various industry sources.

30-33a. Package costs include the cost of the header on which the chip is mounted, and the cost of enclosing the package after the leads have been connected. For a description of the TO-5 and DIP packages, see Table II.4.12.3. The costs shown here once again were estimated after consultation with various industry sources. The ceramic DIP package whose price is given on line 31 is suitable for IC's whose largest dimension is less than 130 mils. Larger IC's require the packages whose price is given on line 33 or 33a. For information (but little cost data) on packaging problems, see LongT70 and ScruS71.

34-35. Labor cost per hour for U.S. labor is from Table II.1.4.3, augmented by manufacturing labor overhead figures from Table II.4.11.1. The overseas hourly figure assumes a labor rate of 50 cents per hour and an overhead rate of 175%.

36-40. Die attach time includes both the set-up time for die-attach and pin-connect operations, and the time required actually to bond chip to header. I assume it has essentially remained constant and is independent of chip size. Pin connect time is the time required for an operator to attach one end of a lead to a pad on the chip and the other end to the corresponding header pin, using a microscope-equipped tool. The times shown are my own estimates, intended to reflect improvements which have taken place in tooling since 1960. The cost examples on lines 39-40 are based on the sample number of pins on line 38, the times of lines 36-37, and the labor costs of lines 34-35.

41. The connection operations are followed by a visual inspection which eliminates some parts, as indicated by the packaging yield shown on line 29. The last costs to be quantified are those of completing the package, marking it, and putting the finished IC through an extensive series of tests. The cost of these operations is estimated on line 41. They have dropped, despite the fact that chips (and tests) have grown more complicated because of the development and improvement of automatic equipment which performs the various steps. The principal components of cost are the depreciation of the automatic testers and the labor to man them. A sophisticated tester in use in 1970 and equipped with an automatic IC feed mechanism might have cost $150,000 and have had a useful life of two years. If it were used one shift per day, its depreciation cost alone came to ten cents per ten seconds. Two such testers could be manned by a single operator whose salary-plus-overhead costs would be 1.4 cents per ten seconds. Thus a situation in which such a tester was tied up for 10 seconds per IC (for loading, testing, and unloading) would incur a cost of about 11.4 cents. Earlier testers were less expensive but required considerably more operator attention and contributed a substantially higher cost per IC.

42-74. These costs were calculated using the formulas of Figure 4.12.9 and the data from earlier lines in this table. Starting with the component counts on lines 14-16 and the effective component areas on lines 8-9, I compute the required chip size in each year, and from that parameter find the processing cost. (I assume that the only difference in cost between bipolar and MOS devices derives from the difference in these component counts and areas.) Packaging and test costs are based on the assumption that the number of pins necessary for an IC memory device is five greater than the number of address bits necessary. The five non-address pins are for power, ground, input, output, and read/write control. Thus the 16-bit unit requires only 9 pins and fits in a TO-5 can; the 4096-bit device requires 17 pins and the expensive 24-pin DIP; and the other memory IC's employ either the 16-pin plastic DIP package of line 32, or (if the IC is bigger than 130 mils square) the ceramic package of line 33. I used overseas labor figures for all calculations.

### TABLE II.4.12.1 INTEGRATED CIRCUIT TECHNOLOGY CHARACTERISTICS ●

| | | Units | 1962 | 1964 | 1966 | 1968 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|
| | **IC Geometry** | | | | | | | | |
| 1. | Wafer Diameter | in. | 1 | 1 | 1.5 | 1.5 | 2 | 2 | 3 |
| | Component Area | | | | | | | | |
| 2. | Resistors (PhilC67) | sq. mils | 28 | 20 | 4 | 2 | | | |
| 3. | Transistors (PhilC67) | sq. mils | 25 | 12 | 6 | 3 | | | |
| 4. | MECL (CallM6) | sq. mils | 40 | 16 | 8 | 8 | 4 | | |
| 5. | Bipolar | sq. mils | 27 | 21 | 16 | 12 | 5 | 4.5 | 4 |
| 6. | MOS | sq. mils | | | | 4 | 3 | 2 | 1.5 |
| 7. | Stacking Factor | | .10 | .18 | .24 | .30 | .40 | .50 | .60 |
| | Effective Comp. Area | | | | | | | | |
| 8. | Bipolar | sq. mils | 270 | 117 | 67 | 40 | 12.5 | 9.0 | 6.7 |
| 9. | MOS | sq. mils | | | 19 | 13 | 7.5 | 4.0 | 2.5 |
| | Components per Circuit | | | | | | | | |
| 10. | Per Gate | | 9 | 7 | 5.5 | 4 | 4 | 4 | 4 |
| 11. | Per Flip-Flop | | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | Per Shift Register Bit | | | | | | | | |
| 12. | Bipolar | | | | 20 | 20 | 20 | 20 | 20 |
| 13. | MOS | | | | | 10 | 10 | 10 | 10 |
| | Per Memory Array Bit | | | | | | | | |
| 14. | Bipolar | | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 15. | MOS—Static | | | | | 6 | 6 | 6 | 6 |
| 16. | MOS—Dynamic | | | | 3 | 3 | 3 | 3 | 3 |

## TABLE II.4.12.1 INTEGRATED CIRCUIT TECHNOLOGY CHARACTERISTICS (continued) ●

| | | Units | 1962 | 1964 | 1966 | 1968 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|---|
| | Circuits per Sq. Inch | | | | | | | | |
| 17. | Gates–Bipolar | k | .412 | 1.22 | 2.73 | 6.25 | 20.0 | 27.8 | 37.5 |
| 18. | MOS | k | | | | 19.2 | 33.3 | 62.5 | 100.0 |
| 19. | Flip-Flop–Bipolar | k | .123 | .28 | .50 | .83 | 2.67 | 3.70 | 5.0 |
| 20. | MOS | | | | | 2.56 | 4.44 | 8.33 | 13.3 |
| | Shift Register Bits | | | | | | | | |
| 21. | Bipolar | k | | | .75 | 1.25 | 4.00 | 5.55 | 7.5 |
| 22. | MOS | k | | | | 7.69 | 13.33 | 25.0 | 40.0 |
| | Memory Array Bits | | | | | | | | |
| 23. | Bipolar | k | .926 | 2.14 | 3.75 | 6.25 | 20.0 | 27.8 | 37.5 |
| 24. | Static MOS | k | | | | 12.8 | 22.2 | 41.7 | 66.7 |
| 25. | Dynamic MOS | k | | | 17.5 | 25.6 | 44.4 | 83.3 | 133.3 |
| | **Costs** | | | | | | | | |
| 26. | Wafer Cost (Cw) | $ | 20 | 20 | 25 | 25 | 25 | 30 | 45 |
| 27. | per Unit Area | $/sq. in. | 25.5 | 25.5 | 14.1 | 14.1 | 7.96 | 9.55 | 6.37 |
| 28. | Defect Density (k) | | 141 | 102 | 73 | 53 | 38 | 28 | 20 |
| 29. | Packaging/Test Yields | % | 60 | 70 | 75 | 80 | 85 | 90 | 90 |
| | Package Costs | | | | | | | | |
| 30. | Metal TO-5 | cents | 20 | 18 | 16 | 14 | | | |
| 31. | Ceramic DIP (14-16 pins) | cents | 28 | 18 | 13 | 12 | 12 | 12 | 12 |
| 32. | Plastic DIP (14-16 pins) | cents | | | 9 | 5 | 4 | 4 | 4 |
| 33. | LSI DIP–16 pins | $ | | | | 1.30 | 1.00 | 0.70 | .80 |
| 33a. | 24 pins | $ | | | | | 1.30 | 1.10 | 1.10 |
| 34. | Labor Cost–U.S. | $/hr. | 7.10 | 7.35 | 7.82 | 8.79 | 10.31 | 11.61 | 12.46 |
| 35. | Overseas | $/hr. | | 1.38 | 1.38 | 1.38 | 1.38 | 1.38 | 2. |
| 36. | Die Attach Time | secs. | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 37. | Pin Connect Time | secs. | 20 | 20 | 17 | 12 | 10 | 8 | 7 |
| 38. | Typical No. of Pins | | 8 | 10 | 14 | 14 | 16 | 16 | 24 |
| 39. | Connect Cost–U.S. | cents | 37.5 | 47.0 | 58.2 | 48.3 | 54.4 | 51.0 | 68.5 |
| 40. | Overseas | cents | | 8.8 | 10.3 | 7.6 | 7.2 | 6.1 | 11.0 |
| 41. | Test Cost | cents | 25. | 20. | 16. | 14. | 12. | 12. | 12. |
| | Memory IC's | | | | | | | | |
| 42. | 16 bit–Edge | mils | 131 | 86 | 65 | 51 | | | |
| 43. | Process Yield | % | 2.0 | 14.8 | 35.7 | 54.3 | | | |
| 44. | Cost | $ | 134. | 4.81 | .86 | .46 | | | |
| 45. | 64 bit–Edge | mils | | 173 | 131 | 101 | 57 | | |
| 46. | Process Yield | % | | 1.2 | 7.0 | 21.9 | 56.4 | | |
| 47. | Cost | $ | | 426. | 10.00 | 1.76 | .34 | | |
| 48. | 256 bit–Edge | mils | | | | 202 | 113 | 96 | 83 |
| 49. | Process Yield | % | | | | 2.5 | 24.4 | 40.2 | 54.3 |
| 50. | Cost | $ | | | | 79.51 | 1.03 | .58 | .38 |
| 51. | 1024-Bit | mils | | | | | 226 | 192 | 165 |
| 52. | Process Yield | % | | | | | 3.2 | 9.5 | 21.7 |
| 53. | Cost | $ | | | | | 33.93 | 8.54 | 2.47 |
| 54. | 4096 bit–Edge | mils | | | | | | 384 | 330 |
| 55. | Process Yield | % | | | | | | 0.6 | 2.5 |
| 56. | Cost | $ | | | | | | 1251. | 63.57 |
| | Dynamic MOS | | | | | | | | |
| 57. | 256 bit–Edge | mils | | | 121 | 100 | 76 | 55 | 44 |
| 58. | Process Yield | % | | | 9.0 | 22.3 | 44.2 | 62.5 | 71.4 |
| 59. | Cost | $ | | | 6.54 | 1.71 | .45 | .31 | .29 |
| 60. | 1024 bit–Edge | mils | | | 242 | 200 | 152 | 111 | 88 |
| 61. | Process Yield | % | | | 0.5 | 2.6 | 12.1 | 32.9 | 52.1 |
| 62. | Cost | $ | | | | 76.60 | 4.66 | .82 | .41 |
| 63. | 4096 bit–Edge | mils | | | | | 304 | 222 | 175 |
| 64. | Process Yield | % | | | | | 0.9 | 5.9 | 19.0 |
| 65. | Cost | $ | | | | | 308 | 19.42 | 3.25 |
| | Static MOS | | | | | | | | |
| 66. | 256 bit–Edge | mils | | | | 141 | 107 | 78 | 62 |
| 67. | Process Yield | % | | | | 9.2 | 27.1 | 49.7 | 64.1 |
| 68. | Cost | $ | | | | 10.00 | .87 | .42 | .32 |
| 69. | 1024 bit–Edge | mils | | | | 283 | 215 | 157 | 124 |
| 70. | Process Yield | % | | | | 0.6 | 3.8 | 16.6 | 35.8 |
| 71. | Cost | $ | | | | 1410. | 23.51 | 3.64 | .68 |
| 72. | 4096 bit–Edge | mils | | | | | | 314 | 248 |
| 73. | Process Yield | % | | | | | | 1.5 | 7.2 |
| 74. | Cost | $ | | | | | | 207. | 11.60 |

## TABLE II.4.12.2 CHARACTERISTICS OF 54/74 TTL INTEGRATED CIRCUITS ●

| Device Number | Logic Description | Chip Dimen. (mils) | Chip Area (sq. mils) | Number of Devices | Device Area (sq. mils) | Number of Gates | Gate Area (sq. mils) | Number of Devices per Gate |
|---|---|---|---|---|---|---|---|---|
| | **1965-1966 IC's** | | | | | | | |
| 5400 | Quad 2-Input Gate | 50x60 | 3000 | 36 | 83 | 4 | 750 | 9.0 |
| 5410 | Triple 3-Input Gate | 50x60 | 3000 | 27 | 110 | 3 | 1000 | 9.0 |
| 5420 | Dual 4-Input Gate | 45x45 | 2025 | 18 | 125 | 2 | 1012 | 9.0 |
| 5430 | Single 8-Input Gate | 40x40 | 1600 | 9 | 180 | 1 | 1600 | 9.0 |
| 5440 | Power Dual 4-Input Gate | 50x50 | 2500 | 22 | 114 | 2 | 1250 | 11.0 |
| 5450 | Dual 2-Wide, 2-Input And/Or Inv | 50x55 | 2750 | 24 | 115 | 6 | 460 | 4.0 |
| 5453 | 4-Wide, 2-Input And/Or Inv | 50x55 | 2750 | 18 | 153 | 5 | 550 | 3.6 |
| 5460 | Dual 4-Input Expander | 35x40 | 1400 | 6 | 230 | 2 | 700 | 3.0 |
| 5470 | J-K Flip-Flop | 55x60 | 3300 | 56 | 57 | 8 | 400 | 7.0 |
| 5472 | J-K Flip-Flop Master/Slave | 55x60 | 3300 | 40 | 80 | 6 | 535 | 6.7 |
| | Averages | | 2600 | 25 | 104 | 4.2 | 620 | 6.6 |
| | **1967-1968 IC's** | | | | | | | |
| 5474 | BCD to Decimal Decoder | 60x60 | 3600 | 50 | 72 | 17 | 212 | 2.9 |
| 5475 | Quad Latch | 60x120 | 7200 | 120 | 60 | 24 | 300 | 5.6 |
| 5480 | Gated Full Adder | 65x65 | 4225 | 69 | 61 | 14 | 301 | 4.9 |
| 5482 | 2-Bit Full Adder | 65x65 | 4225 | 83 | 51 | 21 | 200 | 4.0 |
| 5490 | BCD Decade Counter | 50x115 | 5750 | 102 | 56 | 18 | 320 | 5.7 |
| 5491 | 8-Bit Shift Register | 55x110 | 6050 | 143 | 42 | 35 | 173 | 4.1 |
| 5492 | Divide by 12 Counter | 50x115 | 5750 | 96 | 60 | 17 | 340 | 5.7 |
| 5493 | Divide by 16 Counter | 50x115 | 5750 | 96 | 60 | 17 | 340 | 5.7 |
| 5494 | Dual P.I., S.O. 4-Bit S.R. | 70x110 | 7700 | 125 | 62 | 20 | 385 | 6.3 |
| 5496 | P.I., S.O., P.O. 5-Bit S.R. | 70x140 | 9800 | 158 | 62 | 24 | 450 | 6.6 |
| 5486 | P.L. Serial 5-Bit Ring Counter | 70x140 | 9800 | 169 | 58 | 30 | 327 | 5.6 |
| 5487 | Dual P.L. Count. to-zero 5-Bit R.C. | 70x110 | 7700 | 153 | 50 | 33 | 230 | 4.6 |
| 5488 | Dual P.L., S.S., 5-Bit R.C. | 70x140 | 9800 | 191 | 51 | 30 | 327 | 6.4 |
| 5484 | Active Element Memory | 60x120 | 7200 | 100 | 72 | 40 | 180 | 2.5 |
| 5495 | 4-Bit Up/Down Shift Reg. | 70x120 | 8400 | 156 | 54 | 33 | 255 | 4.7 |
| 5497 | Synchronous BCD Counter | 75x120 | 9000 | 171 | 53 | 28 | 320 | 6.1 |
| | Averages | | 7000 | 124 | 56 | 25 | 280 | 5.0 |

## TABLE II.4.12.3 INTEGRATED CIRCUIT PACKAGES ●

| Source | Package Designations | Number of Pins | Dimensions (inches) | Area (sq. in.) | Pins per sq. in. | Remarks |
|---|---|---|---|---|---|---|
| | TO-5 | 6,8,10 | 0.31 D | 0.1 | 60,80,100 | |
| | TO-8 | 12 | 0.50 D | 0.25 | 48 | |
| | TO-8 (Large) | 12,16 | 0.60 D | 0.36 | 33.3, 44.4 | |
| PetrR67 | Dual In-Line (DIP) | 14 | 0.77x0.3 | 0.231 | 60.6 | Most common DIP |
| | DIP | 16 | 0.843x0.3 | 0.253 | 63.3 | |
| | DIP | 24 | 1.25x0.5 | 0.625 | 38.4 | |
| | DIP | 50 | 1.0x2.5 | 2.50 | 20.0 | |
| ScruS71 | Frenchtown | 40 | 1.0x2.0 | 2.00 | 20.0 | |
| | American Lava | 64 | 3.0x0.9 | 2.70 | 23.7 | |
| | National Beryllia | 51 | 1.38x1.38 | 1.89 | 27.0 | |
| | National Beryllia | 40 | 1.0x0.8 | 0.80 | 50.0 | Six rows of leads |
| | Metceram | 42 | 1.0x0.6 | 0.60 | 70.0 | Four rows of leads |
| | Metceram | 40 | 1.0x0.25 | 0.25 | 160.0 | Edge mount. 3/4 in. high |
| | Texas Instruments | 40 | 2.5x0.6 | 1.50 | 2,.7 | |
| | U.S.E.S. | 24 | 1.2x0.6 | 0.72 | 33.3 | |
| | Dielectric Systems | 100 | 1.6x1.6 | 2.56 | 39.1 | Mounts several chips |

## TABLE II.4.12.2 CHARACTERISTICS OF 54/74 TTL IC's—NOTES

The data in this table is from PetrR67, and describes a set of Texas Instruments integrated circuits. The column and row entries are generally self-explanatory. "Devices" means components, and "gates" makes use of equivalences (not defined by Petritz) between gates, flip-flops, inverters, etc. The dates assigned to the two halves of the table are my own estimates. The IC's appear in Petritz's paper in two separate tables, and are undated except by implication.

## TABLE II.4.12.3 INTEGRATED CIRCUIT PACKAGES—NOTES

The TO-type packages, which evolved from three-lead transistor packages, are cylinders, and their diameters are given in the table. Area, however, is computed as if the packages occupied squares whose edge is equal to the cylinder diameter.

The 14-, 16-, and 24-pin DIP's are very common. The nine packages at the end of the table represent attempts by various manufacturers to devise packages which occupy little space yet provide many pins.

## II 4.13 MAGNETIC CORE MEMORY COSTS—NOTES

The bibliography of Part III lists several articles on core memories, including a particularly interesting one which presents some specifics on costs. However, the cost figures given here are the author's interpretation of a series of interviews he carried out with engineers who had been working in the field since the late 1950's, and of a few private reports on 1970-vintage memories he was permitted to see. The results have been reviewed by the original interviewees, and by other knowledgeable engineers; however, they must of course be considered simply as an attempt to piece together a quantitative discussion of a complex and generally undocumented history.

## TABLE 4.13.1 CHARACTERISTICS OF TYPICAL MEMORIES—NOTES

The memories which form the basis for the entire analysis are described by this table. They are meant to typify memories in large scale production in each of the years shown—where "large scale" refers to the production requirements of some computer system manufacturer other than IBM. Cycle times in every era are pushed to the limit of what is practical. Word lengths of first and second generation systems were often multiples of six bits, but the introduction of the third generation with its eight bit byte often resulted in memories whose word length is a multiple of nine—eight bits plus a parity bit. Memory capacity has generally been increased as technology permitted, in order to reduce the cost per bit. However, memory size has also been limited by two factors: the need to provide a small memory for a minimal system, and to improve memory system access time by operating two or more memories in parallel (a 16k system made up of two 8k systems would be more expensive than a 16k memory, but would provide better performance because the processor could be accessing a word from one half of the memory while the other half was recovering from a previous reference.) Finally, a word about arrays: logically, cores are arranged in bit planes, one plane for each bit in a word; physically, they are arranged in arrays, where an array is a set of cores which are mounted and threaded together, and which may include one or more bit planes; and a stack is the name given to the set of arrays which comprise a complete memory. Array size is an extremely important parameter, as has been discussed in Part I, and the arrays chosen are representative of the various years.

## TABLE II 4.13.1 MAGNETICS COSTS—NOTES

1-4. These are typical dimensions. Line 4 is the number of cores which can be made from a cubic inch of material, as computed from the dimensions.

5. About 4,000,000 18 mil cores can be made from a kilogram of today's material. The other numbers in line 5 are computed from line 4, under the assumption that the density of the material has remained constant.

6. Material costs per kilogram have increased despite the increase in production rate, which normally encourages a reduction in unit cost. A change in materials (from magnesium/manganese to lithium) in 1965 accounts for part of the increase, but in general it has come about because of specification changes which have made it possible to produce more uniform cores with higher manufacturing yields.

7. Cost per thousand cores is computed by dividing line 6 by line 5.

To determine depreciation and labor costs per thousand cores, we must envision a specific manufacturing plant. The next few entries in the table describe that imaginary plant, which is assumed to grow substantially over this 17-year period.

8-10. The plant production rate represents the number of cores pressed per week. For the years 1955 through 1970, inclusive, we assume this number of cores is carried through to final test, and that the percentage yield at final test, shown in line 9, results in the net production shown in line 10. For 1972, we assume that inspections and tests carried out immediately after the cores are molded eliminates 50% of the cores, and that the remaining 100 million cores reach final test, where they experience a relatively high yield. Because of the 50% yield early in the process, the material cost of cores entering final test is 5 cents per thousand cores rather than the 2.5 cents shown in line 7 above.

11-12. These entries describe the size of the core manufacturing plant. Total core costs per week is found by multiplying the net production rate in line 10 by the total manufacturing cost in line 23. The number of memories produced per week is found by dividing line 10 by the number of cores per system from Table 4.13.1.

13-14. As production rate increases, the capital investment in presses, kilns, test equipment, etc., must also increase. An assumed capital investment is shown in line 13. The capital investment per million cores per week produced, shown in line 14, is computed by dividing line 13 by line 10. Despite the fact that manufacturing equipment has grown more sophisticated, the investment per production rate has dropped substantially. This reduction has come about in part because of increases in the average number of production hours per week; but mostly it has occurred simply because of changes and improvements made in the equipment to handle the large and growing production rates.

15. Depreciation per thousand cores produced is based on a uniform depreciation rate over four years. It is computed

by multiplying the production rate into final test, from line 8, by 208 weeks, and dividing the result into the capital investment on line 13.

16-17. Line 16 shows the number of employees required to operate the plant in each selected year, and line 17 shows the employees per million cores per week—found by dividing line 16 by line 10. The number of employees includes engineering personnel associated with production, as well as production workers themselves. The 150-to-one reduction in manpower shown in line 17 comes about in part because less engineering support is required today than was necessary in 1955; in part because the addition of extra shifts does not require a proportionate increase in total manpower; and in part because of improvements in production equipment.

18-19. The labor cost per week on line 18 is the same figure used for assembly labor in Section 4.11. It includes overhead, and is derived from government figures on average U.S. factory labor rates. The cost per thousand cores on line 19 is found by multiplying lines 16 and 18 to get the total labor costs per week, and dividing the result by the production rate into final test from line 8. (Since the employee count includes engineering personnel, but the labor rate is for production people only, the labor cost is somewhat understated, especially in the early years when much engineering support was required.)

20. This line shows the cost of the tool actually used to form the core in a press. Tools are assumed to cost $50. In the early (asperin) presses, tool life was only 500,000 cores; but starting between 1965 and 1970, the new Pentronics presses, employing a different tool design, extended tool life to one million cores.

21. "Other" costs include utilities, some miscellaneous tooling, and (until 1972 when patents began to expire) royalties of 5 cents per thousand bits.

22-23. The subtotal is the cost of the cores arriving at final test, found by adding lines 7, 15, 19, 20, and 21. The total cost is then found by dividing this figure by the yield on line 9. In evaluating these figures, we must remember they represent manufacturing costs only, and do not include General and Administrative, Marketing, or Engineering costs, or profits. The cost of cores in quantity to a moderate-sized system company is likely to be from 1.5 to 3 times the numbers shown on line 23.

24-29. As was mentioned in Part I, the primary components of manufacturing cost of the arrays of Figure 4.13.7 are the costs of threading and terminating wires, and of testing and repairing the wired assembly. Threading time is a function of the number of times the threading needle must be inserted in the array, and the calculation can perhaps best be illustrated with an example. In the 1955 system, each of twelve bit-planes contains 32 X-wires, 32 Y-wires, and 32 inhibit wires. Each of these 96 wires must be inserted in each of twelve planes, for a total of 1,152 insertions. In addition, the sense wire on each of the twelve planes linked all cores in that plane in a diagonal pattern which was reversed in each diagonal to help cancel noise from half-selected cores during readout. There are 64 diagonals, and the reversal requires 128 insertions for each of twelve planes for a total of 1,536 insertions. The total number of insertions for the 1955 system is thus 2,688. The threading time is calculated assuming that the first wire requires 25 seconds for insertion, the second 30, the third 36, and the fourth 43.2—each wire requiring 20% longer than the previous one because of the increasing difficulty of threading wire through cores already linked with wires. A count of terminations must include both those on the plane and (for all systems except the 1972 system which contains only one plane) the terminations required to connect planes together. For the 1955 system, 32 X-wires and 32 Y-wires must each be terminated on each end for a total of 128 terminations per plane. In addition, the sense and inhibit wires must each be terminated; so the total terminations per plane is 132. Finally we must connect the X-wires and Y-wires on each plane to corresponding wires on adjacent planes; and this requires 11x64 wires and 1,408 additional terminations. The total number of terminations is thus 1,584 + 1,408 = 2,992. Termination time is figured on the basis of 30 seconds per termination. Lines 27 and 29 are computed by dividing total threading and termination times by the total number of cores in the array—12,288 for the 1955 system, for example.

30-37. Each core is individually tested at the final stage of manufacture, and those testing costs are included in the figures on line 23 above. The entire magnetics assembly—a stack of planes—must of course also be tested, and repaired where necessary. Repairs are required to replace broken or marginal cores, to correct open or short circuits, and to cure noise and crosstalk problems. The repair frequency as indicated in line 30 has improved substantially over the years as improvements were made in core uniformity, in wire and its insulation, and in threading and soldering techniques. The very great improvement between 1970 and 1972 came about partly because of improvements in the cores themselves, but mostly because of the reduction in terminations (see line 25) resulting from the fact that all cores are on one assembly. The repairs per system on line 31 are calculated by dividing cores per system by line 30. The repair time in line 32 takes into account the difficult and delicate problems of removing and reinserting wires, of replacing individual cores, and (in situations where a bad plane is discovered after the plane is assembled in the stack) partial or entire disassembly and reassembly of the stack. Test time in line 33 includes the time required to make connections between planes or stack and the test equipment. The total test and repair time on line 34 is computed by multiplying line 31 by the total test and repair time, and then adding one more test time for the final test after the last repair. Line 36 is the sum of threading, termination, and test/repair time; and lines 35 and 37 are found by dividing lines 34 and 36 by the number of thousand cores per array.

38-41. The labor rate shown in line 38 is the same as that in line 18 above, except for the years 1970 and 1972. For those years, an overseas labor rate of $.50 per hour was used, with an overhead rate of 175%. Total stringing cost per thousand cores is found by multiplying lines 37 and 38. Lines 40 and 41 show the effect on labor cost of using U.S. labor rates.

42-43. In 1955 and 1960, core planes were assembled in square frames which had provision for terminating the wires, and which permitted the passage of cooling air through the stack perpendicular to the plane of the cores. Starting in the early 1960's, core planes have been assembled on printed circuit boards, and have been cooled by a flow of air parallel to the planes. The cost of frames or PC boards are given in line 42, and the cost per thousand cores is computed on line 43.

44-45. The total magnetics cost per thousand cores is computed by adding core costs (line 23), stringing costs (line 39), and frame costs (line 43). Line 45 indicates that magnetics costs would have been three times higher than they actually were in 1970 and 1972 if manufacturers had not made use of overseas labor.

**TABLE II 4.13.1 MAGNETICS COST OF TYPICAL MEMORIES**

| Line | Item | Units | 1955 | 1960 | 1965 | 1970 | 1972 |
|---|---|---|---|---|---|---|---|
| | **Cores** | | | | | | |
| | Materials | | | | | | |
| 1. | Outside Diameter | mils | 120 | 80 | 30 | 22 | 18 |
| 2. | Inside Diameter | mils | 75 | 50 | 20 | 14 | 11 |
| 3. | Thickness | mils | 38 | 25 | 10 | 5.5 | 3.5 |
| 4. | Cores Per Cu. Inch | k | 3.8 | 13.1 | 255 | 804 | 1792 |
| 5. | Cores Per kgram | k | 8.5 | 30 | 570 | 1800 | 4000 |
| 6. | Material Cost | $/kg | 1.7 | 6 | 55 | 85 | 100 |
| 7. | Mat'l Cost per 1 k Cores | $ | .20 | .20 | .10 | .05 | .025 |
| | Manufacturing Plant | | | | | | |
| 8. | Production Rate, Cores/wk. | M | 1 | 5 | 10 | 50 | 200 |
| 9. | Yield | % | 20 | 30 | 40 | 50 | 80 |
| 10. | Net Prod'n Rate, Cores/wk. | M | .2 | 1.5 | 4 | 25 | 80 |
| 11. | Total Core Cost/wk. | $k | 5 | 18 | 25 | 35 | 39 |
| 12. | Memories/wk. | | 16 | 15 | 27 | 85 | 270 |
| 13. | Capital Investment | $M | .2 | .75 | .9 | 1.0 | 1.4 |
| 14. | Per M/wk. Produced | $M | 1 | .5 | .23 | .04 | .018 |
| 15. | Depreciation Per 1 k Cores | $ | 1 | .7 | .45 | .10 | .07 |
| | Labor | | | | | | |
| 16. | Employees | | 15 | 45 | 55 | 50 | 40 |
| 17. | Per M/wk. Produced | | 75 | 30 | 14 | 2 | .5 |
| 18. | Labor Cost/wk. With OH | $ | 225 | 269 | 312 | 412 | 464 |
| 19. | Labor Cost Per 1 k Cores | $ | 3.40 | 2.40 | 1.72 | .41 | .19 |
| | Other | | | | | | |
| 20. | Tooling Cost Per 1 k Cores | $ | .10 | .10 | .10 | .05 | .05 |
| 21. | Other Costs Per 1 k Cores | $ | .30 | .20 | .15 | .10 | .05 |
| | Totals | | | | | | |
| 22. | Cost Into Final Test | $/k | 5.00 | 3.60 | 2.52 | .71 | .39 |
| 23. | Core Cost After Yield | $/k | 25 | 12 | 6.30 | 1.42 | .49 |
| | **Stringing** | | | | | | |
| 24. | Total Insertions | | 2688 | 10752 | 13824 | 5504 | 3072 |
| 25. | Total Terminations | | 2992 | 12128 | 9360 | 3472 | 456 |
| 26. | Threading Time | hrs. | 25.8 | 103.3 | 137.4 | 48.1 | 28.9 |
| 27. | Per 1 k Cores | hrs. | 2.1 | 1.1 | .93 | .16 | .20 |
| 28. | Termination Time | hrs. | 24.9 | 101.1 | 78.0 | 28.9 | 3.8 |
| 29. | Per 1 k Cores | hrs. | 2.0 | 1.0 | .53 | .10 | .03 |
| 30. | Cores Per Repair | | 750 | 1000 | 1500 | 2000 | 8000 |
| 31. | Repairs Per System | | 16 | 98 | 98 | 147 | 18 |
| 32. | Time Per Repair | hrs. | 1 | 1 | .8 | .5 | .5 |
| 33. | Time Per Test | hrs. | .5 | .5 | .4 | .25 | .25 |
| 34. | Test/Repair Time | hrs. | 24.5 | 147.5 | 118. | 111. | 13.8 |
| 35. | Per 1 k Cores | hrs. | 2.0 | 1.5 | .80 | .38 | .09 |
| 36. | Total Time | hrs. | 75.2 | 351.9 | 333.4 | 188. | 46.5 |
| 37. | Per 1 K Cores | hrs. | 6.1 | 3.6 | 2.26 | .64 | .32 |
| 38. | Labor Costs/hour With OH | $ | 5.62 | 6.72 | 7.80 | 1.38 | 1.38 |
| 39. | Stringing Cost Per 1 k Cores | $ | 34 | 24 | 17.60 | .88 | .44 |
| 40. | U.S. Labor Cost/hr. | $ | | | | 10.31 | 11.61 |
| 41. | Stringing Cost Per 1 k Cores | $ | | | | 6.60 | 3.72 |
| | **Frame** | | | | | | |
| 42. | Materials | $ | 60 | 120 | 81 | 100 | 20 |
| 43. | Material Cost Per 1 k Cores | $ | 5 | 1 | .55 | .34 | .14 |
| 44. | **Total Cost Per 1 k Cores** | $ | 64 | 37 | 24.45 | 2.64 | 1.07 |
| 45. | With U.S. Labor | $ | | | | 8.36 | 4.35 |

## TABLE II 4.13.2 ELECTRONIC AND OTHER COSTS OF TYPICAL MEMORIES—NOTES

**Drivers.** 1. As was mentioned in the text, early memories used a coincident-current switch core or "transformer" to supply drive current to X and Y wires of the array. One such transformer was required for each X and each Y wire.

2-4. The cost of these switch cores and their associated circuits, interconnected and tested, is shown on line 2; line 3 is the product of lines 1 and 2, and line 4 the quotient of line 3 and the number of thousand cores in the array.

5. The 1965 3D system made use of drivers in a straightforward way. Recall that there are 64 X and 64 Y lines. The 64 X lines, driven from the circuit of Figure 4.13.10, are selected via an 8x8 array of positive and negative current sources. Sixteen positive and sixteen negative sources are required for the X side, and another 32 on the Y side for a total of 64. Looking at the 1972 3D system, we recall that each plane contains 64x128 cores. If the 1965 scheme were used, we would need 32 drivers for the X switches, and 48 for the Y switches—since one of 128 lines must be selected by an 8x16 array, requiring 24 positive and 24 negative current sources. However, by sharing 16 sources between the X and Y side, circuit designers were able to reduce the number of switches required to 64. The switches for the 2 1/2D memory are of course more numerous because of the nature of a 2 1/2D configuration. Suppose for the moment that the 16k, 18-bit 1970 system were laid out on 18 planes, each 256x64. The 256 Y lines would be selected by a 16x16 array requiring 32 positive and 32 negative current sources. Each of the 18 X drive systems would select one of 64 lines using an 8x8 matrix requiring 16 positive and 16 negative drivers. 18x32 = 576 X switches would thus be required in addition to the 64 Y switches for a total of 640 switches. In fact, configuring the magnetics on four large circuit cards complicates the drive electronics, and though various clever schemes are used to share drivers, the number finally required turns out to be 672.

6-8. Total switch costs, and cost per thousand cores are based on the unit cost of line 6. Comment 17, below, supplies some additional detail on unit switch costs.

9. Isolating diodes were not required for the transformer drivers of 1955 and 1960. As indicated in Figure 4.3.10, later systems require two diodes for each driven X or Y line. In the 1965 system, for example, the 64X and 64Y lines each required two diodes for a total of 256.

10-11. The cost of fast-switching memory diodes has fallen along with the cost of other electronic components. The 1972 diodes are packaged eight to a dual-inline package.

12-13. The time to insert and solder an individual diode is estimated at 36 seconds. The corresponding time for an eight-diode DIP is estimated at 48 seconds. Labor cost on line 13 is based on the hourly costs of line 38, Table II 4.13.2, and again assumes that diodes were installed overseas in 1970 and 1972. (Isolating diodes are physically located on the magnetics assembly, and it is therefore convenient to install them overseas when magnetics labor is carried out there. Because diodes are on the magnetic assembly, their cost is often included with the magnetics.)

14-15. Total diode cost in line 14 is the sum of lines 11 and 13.

16. A 3D memory must have at least one inhibit driver for each bit in a memory word. (It may have more if a single driver is incapable of driving the number of cores in a bit-plane.) I assume that the drivers of 1955, 1960, 1965, and 1972 can handle 1k, 4k, 4k, 8k cores respectively. The 2 1/2D memory of course requires no inhibit drivers, since there is an individual X driver for each bit in a word.

17. I assume that an inhibit driver and a switch (line 6 above) are comparable and have the same cost. Unit costs shown here, which include labor and materials for components, interconnects and unit testing, have continually fallen as technology has changed and improved. Although the circuits don't generally lend themselves to implementation using integrated circuit technology, some IC fabrication and packaging techniques are used in the 1970 and 1972 systems, where components containing multiple transistors, multiple diodes, or multiple resistors in special configurations are used.

18-19. Total inhibit cost is the product of lines 16 and 17, and line 19 as usual is found by dividing line 18 by the number of thousand cores in the memory.

20-21. Total driver costs is the sum of lines 3, 7, 14, and 18—that is to say, the sum of the costs of XY drives, diodes, and inhibit drivers.

**Sense Amplifiers.** 22. Although conceptually no more sense amplifiers are required than there are bits in a memory word, in practice it may be necessary to use two or more amplifiers per bit to reduce the noise seen by individual amplifiers. The key parameter is the maximum number of cores allowed per sense amplifier, and that number has increased from 1k to 8k since 1955 with improvements in amplifier circuits, and particularly with improvements in the uniformity of cores and stacks.

23. Taking into account the data on line 22, line 23 shows that the 1955, 1965, and 1972 memories required one sense amplifier per bit, while the 1960 and 1970 configurations required two.

24-26. Sense amplifier unit costs have fallen even more rapidly than have inhibit driver costs. The greater improvement comes about in part because improved stack uniformity has permitted great simplifcation in sense amplifier circuit design; and in part because the sense amplifier circuits lend themselves better to implementation in IC technology than do the driver circuits.

**Digital Electronics.** 27-30. The number of flip-flops in the data register is equal to the number of bits in a memory word; the address register must contain enough flip-flops to address any word in the memory, and its length is therefore the base-two logarithm of the number of memory words; and I assume six flip-flops are sufficient to control the memory, and provide timing signals for accepting data and addresses from an external processor for turning the various drivers on and off, for strobing the output of the sense amplifiers into the data register, and for delivering data up to the requesting processor. Line 27 is the sum of lines 28 through 30.

31-33. Line 31 is the component and interconnect cost of a flip-flop and its associated gating, derived directly from Table 4.11.8. Packaging and power costs for the digital electronics, and for other parts of the memory, will be considered below.

**Power.** 34. Driver power requirements are a function of

**TABLE II 4.13.2 ELECTRONICS AND OTHER COSTS OF TYPICAL MEMORIES**

| Line | Item | Units | 1955 | 1960 | 1965 | 1970 | 1972 |
|---|---|---|---|---|---|---|---|
| | **Drivers** | | | | | | |
| 1. | Number of Transformers | | 64 | 128 | | | |
| 2. | Transformer Cost | $ | 2.50 | 1.80 | | | |
| 3. | Total Cost | $ | 160 | 230 | | | |
| 4. | Per 1 k Cores | $/k | 13 | 2.50 | | | |
| 5. | Number of Switches | | | | 64 | 672 | 64 |
| 6. | Switch Cost | $ | | | 10 | 3 | 1 |
| 7. | Total Cost | $ | | | 640 | 2016 | 64 |
| 8. | Per 1 k Cores | $/k | | | 4.30 | 6.83 | .43 |
| 9. | Number of Diodes | | | | 256 | 3328 | 384 |
| 10. | Diode Unit Cost | $ | | | .12 | .10 | .05 |
| 11. | Total Cost | $ | | | 31 | 333 | 19 |
| 12. | Diode Insert/Solder Time | sec. | | | 36 | 36 | 6 |
| 13. | Labor Cost | $ | | | 20 | 46 | 1 |
| 14. | Total Diode Cost | $ | | | 51 | 379 | 20 |
| 15. | Per 1 k Cores | $/k | | | .40 | 1.29 | .14 |
| 16. | Number of Inhibit Drivers | | 12 | 24 | 36 | 0 | 18 |
| 17. | Inhibit Driver Cost | $ | 20 | 15 | 10 | 3 | 1 |
| 18. | Total Cost | $ | 240 | 360 | 360 | | 18 |
| 19. | Per 1 k Cores | $/k | 20 | 3.50 | 2.40 | | .12 |
| 20. | Total Driver Costs | $ | 400 | 590 | 1051 | 2395 | 102 |
| 21. | Per 1 k Cores | $/k | 33 | 6 | 7.10 | 8.12 | .69 |
| | **Sense Amplifiers** | | | | | | |
| 22. | Maximum Cores Per S.A. | | 1024 | 2048 | 4096 | 8192 | 8192 |
| 23. | Number of Sense Amplifiers | | 12 | 48 | 36 | 36 | 18 |
| 24. | Sense Amplifier Cost | $ | 175 | 110 | 30 | 5 | 1.5 |
| 25. | Total Cost | $ | 2100 | 5280 | 1080 | 180 | 27 |
| 26. | Per 1 k Cores | $/k | 171 | 54 | 7.30 | .61 | .18 |
| | **Digital Electronics** | | | | | | |
| 27. | Total Flip-Flops | | 28 | 42 | 54 | 38 | 37 |
| 28. | Data Register | | 12 | 24 | 36 | 18 | 18 |
| 29. | Address Register | | 10 | 12 | 12 | 14 | 13 |
| 30. | Control | | 6 | 6 | 6 | 6 | 6 |
| 31. | Component & Interconnect Cost | $/FF | 82 | 40 | 30 | 11.20 | 2.90 |
| 32. | Total Digital Electronics Cost | $ | 2296 | 1680 | 1620 | 426 | 107.30 |
| 33. | Per 1 k Cores | $/k | 187 | 17.10 | 11.00 | 1.44 | 0.73 |
| | **Power** | | | | | | |
| 34. | Driver Unit Power | watts | 20 | 6.7 | 3.3 | 6 | 2 |
| 35. | Total Power | watts | 240 | 160 | 120 | 108 | 36 |
| 36. | Sense Amplifier Unit Power | watts | 40 | 5 | 1.2 | .2 | .2 |
| 37. | Total Power | watts | 480 | 240 | 45 | 7 | 4 |
| 38. | Digital Electronics Unit Power | watts/FF | 11.8 | 3.275 | 0.83 | 0.305 | 0.22 |
| 39. | Total Power | watts | 330 | 138 | 45 | 12 | 8 |
| 40. | System Total Power | watts | 1050 | 538 | 210 | 127 | 48 |
| 41. | Power Per Bit | mw. | 85 | 5.5 | 1.4 | .43 | .33 |
| 42. | Memory Power Cost | $ | 363 | 221 | 138 | 147 | 34 |
| 43. | Per 1 k Cores | $/k | 29 | 2 | 0.94 | 0.50 | 0.23 |
| | **Packaging** | | | | | | |
| 44. | Total Volume | in.$^3$ | 9600 | 9275 | 4345 | 4348 | 744 |
| 45. | Electronics | in.$^3$ | 4200 | 5500 | 2500 | 3200 | 240 |
| 46. | Magnetics | in.$^3$ | 675 | 1350 | 900 | 576 | 288 |
| 47. | Power | in.$^3$ | 2625 | 1350 | 525 | 318 | 120 |
| 48. | Cooling System | in.$^3$ | 2100 | 1075 | 420 | 254 | 96 |
| 49. | Cabinet Volume | ft.$^3$ | 22.2 | 21.5 | 10.1 | 10.1 | 1.72 |
| 50. | Cabinet Cost | $ | 80 | 96 | 48 | 64 | 12 |
| 51. | Module Mount Cost | $ | 385 | 551 | 282 | 470 | 40 |
| 52. | Cooling System Cost | $ | 52 | 27 | 13 | 10 | 4 |
| 53. | Total Package Cost | $ | 517 | 674 | 343 | 544 | 56 |
| 54. | Per 1 k Cores | $/k | 42 | 7 | 2.35 | 1.84 | 0.38 |
| | **System Assembly & Test** | | | | | | |
| 55. | Assembly/Test Time | hrs. | 640 | 1280 | 360 | 120 | 4 |
| 56. | Labor Cost/hr. With OH | $ | 8.43 | 10.08 | 11.70 | 15.47 | 17.42 |
| 57. | Costs | $ | 5400 | 12900 | 4200 | 1855 | 70 |
| 58. | Per 1 k Cores | $/k | 440 | 130 | 28.60 | 6.29 | 0.47 |
| 59. | **Storage Density** | kBy./ft.$^3$ | 0.09 | 0.744 | 2.380 | 3.17 | 9.30 |

driver current and voltage, duty cycle, and the number of drivers simultaneously delivering power. For 3D memories, most of the driver power is associated with the inhibit drivers, since only one X and one Y driver are turned on at a time. For the 2 1/2D memory, the X drivers are the critical factor; and since they are used both for selection and for "inhibition", their duty cycle is substantially higher than that of the inhibit drivers. Early (1955) cores required a one ampere drive for switching, but subsequent cores have only required 400ma. Finally, changes in electronic technology have led to continual reductions in power supply voltages. The net result of these various factors is a reduction in driver unit power from 20 to 2 watts between 1955 and 1972.

35. Total power is found by multiplying line 34 by the number of bits per word, since the latter determines how many drivers are turned on simultaneously.

36-37. The sense amplifier unit power has dropped substantially as the circuits were simplified and new technology were introduced. Total power is found by multiplying line 36 by the total number of sense amplifiers (line 23 above).

38-39. Digital electronic power per flip-flop, shown in line 38, comes from Table 4.11.8. Total digital power is the product of line 38 and the total flip-flops per memory, line 27.

40-41. System total power is the sum of driver, sense amplifier, and digital electronics power.

42-43. Memory power supply costs are calculated using the formulas of Section 4.11—that is to say, assuming that memory power cost per watt is the same as cost per watt for digital electronics. To the extent that older memories often require several voltages, together with power supply regulation automatically tied to magnetics temperature, the numbers on lines 42 and 43 are understated. Because of its compactness, and because new memories can often share power supplies with other system components, I computed 1972 power requirements based on a flat charge which was determined by assuming that the fixed component of power supply cost—see discussion in Section 4.11—is apportioned equally to all subsystems in a cabinet. However, since earlier memories occupied a substantial fraction of a large cabinet, and since they often required special power, I charged them with the entire fixed cost and used the power cost formula directly.

**Packaging.** 44-49. Electronics volume is the estimated module volume occupied by drivers, sense amplifiers, and digital electronics. Magnetics volume comes from Table 4.13.1, and is based on the actual dimensions of the array of cores. Power supply and cooling system volumes are computed from power requirements on line 40, using the formulas from Section 4.11 on general electronics costs. Total volume is the sum of these four components, in cubic inches. Cabinet volume, in cubic feet, is estimated at four times line 44. I thus make the same assumption here I made in Section 4.11 regarding unused space within a cabinet unit.

50-54. Cabinet, cooling system, and module mount costs are computed using the formulas of Section 4.11. I assumed that the 1955 and 1960 systems occupied complete cabinets, but that the later systems shared cabinets with other equipment, so that the fixed component of a 24 cubic foot cabinet is allocated to the memory. Module mount costs are based on the assumption that module volume Vm is given by line 45. The electronics for the five systems are assumed to require 6, 8, 4, 5, and 0.34 module mounts, respectively. Total package cost is the sum of cabinet, cooling system, and module mount costs.

**System Assembly and Test.** 55-58. Early systems required extraordinarily long system assembly and test times, for reasons which were discussed in Part I. For the earliest systems, the standard deviation for test time was very large, so that some systems might be wrapped up in four man-weeks where other identical ones might take 40. The assumed labor cost per hour is from line 5 of Table II.4.11.1.

**Storage Density.** 59. Gross storage density is the quotient of memory capacity in kilobytes and cabinet volume from line 49. For the years 1955-1965 a byte was assumed to be six bits; for 1970-1972, a byte was nine bits (eight plus one parity bit.)

## II.4.2 Development Costs

### TABLE II.4.21.1 DEVELOPMENT COSTS FOR A $100,000 PROCESSOR—NOTES

**Manufacturing Cost.** The cost per flip-flop is from Table 4.11.8. It assumes a system contains flip-flops and gates only, and that there are an average of seventeen gates per flip-flop. The cost figures include component costs (for flip-flops and gates), interconnect costs, power costs, packaging costs, and system assembly and test costs. The $20,000 figure for the cost of a $100,000 system is my own estimate of the proportion of these direct manufacturing costs to the sales price—20%. The difference between this figure and the "cost of sales" figures included in the manufacturer's report to his stockholders (typically 40% to 70% of *revenues*, as shown in the tables of Section 1.3 for different manufacturers) is partly due to the fact that "cost of sales" is not well defined and includes other things beside direct material, labor, and overhead; and is partly due to the fact that "cost of sales" figures represent the average of a variety of products, of which all-electronic assemblies are typically among the most profitable.

**Product Complexity.** The number of flip-flops per system is the ratio of the second line to the first. The number of components, plug-in modules, signal pins, and cabinets are derived from corresponding data in Table II.4.11.2, taking into account the computed number of flip-flops in a $100,000 system. The number of "logical elements" is derived from the data given in the notes to lines 17-25 of Table II.4.11.2. When systems were constructed from diodes, transistors, etc., the logic elements which the designer used in conceiving his product were individual flip-flops and gates. And since we assumed seventeen gates per flip-flop, the number of logical elements in pre-1970 systems was eighteen times the number of flip-flops in the system. With the introduction of the IC, designers had available much larger building blocks. For example, the 100-flip-flop system manufactured in 1970 is assumed to have been assembled from 84 individually-wired flip-flops and attendant gates together with 16 flip-flops and gates in a regular array in four IC packages. The number of logic elements per 100 flip-flops was thus $18 \times 84 + 4 = 1516$ in 1970.

Note that I assume no difference in product cost or complexity resulting from the minimum and the maximum (i.e. "substantial", to use the terminology of Table 4.21.2) development program. In fact, it could be argued that a minimum technology development project undoubtedly would provide a technology with a higher cost per flip-flop than that shown; and a minimum product development project would also result in a number of flip-flops larger than that shown (to perform the functions required of a $100,000 processor) because the designers would not have time enough to optimize the design.

**Project Data.** Project duration and the average number of engineers assigned to a project are estimates based on recollections of my own personal experience. I have more confidence in the reasonableness of the 1970 figures than I have in the others. The complexity of the $100,000 processor, as measured by number of flip-flops or logic elements, has increased greatly, but simultaneously the productivity of designers has improved. For example, in 1955 typically the block-diagram design was manually converted to wiring lists which were then used by assembly workers who soldered wires between connectors. These manual operations were time-consuming, and resulted in numerous errors (in addition to the engineers' design errors) which had to be located and corrected during system test. By 1972 Design Automation systems automatically converted the designers' logic into punched cards used to control an automatic wire-wrap machine. This conversion, and the use of the automatic machine, reduced the manpower devoted to preparing wire lists, the elapsed time required to construct a prototype, the wiring errors in that prototype, and consequently the test time. I have derived the figures on total project resources from the estimated number of logic elements in the processor by assuming that productivity *as measured by logic elements completed per man-month* has improved at a fairly uniform rate over the years—see the note on productivity, below.

The breakdown of project resources into its various component parts is also based on my personal experience. Note that the importance of maintainability and reliability led to increased emphasis on diagnostics and maintenance documentation, and to the concept of the product verification test. The latter is not feasible in a project having very limited resources, and in minimum projects the project engineer must therefore try to represent the maintenance group's point of view in planning and conducting system tests.

**TABLE II.4.21.1 DEVELOPMENT COSTS FOR A $100,000 PROCESSOR**

| | Units | 1955 | | 1960 | | 1965 | | 1970 | | 1974 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| Manufacturing Cost—per f/f | $ | 102 | | 53.6 | | 34.1 | | 12.8 | | 2.04 | |
| For $100k System | $k | 20 | | 20 | | 20 | | 20 | | 20 | |
| Product Complexity—No. f/f | | 196 | | 373 | | 587 | | 1563 | | 9804 | |
| Number of Components | | 15092 | | 28721 | | 45199 | | 6252 | | 12745 | |
| No. of Logical Elements | | 3528 | | 6714 | | 10566 | | 23695 | | 92158 | |
| No. of Plug-in Circuits | | 1139 | | 1094 | | 915 | | 829 | | 137 | |
| No. of Signal Pins | | 10229 | | 19632 | | 26944 | | 55217 | | 20315 | |
| No. of Cabinets | | 3.4 | | 2.5 | | 1.3 | | 1.2 | | 1.6 | |
| Project Duration | mo. | 24 | 33 | 24 | 32 | 20 | 30 | 24 | 32 | 33 | 45 |
| Average Project Engineers | | 5 | 7.5 | 5 | 7.5 | 5 | 7 | 5 | 7.5 | 7 | 10 |
| Project Resources—Total | mm | 120 | 248 | 120 | 240 | 102 | 208 | 120 | 240 | 231 | 450 |
| Project Plan | mm | 1 | 2 | | | | | | | 2 | 3 |
| System Design | mm | 8 | 15 | | | | | | | 15 | 22 |
| Detailed Design | mm | 56 | 127 | | | | | | | 116 | 150 |
| Diagnostic Prog. Design | mm | 11 | 14 | | | | | | | 36 | 111 |
| Test | mm | 25 | 53 | | | | | | | 41 | 70 |
| Documentation | mm | 19 | 37 | | | | | | | 21 | 67 |
| Product Verification | mm | - | - | | | | | | | 0 | 27 |
| Special Circuits—No. Req'd. | | 5 | 5 | 5 | 5 | 5 | 5 | 10 | 10 | 20 | 20 |
| Engineering Time/Circ. | mm | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 2 | 4 |
| Circuit Design Resources . | mm | 5 | 10 | 5 | 10 | 5 | 10 | 10 | 20 | 40 | 80 |
| Total Development Resources | mm | 125 | 258 | 125 | 250 | 107 | 218 | 130 | 260 | 271 | 530 |
| Productivity—Logical Elements | le/mm | 28.2 | 13.7 | 54 | 27 | 99 | 48 | 182 | 91 | 340 | 174 |
| Flip-Flops | ff/mm | 1.6 | 0.76 | 3.0 | 1.5 | 5.5 | 2.7 | 12 | 6 | 36 | 18 |
| Total Project Cost | $k | 328 | 676 | 375 | 750 | 380 | 774 | 573 | 1147 | 1466 | 2867 |
| Per Logical Element | $ | 93.0 | 191.6 | 55.9 | 111.7 | 36.0 | 73.3 | 24.2 | 48.4 | 15.9 | 31.1 |
| Per Flip-Flop | $k | 1.67 | 3.45 | 1.01 | 2.01 | 0.65 | 1.32 | 0.37 | 0.73 | 0.15 | 0.29 |
| Technology Development | $k | 89 | 1148 | 102 | 1314 | 121 | 1555 | 128 | 1843 | 130 | 2153 |
| Project and Tech. Dev. Cost | $k | 417 | 1824 | 477 | 2064 | 501 | 2329 | 701 | 2990 | 1596 | 5020 |

**Special Circuits.** As was indicated in Table 4.21.2, some unique circuits were generally required for projects in early pre-IC days. Typically such circuits implemented special logic functions where regular arrays of flip-flops and/or gates were required, and where one special plug-in module could do the work of two to four of the general-purpose modules. With the advent of integreated circuits the opportunities for such savings increased and more special circuits were requested by the project. And with the large-card MSI implementation hypothesized for 1974, all 82 plug-in cards were specially designed for the project, and I estimated there were 20 different card types. The engineering time required to design these large cards is my estimate, and assumes the existence of a design automation system with facilities which help the designer with layout and documentation.

**Total Resources and Productivity.** Total development resources is the sum of project and circuit design resources. Productivity is the quotient of the number of logic elements or the number of flip-flops and total resources in man-months. Note that productivity based on logic elements increases in a regular fashion. As mentioned above, I based the history of project resource requirements on the assumption that this measure of productivity has been improving steadily. Total project cost is found by multiplying total development resources by the burdened cost per man-month from Table 4.21.1, and cost per logic element and per flip-flop are again found by dividing by the number of elements and flip-flops. Technology development cost for the years through 1965 is the product of total technology man-months, from Table 4.21.2, and cost per man-month again from Table 4.21.1. For 1970, however, I used only half of the circuit design man-months included in Table 4.21.2 and for 1974, none of those man-months, since the use of IC's reduced and then eliminated the general-purpose logic cards. The final cost figure in the table is the sum of project and technology development costs.

## TABLE 4.22.1 SOFTWARE DEVELOPMENT OVERHEAD—NOTES

The data on programmer, systems analyst, secretary, and clerk salaries comes from Table II.1.4.3. Managers' salaries are estimated to be 50% greater than that of those managed, and technical writers' salaries are assumed to be the same as that of technicians. Fringe benefit percentages are from Table 4.21.1. The ratio of programmers to systems analysts (0.58 to 0.42) is the 1.4 to 1 ratio used in Table II.1.4.2.

## TABLE II.4.22.1 PROGRAMMING RESOURCES REQUIRED—NOTES

This table is copied directly from NelsE67, pages 66-67.

## TABLE II.4.22.2 ANALYSES OF PROGRAM DEVELOPMENT EFFORT—NOTES

Source (1) is L. Fried, "Estimating the Cost of System Implementation," in *Data Processing Magazine*, April, 1969. He reports the results of several other surveys. Source (2) is BoehB73, and source (3) is BrooF74. Source (4) is WolvR72, and I have combined his "Analysis" and "Design" categories.

## TABLE II.4.22.3 PROGRAMMING PRODUCTIVITY—NOTES

1-4. The percentage of programming done in machine-oriented languages is estimated from Figure 2.15.1. Man-months per 1000 instructions, on lines 2 and 3, are estimated assuming a uniform improvement rate of 3.5% per year, and assuming the SDC study data (NelsE67, Table II.4.22.1) represented 1964 productivity. The 3.5% per year, which corresponds to an improvement of 100% in 20 years, was arbitrarily chosen to reflect the various improvements in programming productivity. Line 4 is the weighted average of lines 2 and 3, using the weight of line 1.

5-7. These lines are the reciprocals of lines 2-4.

8-15. The rates on lines 8 and 9 are from Table 4.22.1. The costs per object instruction, lines 10-15, were found by dividing cost per man-month, lines 8 and 9, by instructions per man-month, lines 5-7.

16-21. Lines 16 and 17 were estimated assuming a uniform improvement rate of 7.18% per year, and assuming the SDC study data (NelsE67, Table II.4.22.1) represented 1964 productivity. The 7.18% per year, which corresponds to an improvement of 300% in 20 years, was arbitrarily chosen as representing a reasonable reflection of the many changes which have taken place in computer use during program development, and reflects my supposition that efficiency in computer use has improved more rapidly than efficiency of manpower usage. Line 18 is the weighted average of lines 16 and 17, and lines 19-21 are the reciprocals of lines 16-18.

22-25. Line 22 represents average (U.S.) costs of operating a GP computer system, *not* including the costs of systems analyst or programmer salaries. It was computed from the data in Table II.3.25.5 by taking total operating cost per month, dividing by the number of systems, subtracting monthly systems analyst and programmer costs, and dividing by the number of operating hours per month—all of which data appears in Table II.3.25.5. Lines 23-25 were computed by dividing operating cost per hour, from line 22, by instructions per hour, from lines 19-21.

26-31. The total costs shown on these lines are the sums of the appropriate pairs of programmer costs (lines 10-15) and computer operating costs (lines 23-25).

**TABLE II 4.22.1 PROGRAMMING RESOURCES REQUIRED PER 1000 SOURCE OR OBJECT INSTRUCTIONS**

| Type of Computer Program | Man-Months per 1000 Instructions Mean | S.D. | Median | Max. | Min. | Computer Hours per 1000 Inst. Mean | S.D. | Median | Max. | Min. | Number of Programs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Per 1000 Source Instructions | | | | | | |
| By Language | | | | | | | | | | | |
| Machine-Oriented | 6.34 | 10.30 | 4.00 | 100.00 | 0.15 | 31.39 | 45.78 | 15.00 | 331.3 | 0.23 | 123 |
| Procedure-Oriented | 8.20 | 10.36 | 3.57 | 46.25 | 0.27 | 31.96 | 42.97 | 15.59 | 211.6 | 1.18 | 46 |
| Fortran | 12.75 | 14.59 | 4.09 | 38.46 | 1.33 | 43.75 | 71.75 | 11.97 | 211.5 | 1.24 | 8 |
| Jovial | 10.27 | 12.01 | 6.15 | 46.25 | 2.13 | 47.60 | 41.94 | 33.11 | 137.0 | 2.67 | 15 |
| COBOL | 4.83 | 7.53 | 2.68 | 28.00 | 0.27 | 18.08 | 31.68 | 7.17 | 115.0 | 1.18 | 12 |
| Other POL | 5.73 | 5.10 | 3.23 | 16.67 | 0.57 | 17.18 | 13.77 | 12.90 | 42.7 | 2.77 | 11 |
| By Application | | | | | | | | | | | |
| Business | 5.75 | 8.27 | 2.73 | 46.25 | 0.15 | 20.59 | 27.34 | 8.11 | 115.0 | 0.23 | 79 |
| Scientific | 6.85 | 7.96 | 4.44 | 38.46 | 0.57 | 30.67 | 50.69 | 10.44 | 211.5 | 0.25 | 27 |
| Utility | 10.43 | 18.80 | 5.75 | 100.00 | 0.50 | 62.71 | 74.34 | 38.19 | 331.3 | 2.53 | 28 |
| Other | 6.46 | 5.11 | 4.63 | 24.50 | 1.49 | 32.00 | 28.58 | 25.00 | 129.0 | 3.86 | 35 |
| By Computer Size | | | | | | | | | | | |
| Large | 7.94 | 11.99 | 4.75 | 100.00 | 0.19 | 36.14 | 50.84 | 18.72 | 331.3 | 0.23 | 105 |
| Medium | 4.62 | 5.15 | 3.05 | 28.00 | 0.15 | 22.34 | 33.29 | 8.70 | 177.8 | 1.25 | 53 |
| Small | 7.11 | 10.75 | 4.00 | 38.82 | 1.23 | 32.05 | 23.73 | 34.69 | 80.0 | 1.11 | 11 |
| Total Sample | 6.85 | 10.31 | 4.00 | 100.00 | 0.15 | 31.54 | 44.91 | 15.00 | 331.3 | 0.23 | 169 |
| | | | | | Per 1000 Object Instructions | | | | | | |
| By Language | | | | | | | | | | | |
| Machine-Oriented | 5.89 | 10.18 | 4.00 | 100.00 | 0.14 | 29.52 | 42.75 | 15.00 | 294.0 | 0.05 | 123 |
| Procedure-Oriented | 2.13 | 2.61 | 1.16 | 9.49 | 0.07 | 9.76 | 13.74 | 2.86 | 52.5 | 0.30 | 46 |
| Fortran | 2.75 | 3.88 | 0.97 | 9.49 | 0.11 | 10.25 | 18.02 | 2.68 | 50.7 | 0.31 | 8 |
| Jovial | 3.07 | 2.31 | 2.50 | 7.60 | 0.66 | 17.73 | 15.06 | 16.67 | 52.5 | 0.77 | 15 |
| COBOL | 1.25 | 2.53 | 0.49 | 9.33 | 0.07 | 5.25 | 10.70 | 1.80 | 38.3 | 0.30 | 12 |
| Other POL | 1.36 | 1.57 | 0.57 | 4.10 | 0.12 | 3.45 | 3.86 | 2.43 | 14.5 | 0.31 | 11 |
| By Application | | | | | | | | | | | |
| Business | 3.13 | 5.11 | 1.54 | 38.82 | 0.07 | 11.95 | 17.93 | 3.09 | 80.0 | 0.23 | 79 |
| Scientific | 3.55 | 2.90 | 3.14 | 12.00 | 0.14 | 17.78 | 28.52 | 4.83 | 140.0 | 0.05 | 27 |
| Utility | 9.79 | 18.83 | 5.28 | 100.00 | 0.49 | 57.36 | 68.30 | 38.18 | 294.0 | 1.06 | 28 |
| Other | 5.89 | 4.16 | 4.20 | 17.65 | 0.66 | 30.00 | 28.42 | 20.98 | 129.0 | 3.86 | 35 |
| By Computer Size | | | | | | | | | | | |
| Large | 5.50 | 10.51 | 3.17 | 100.00 | 0.07 | 26.72 | 42.47 | 12.50 | 294.0 | 0.05 | 105 |
| Medium | 3.19 | 3.09 | 2.54 | 16.67 | 0.12 | 17.57 | 30.22 | 5.20 | 177.8 | 0.31 | 63 |
| Small | 6.97 | 10.81 | 4.00 | 38.82 | 0.93 | 31.14 | 24.51 | 34.69 | 80.0 | 1.09 | 11 |
| Total Sample | 4.87 | 8.94 | 2.93 | 100.00 | 0.07 | 24.14 | 38.16 | 10.44 | 294.0 | 0.05 | 169 |

**TABLE II.4.22.2 ANALYSES OF PROGRAM DEVELOPMENT EFFORT**

| Source (See Note) | Percent of Total Program Development Man-Months — Including Documentation: Program Design | Coding | Check | Documentation | Excluding Documentation: Program Design | Coding | Check |
|---|---|---|---|---|---|---|---|
| Delaney (1) | 25. | 31. | 31. | 13. | 29. | 36. | 36. |
| RCA (1) | 30. | 20. | 45. | 5. | 32. | 21. | 47. |
| Brandon (1)–Simple | 11. | 11. | 50. | 28. | 15. | 15. | 69. |
| Average | 27.5 | 24.0 | 34.5 | 14.0 | 32. | 28. | 40. |
| Complex | 30. | 27. | 33. | 10. | 33. | 30. | 37. |
| Test Group (1)–Autocoder | 11.9 | 30.0 | 39.9 | 18.2 | 15. | 37. | 49. |
| Assembler | 7.3 | 29.4 | 46.9 | 16.4 | 9. | 35. | 56. |
| Informatics (4) | 36. | 16. | 32. | 16. | 43. | 19. | 38. |
| Raytheon (4) | 40. | 25. | 25. | 10. | 44. | 28. | 28. |
| TRW (4) | 40. | 24. | 28. | 8. | 43. | 26. | 30. |
| SAGE (2) | | | | | 39. | 14. | 47. |
| NTDS (2) | | | | | 30. | 20. | 50. |
| Gemini (2) | | | | | 36. | 17. | 47. |
| Saturn V (2) | | | | | 32. | 24. | 44. |
| OS/360 (2) | | | | | 33. | 17. | 50. |
| Brooks (3) | | | | | 33.3 | 16.7 | 50.0 |
| Average | 25.8 | 23.7 | 36.5 | 14.0 | 30.9 | 24.0 | 45.1 |

**TABLE II.4.22.3 PROGRAMMING PRODUCTIVITY**

| | | Units | 1955 | 1960 | 1965 | 1970 | 1972 | 1974 |
|---|---|---|---|---|---|---|---|---|
| | MOL/POL Usage | | | | | | | |
| 1. | Percent Machine-Oriented Language | % | 100 | 95 | 58 | 26 | 18 | 14 |
| | Program Productivity | | | | | | | |
| | Effort per 1000 Object Instr. | | | | | | | |
| 2. | MOL Programs | mm | 8.03 | 6.76 | 5.69 | 4.79 | 4.47 | 4.18 |
| 3. | POL Programs | mm | - | 2.44 | 2.06 | 1.73 | 1.62 | 1.51 |
| 4. | Average U.S. | mm | 8.03 | 6.54 | 4.17 | 2.53 | 2.13 | 1.88 |
| | Instructions per Man-Month | | | | | | | |
| 5. | MOL | | 125 | 148 | 176 | 209 | 224 | 239 |
| 6. | POL | | | 410 | 485 | 578 | 617 | 662 |
| 7. | Average U.S. | | 125 | 153 | 240 | 395 | 470 | 532 |
| | Costs, Including Overhead | | | | | | | |
| 8. | User Programmer | $k/mo. | .85 | .98 | 1.27 | 1.73 | 1.93 | 2.13 |
| 9. | Supplier Programmer | $k/mo. | 1.14 | 1.43 | 1.91 | 2.70 | 3.03 | 3.35 |
| | Cost per Object Instruction | | | | | | | |
| 10. | User—MOL | $ | 6.80 | 6.62 | 7.22 | 8.28 | 8.62 | 8.91 |
| 11. | POL | $ | | 2.39 | 2.62 | 2.99 | 3.13 | 3.22 |
| 12. | Average U.S. | $ | 6.80 | 6.41 | 5.29 | 4.38 | 4.11 | 4.00 |
| 13. | Supplier—MOL | $ | 9.12 | 9.66 | 10.85 | 12.92 | 13.53 | 14.02 |
| 14. | POL | $ | | 3.49 | 3.94 | 4.67 | 4.91 | 5.06 |
| 15. | Average U.S. | $ | 9.12 | 9.35 | 7.96 | 6.84 | 6.45 | 6.30 |
| | Computer Usage | | | | | | | |
| | Hours per 1000 Object Instr. | | | | | | | |
| 16. | MOL Programs | hrs. | 55.09 | 38.95 | 27.54 | 19.48 | 16.95 | 14.76 |
| 17. | POL Programs | hrs. | | 12.88 | 9.11 | 6.44 | 5.61 | 4.88 |
| 18. | Average U.S. | hrs. | 55.09 | 37.64 | 19.80 | 9.83 | 7.65 | 6.26 |
| | Instructions per Computer Hour | | | | | | | |
| 19. | MOL | | 18.15 | 25.67 | 36.31 | 51.33 | 59.00 | 67.75 |
| 20. | POL | | | 77.64 | 109.8 | 155.3 | 178.3 | 204.9 |
| 21. | Average U.S. | | 18.15 | 26.57 | 50.50 | 101.7 | 130.7 | 159.7 |
| | Computer Operating Costs | | | | | | | |
| 22. | Total Costs Excluding SA&P | $/hr. | 82.92 | 58.05 | 52.93 | 71.46 | 76.31 | 85.48 |
| 23. | Per Object Instruction—MOL | $ | 4.57 | 2.26 | 1.46 | 1.39 | 1.29 | 1.26 |
| 24. | POL | $ | - | 0.75 | 0.48 | 0.46 | 0.43 | 0.42 |
| 25. | Average U.S. | $ | 4.57 | 2.19 | 1.05 | 0.70 | 0.58 | 0.54 |
| | Cost Summary | | | | | | | |
| 26. | User—MOL | $ | 11.37 | 8.88 | 8.68 | 9.67 | 9.91 | 10.17 |
| 27. | POL | $ | - | 3.14 | 3.10 | 3.45 | 3.56 | 3.64 |
| 28. | Average U.S. | $ | 11.37 | 8.60 | 6.34 | 5.08 | 4.69 | 4.54 |
| 29. | Supplier—MOL | $ | 13.69 | 11.92 | 12.31 | 14.31 | 14.82 | 15.28 |
| 30. | POL | $ | - | 4.24 | 4.42 | 5.13 | 5.34 | 5.48 |
| 31. | Average U.S. | $ | 13.69 | 11.54 | 9.01 | 7.54 | 7.03 | 6.84 |

**TABLE II.4.22.4 PROGRAM MAINTENANCE FACTORS**

| | | Symbol | Units | Application Programs | | Operating System | |
|---|---|---|---|---|---|---|---|
| 1. | Program Size | P | Instruct. | 2000 | 20,000 | 100,000 | 40,000 |
| 2. | Error Incidence | $\epsilon$ | | .005 | .005 | .001 | .0039 |
| 3. | Initial Errors | | | 10 | 100 | 100 | 156 |
| 4. | Computer Raw Speed | | kop/sec. | 100 | 100 | 100 | 1200 |
| 5. | CPU Time on Program | | % | 65 | 65 | 15 | 15 |
| 6. | Effective Speed | C' | kop/sec | 65 | 65 | 15 | 180 |
| 7. | Program Time/Week | | hours | 1/3 | 1 | 84 | 100 |
| 8. | Number of Partitions | | | 3 | 3 | - | - |
| 9. | Actual Program Usage | u | | .000661 | .00198 | 0.500 | 0.595 |
| 10. | Time Constant | | months | 13.63 | 45.49 | 3.90 | 0.109 |
| 11. | Initial Error Rate | dn/dt | Err./mo. | 0.7339 | 2.198 | 25.62 | |
| 12. | Time to Fail | | weeks | 5.90 | 1.97 | 0.17 | |
| 13. | Rewrite Factor | w | | 5 | 5 | 5 | |
| 14. | Initial Rewrite Rate | | %/mo. | 0.183 | 0.055 | 0.128 | |
| 15. | Instructions | | Instr./mo. | 3.67 | 11.0 | 128 | |

### TABLE II.4.22.4 PROGRAM MAINTENANCE FACTORS—NOTES

This table provides notes on the assumptions made in applying the formulas of Figure 4.22.14 to four programs run on two different computers. Each of the four columns describes a different program. The first two are applications programs run on a computer comparable to the IBM 370/135. The third represents an operating system run on the same computer, and the fourth an operating system run on a Univac 1108.

1-3. These rows describe assumptions made about the programs. The applications programs are assumed to have initial error incidences of 5 per 1000 machine instructions. The large operating system is presumed to have been better checked out, starting with only one error per thousand instructions. The Univac 1108 operating system seemed to have around 156 errors when installed (see Table II.2.23.10 and Figure 4.22.18), which corresponds to 3.9 errors per thousand instructions.

4-6. The computer raw speed is assumed to be 100,000 operations per second for the first three columns. For the Univac 1108, the raw speed is computed assuming a mixture of 95% additions and 5% multiplications. "CPU time on the program" is based on the assumption that the CPU is idle 20% of the time, spends 15% of its time in the operating system, and the remaining 65% of its time executing user programs (see e.g. Table 2.23.5). The effective speed on line 6 is the product of lines 4 and 5.

7-9. For the first three columns, program time per week is assumed. For the last column, the weekly operating time of 20 hours per day, five days per week, was established in conversation with the authors of LyncW75. The multiprogramming partitions for the application programs (line 8) are assumed. The actual program usage on line 9 is found by dividing line 7 by line 8 and then dividing that result by 168, the total number of hours in a week.

10-12. The time constant is computed from the formula in Figure 4.22.14 (P/kuC'), as is the initial error rate ($\epsilon$kuC'). I use a value for k ($1.3/10^6$) from MusaJ75, and assume a month contains 2,628,000 seconds. The initial mean time to failure, on line 12, is the reciprocal of line 11. Note that the time constant for the Univac 1108 system is only 0.109 months. The experimental data indicates a time constant of *eight* months, and the discrepancy is so great I don't bother to compute the other factors.

13-15. I assume five instructions must be written (or rewritten) to correct an error. The number of instructions which must be rewritten per month initially is then five times line 11, and the percentage is that result divided by line 1.

## II.4.3 Sales and Marketing Costs

### TABLE 4.3.1 THE GROWTH IN IBM SALES AND SERVICE—NOTES

1-5. The reported number of salesmen, systems engineers, and customer engineers (or servicemen) is from IBM Prospectuses dated May 21, 1957, and May 31, 1966. Note I assume the figures given are for the year prior to the date of the prospectus. The total number of employees comes from Table II.1.311. Line 3 is the quotient of lines 1 and 2, and lines 4 and 5 show the percent increases in lines 1 and 2 for the nine-year period.

6-7. Total revenue, and that portion of total revenue attributed by IBM to data processing is from Table II.1.311, which in turn comes from IBM annual reports.

8. The total value of GP and minisystems ordered worldwide is from Table II.1.31.1, line 126. It assumes that orders in a given year are equal to the average of the shipment values in that year and in the next year. To compute U.S. orders, I assumed they bore the same relationship to worldwide orders as U.S. revenues did to worldwide revenues.

9. The total value of IBM computers in use worldwide is from Table II.1.31.1, line 85. The value in use in the U.S. is computed by multiplying the number in use in the U.S., from line 1 of Table II.1.31.1, by the average value worldwide, from line 112 of the same table. Note there is a discrepancy here: the U.S. count is for GP systems only, the worldwide one includes IBM's "minisystems".

10-13. These percentage increases, again for the nine-year period, are computed from the data on lines 6-9.

14-15. The estimated number of salesmen and sales engineers per million dollars in orders received is an estimate based on reports that an IBM salesman and two or three systems engineers have had an average order goal of $500,000 to $1 million; and on the assumption that sales productivity remained fairly constant in the period covered here. Line 15 is the product of line 14 and line 8.

16-17. The estimated number of customer engineers required per $1 million value of equipment in use is from Table II.4.4.5, line 25. Total customer engineers on line 17 is the product of lines 16 and 9.

18-20. Line 18 is the sum of lines 15 and 17. Line 19 is the quotient of lines 18 and 1, and line 20 the quotient of lines 18 and 2.

## II.4.4 Maintenance Costs

### TABLE II.4.4.1 IBM MAINTENANCE PRICES (1971)—NOTES

The purchase price and monthly maintenance price shown in the first two columns come from an IBM price catalogue dated November 1971. The third column is the ratio of the second to the first, multiplied by 100. CRP stands for card reader/punch, R for card reader, P for card punch, and cpm for cards per minute.

### TABLE II.4.4.2 SYSTEM PRICES IN 1967—NOTES

The data in this table comes from, or is derived from, a compilation of price information from GSA Price Schedules for the period July 1, 1966 through June 30, 1967 (SharW69, pp. 270-277). The first section of the table shows, for each manufacturer, the number of devices included in the sample. The second portion shows the price-rental ratios, and the third the monthly maintenance price per $100,000 sales price for each of the classes of device and for each manufacturer.

The number of devices in the sample and the price-rental ratios are given directly in the referenced book. The maintenance price was derived from data given in the book in the following way. Sharpe provides a table showing the ratio of purchase price to total rental, and another table showing the ratio of purchase price to "pure rental" which is equal to total rental per month less maintenance price per month. It can be shown that the maintenance price per $100,000 sales price is the difference between the reciprocals of Sharpe's ratios, times 100,000.

**TABLE II.4.4.1 IBM MAINTENANCE PRICES (1971)**

| | Purchase Price ($k) | Monthly Maintenance ($/mo.) | Maint. Price Per $100k ($/mo.) |
|---|---|---|---|
| **Magnetic Tape Units** | | | |
| 2401 Single Tape Drive | | | |
| 2401-1 (37.5 ips, 800 bpi) | 12.9 | 62 | 481 |
| -2 (75.0 ips, 800 bpi) | 18.7 | 70 | 374 |
| -3 (112.5 ips, 800 bpi) | 30.3 | 86 | 284 |
| -4 (37.5 ips, 1600 bpi) | 14.8 | 74 | 500 |
| -5 (75.0 ips, 1600 bpi) | 20.6 | 82 | 398 |
| -6 (112.5 ips, 1600 bpi) | 32.2 | 98 | 304 |
| -8 (75.0 ips, 7-track) | 13.6 | 85 | 625 |
| 2402 Double Drive | | | |
| 2402-1 (37.5 ips, 800 bpi) | 23.8 | 120 | 504 |
| -2 (75.0 ips, 800 bpi) | 35.5 | 136 | 383 |
| -3 (112.5 ips, 800 bpi) | 58.6 | 168 | 287 |
| -4 (37.5 ips, 1600 bpi) | 27.6 | 144 | 522 |
| -5 (75.0 ips, 1600 bpi) | 39.3 | 160 | 407 |
| -6 (112.5 ips, 1600 bpi) | 62.5 | 192 | 307 |
| 3410/3420 Single Tape Drives | | | |
| 3410-1 (12.5 ips, 1600 bpi) | 7.7 | 45 | 584 |
| -2 (25.0 ips, 1600 bpi) | 10.3 | 50 | 485 |
| -3 (50.0 ips, 1600 bpi) | 12.8 | 55 | 430 |
| 3420-3 (75 ips, 1600 bpi) | 13.6 | 50 | 368 |
| -5 (125 ips, 1600 bpi) | 18.2 | 55 | 302 |
| -7 (320 ips, 1600 bpi) | 22.4 | 65 | 290 |
| **Control Units** | | | |
| 2821 For Card Units & Printers | | | |
| 2821-1 (1 CRP, 1 Printer) | 37.2 | 41 | 110 |
| -2 (1 Printer) | 23.0 | 32 | 139 |
| -3 (2 Printers) | 46.1 | 64 | 139 |
| -4 (1 CRP, 1 Printer) | 40.3 | 44 | 109 |
| -5 (1 CRP, 2 Printers) | 60.2 | 73 | 121 |
| -6 (1 CRP) | 12.7 | 90 | 709 |
| 2803 For Magnetic Tape Units | | | |
| 2803-1 (8 2401-1 to -3's) | 26.1 | 20 | 77 |
| -2 (8 2401-4 to -6's) | 32.1 | 25 | 78 |
| -3 (8 2401-8's) | 15.3 | 30 | 196 |
| **Card Equipment** | | | |
| 1442-5 (P 90 cpm) | 12.4 | 52 | 419 |
| -6 (R 300, P 45 cpm) | 14.1 | 55 | 390 |
| -7 (R 400, P 90 cpm) | 15.3 | 65 | 425 |
| -N1 (R 400, P 90 cpm) | 25.5 | 81 | 318 |
| -N2 (P 90 cpm) | 18.2 | 71 | 390 |
| 2520-A1 (R 500, P 500 cpm) | 31.5 | 98 | 311 |
| -A2 (P 500 cpm) | 28.2 | 93 | 330 |
| -A3 (P 300 cpm) | 27.9 | 72 | 258 |
| -B1 (R 500, P 500 cpm) | 39.5 | 151 | 382 |
| -B2 (P 500 cpm) | 35.0 | 142 | 406 |
| -B3 (P 300 cpm) | 34.7 | 114 | 329 |

TABLE II.4.4.2 SYSTEM PRICES IN 1967

| | | BGH | CDC | GE | HIS | IBM | NCR | RCA | XDS | Univac | All |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number in Sample** | | | | | | | | | | | |
| Processors with Core | | 0 | 7 | 13 | 25 | 43 | 1 | 17 | 0 | 10 | 116 |
| Processors, No Core | | 3 | 5 | 7 | 0 | 9 | 4 | 0 | 14 | 5 | 47 |
| Core | | 7 | 8 | 13 | 0 | 5 | 5 | 0 | 6 | 12 | 56 |
| Controller | | 2 | 7 | 8 | 3 | 14 | 4 | 13 | 3 | 17 | 71 |
| Magnetic Tape | | 5 | 4 | 8 | 7 | 27 | 6 | 8 | 2 | 9 | 76 |
| Punched Card Units | | 5 | 1 | 7 | 4 | 11 | 3 | 7 | 3 | 6 | 47 |
| Printers | | 4 | 2 | 3 | 3 | 2 | 5 | 6 | 2 | 2 | 29 |
| Head-Per-Track Files | | 0 | 1 | 4 | 2 | 2 | 0 | 2 | 0 | 5 | 16 |
| Moving-Head Files | | 5 | 4 | 2 | 0 | 5 | 0 | 0 | 2 | 0 | 18 |
| Mass Storage | | 0 | 0 | 2 | 0 | 1 | 3 | 1 | 0 | 0 | 7 |
| All Devices | | 31 | 39 | 67 | 44 | 119 | 31 | 54 | 32 | 66 | 483 |
| **Price/Rental Ratios** | | | | | | | | | | | |
| Processors with Core | | - | 37.87 | 50.39 | 44.88 | 42.99 | 45.00 | 50.00 | - | 38.19 | 44.55 |
| Processors, No Core | | 48.00 | 35.96 | 44.05 | - | 41.97 | 62.06 | - | 31.57 | 38.95 | 40.32 |
| Core | | 48.00 | 38.37 | 43.15 | - | 46.18 | 46.73 | - | 33.98 | 42.66 | 42.57 |
| Controller | | 48.00 | 43.06 | 42.40 | 44.30 | 49.20 | 45.53 | 50.03 | 35.86 | 39.33 | 44.61 |
| Magnetic Tape | | 48.00 | 45.86 | 40.90 | 44.70 | 48.67 | 41.35 | 47.01 | 37.50 | 37.05 | 44.87 |
| Punched Card Units | | 49.73 | 32.84 | 42.27 | 44.00 | 53.46 | 55.55 | 50.03 | 36.00 | 33.42 | 46.10 |
| Printers | | 56.29 | 44.60 | 45.33 | 42.20 | 45.05 | 47.60 | 50.00 | 36.06 | 31.18 | 46.40 |
| Head-Per-Track Files | | - | 50.91 | 44.45 | 43.98 | 43.33 | - | 50.00 | - | 42.00 | 44.59 |
| Moving-Head Files | | 50.35 | 38.96 | 47.56 | - | 41.21 | - | - | 36.30 | - | 43.41 |
| Mass Storage | | - | - | 46.53 | - | 48.75 | 42.25 | 50.43 | - | - | 45.57 |
| All Devices | | 49.73 | 40.14 | 44.61 | 44.64 | 46.05 | 48.02 | 49.57 | 33.79 | 38.84 | 44.20 |
| **Maint. Price Per $100k** | | | | | | | | | | | |
| Processors with Core | $/mo | - | 273 | 226 | 152 | 104 | 81 | 80 | - | 453 | 161 |
| Processors, No Core | $/mo | 364 | 221 | 107 | - | 73 | 200 | - | 516 | 393 | 268 |
| Core | $/mo | 59 | 227 | 120 | - | 127 | 30 | - | 509 | 170 | 157 |
| Controller | $/mo | 193 | 303 | 130 | 220 | 74 | 175 | 80 | 405 | 367 | 187 |
| Magnetic Tape | $/mo | 414 | 483 | 299 | 434 | 262 | 507 | 298 | 685 | 529 | 361 |
| Punched Card Units | $/mo | 525 | 500 | 475 | 547 | 312 | 271 | 280 | 636 | 822 | 430 |
| Printers | $/mo | 376 | 644 | 505 | 548 | 264 | 320 | 280 | 647 | 1038 | 429 |
| Head-Per-Track Files | $/mo | - | 286 | 250 | 230 | 408 | - | 280 | - | 206 | 277 |
| Moving-Head Files | $/mo | 325 | 278 | 476 | - | 227 | - | - | 508 | - | 336 |
| Mass Storage | $/mo | - | - | 339 | - | 348 | 410 | 159 | - | - | 339 |
| All Devices | $/mo | 334 | 334 | 251 | 284 | 185 | 269 | 173 | 543 | 403 | 272 |

## TABLE II.4.4.3 MAINTENANCE COST MODEL EXAMPLE, 1970—NOTES

This table shows the assumptions and calculations made in applying the maintenance cost model to a system containing three kinds of products: electromechanical peripherals, electronic CPU/Memories, and low-cost terminals.

**System Parameters.** 1-3. I assume an average peripheral sells for $30K, a CPU/Memory increment for $100K, and a terminal for $5K. I further assume a system worth $500K contains nine peripherals, $200K in CPU/Memory, and six terminals.

**Cost Factors.** 4-9. The CE's salary comes from Table II.1.4.3, for the year 1970. The overhead rate, intended to cover field costs not explicitly included in the model, I assume was 175% in 1970. In other words, in addition to the CE's salary, another amount 1.75 times his salary was spent as fringe benefits, supervision, technical support, travel, tools, office space, clerical help, etc. This does not include the home-office costs of managing and supporting the maintenance organization. The total burdened salary cost is the hourly rate multiplied by 2.75 and then divided by f, the proportion of the CE's time available for CM and PM.

The monthly cost of supporting an inventory of spare parts I assume to be 3.5% of the cost of those parts. This figure is the sum of a depreciation of 2% per month, an interest charge of 1% per month, and a handling charge of 0.5% per month. Operating hours per month are essentially two shifts, five days per week.

**Spare Parts.** 10. For reference purposes, I show the manufacturing cost of a unit on line 10, estimated at 25% of its selling price. The spares inventory associated with a unit will be much less than this cost for various reasons—the cost includes system assembly and test labor, for example, and items like frames and chassis which need not be kept in spares inventory. In addition, each unit contains parts which are repeated in that unit and which may be common to other units of different kinds—circuit modules, fans, and power supply subassemblies are examples.

11-14. Typically some spares are located at the equipment site and some are available from a local depot which serves many sites. The total value of spares at each location is a function of the number of units at the site, and in the area served by the depot. The figures given on lines 11-12 are my assumptions about the cost of spares *per unit* at the site and depot—there would be 9x422 = $3.8k worth of peripheral spares and 2x850 = $1.7K of processor spares on site. The peripheral spares complement was calculated assuming the nine peripherals were of four different types (for example, a card reader/punch, a line printer, 2 head-per-track files, and 5 tape units) and this allows for sharing of spares. Note I assume there are no spares at the various (remote) sites where the terminals reside, though there might be local spares if all six terminals were at one site. Line 13 is the sum of lines 11 and 12, and line 14 is the quotient of line 13 and line 1 expressed in units of $100K.

15-16. The inventory costs are the product of the inventories on lines 13 and 14 and the cost rate on line 8. Note: the system costs shown in the right-hand column of these and later lines will be discussed in connection with lines 40-46 below.

17-18. When a failure is cured, a spare part is often, though not always, required. That spare may be repairable, or may have to be scrapped and replaced. Line 17 is the cost of repairing or replacing the average part. I assume the terminal parts are generally more costly than processor or peripheral parts, consisting of large electronic modules or large assemblies.

The estimated hourly cost of the parts used in repair, on line 18, is based on the repair/replace cost of line 17, on the estimated proportion of maintenance actions which require a part, and on the maintenance time required, including travel. The latter figures were taken from lines 21, 22, 32, and 33 below. The hourly cost for terminal parts is substantially higher than that for peripheral and processor parts because parts repair is more expensive, the probability of using a part is high, and the repair time for a terminal is short.

**Preventive Maintenance.** 19. The hourly rate for maintenance is the sum of the CE's hourly rate on line 7 and the spare parts hourly cost on line 18. This hourly rate will apply to corrective as well as to preventive maintenance.

20-24. I assume that PM is applied only to the peripherals—preventive maintenance on electronic equipment is generally not worthwhile, and PM on low-cost equipment like terminals is not economically feasible and should not be necessary. The 90 hours PM interval was arbitrarily chosen—we discussed the criteria which should be used in making a choice in Part I. The PM time is short, and PM travel time is short because it can be planned in advance and because it can be apportioned among several units at a site, all of which undergo PM during a single visit. Line 23 is the sum of lines 21 and 22 divided by line 20, and line 24 is line 23 divided by line 1 and multiplied by 100.

25-26. The monthly PM cost is the hourly rate on line 19 multiplied by the PM hours per month, which in turn is the product of the operating hours on line 9 and the percent PM time on line 23 or line 24.

**TABLE II.4.4.3 MAINTENANCE COST EXAMPLE-1970 ●**

| | | Symbol | Units | Peripheral | CPU and Memory | Terminal | System |
|---|---|---|---|---|---|---|---|
| | **System Parameters** | | | | | | |
| 1 | Unit Value | V | $k | 30 | 100 | 5 | |
| 2 | Number per System | | | 9 | 2 | 6 | |
| 3 | Value per System | | $k | 270 | 200 | 30 | 500 |
| | **Cost Factors** | | | | | | |
| 4 | CE Hourly Rate | S | $/hr | 4.83 | 4.83 | 4.83 | 4.83 |
| 5 | Overhead Rate | r | | 1.75 | 1.75 | 1.75 | 1.75 |
| 6 | CE Fraction Available | f | | 0.65 | 0.65 | 0.65 | 0.65 |

**TABLE II.4.4.3 MAINTENANCE COST EXAMPLE-1970 (continued)** ●

| | | Symbol | Units | Peripheral | CPU and Memory | Terminal | System |
|---|---|---|---|---|---|---|---|
| 7 | Burdened Salary | | $/hr | 20.43 | 20.43 | 20.43 | 20.43 |
| 8 | Inventory Cost | 100C | %/mo. | 3.5 | 3.5 | 3.5 | 3.5 |
| 9 | Operating Hours | H | hr/mo. | 350 | 350 | 350 | 350 |
| | **Spare Parts** | | | | | | |
| 10 | Unit Manufacturing Cost | | $k | 7.5 | 25 | 1.25 | 125 |
| 11 | Spares Inventory-Local | | $ | 422 | 850 | 0 | |
| 12 | At Depot | | $ | 400 | 1900 | 50 | |
| 13 | Total | I | $ | 822 | 2750 | 50 | |
| 14 | Per $100k | | $k | 2.74 | 2.75 | 1.00 | 2.64 |
| 15 | Inventory Cost per Mo | | $/mo | 28.8 | 96.3 | 1.75 | 462.3 |
| 16 | Per $100k | | $/mo | 95.9 | 96.3 | 35.0 | 92.5 |
| 17 | Average Part Cost | | $ | 15 | 15 | 20 | |
| 18 | Hourly Parts Cost | P | $/hr | 3.0 | 3.0 | 10.0 | 3.8 |
| | **Preventive Maintenance** | | | | | | |
| 19 | Total Hourly Rate | R | $/hr | 23.4 | 23.4 | 30.4 | 24.2 |
| 20 | Scheduled PM Interval | T(p) | hrs. | 90 | - | - | |
| 21 | CE PM Time | T(rp) | hrs. | 0.25 | - | - | |
| 22 | CE PM Travel Time | T(tp) | hrs. | 0.20 | - | - | |
| 23 | Percent PM Time | | % | 0.50 | - | - | |
| 24 | Per $100k | | % | 1.67 | - | - | 0.9 |
| 25 | Monthly PM Cost | | $/mo | 41.0 | - | - | 369.0 |
| 26 | Per $100k | | $/mo | 136.5 | - | - | 73.8 |
| | **Fixed Costs/$100k** | | | | | | |
| 27 | PM | | $/mo | 136.5 | | | 73.8 |
| 28 | Inventory | | $/mo | 95.9 | 96.3 | 35.0 | 92.5 |
| 29 | Total | | $/mo | 232.4 | 96.3 | 35.0 | 166.3 |
| | **Incremental Cost** | | | | | | |
| 30 | Per % Downtime | RxH | $/mo | 81.9 | 81.9 | 106.4 | 84.5 |
| | **Typical Costs** | | | | | | |
| 31 | MTBF | T(f) | hrs | 750 | 1000 | 2000 | 58.8 |
| 32 | MTTR | T(rf) | hrs | 1.5 | 3.0 | 0.5 | 1.50 |
| 33 | CM Travel Time | T(tf) | hrs | 1.0 | 1.0 | 1.0 | 1.0 |
| 34 | Percent CM Time | | % | 0.33 | 0.40 | 0.075 | 4.25 |
| 35 | Per $100k | | % | 1.11 | 0.40 | 1.50 | 0.85 |
| 36 | CM Cost | | $/mo | 27.3 | 32.8 | 8.0 | 359.3 |
| 37 | Per $100k | | $/mo | 91.0 | 32.8 | 160.0 | 71.9 |
| 38 | Total Cost | | $/mo | 97.1 | 129.1 | 9.8 | 1190.3 |
| 39 | Per $100k | | $/mo | 323.4 | 129.1 | 195.0 | 238.1 |
| | **System Values** | | | | | | |
| 40 | PM Cost | | $/mo | 369.0 | - | - | 369.0 |
| 41 | Inventory Cost | | $/mo | 258.9 | 192.6 | 10.5 | 462.0 |
| 42 | Total Fixed Costs | | $/mo | 627.9 | 192.6 | 10.5 | 831.0 |
| 43 | CM Cost | | $/mo | 245.7 | 65.6 | 48.0 | 359.3 |
| 44 | Total Cost | | $/mo | 873.6 | 258.2 | 58.5 | 1190.3 |
| 45 | Failures per Month | | | 4.2 | 0.7 | 1.05 | 5.95 |
| 46 | Repair Time per Month | | | 6.3 | 2.1 | .525 | 8.925 |
| 47 | CE Hours per Month-PM | | hr/mo | 15.75 | 0 | 0 | 15.75 |
| 48 | CM | | hr/mo | 10.50 | 2.8 | 1.575 | 14.875 |
| 49 | Total | | hr/mo | 26.25 | 2.8 | 1.575 | 30.625 |
| 50 | Direct Labor Cost | | $/mo | 126.8 | 13.5 | 7.6 | 147.9 |
| 51 | Indirect Labor Cost | | $/mo | 68.3 | 7.3 | 4.1 | 79.7 |
| 52 | Labor Overhead Cost | | $/mo | 340.8 | 36.4 | 20.5 | 397.7 |
| 53 | Total Labor Cost | | $/mo | 535.9 | 57.2 | 32.2 | 625.3 |
| 54 | Parts Cost | | $/mo | 78.8 | 8.4 | 15.8 | 103.0 |
| 55 | Inventory Cost | | $/mo | 258.9 | 192.6 | 10.5 | 462.0 |
| 56 | Total Cost | | $/mo | 873.6 | 258.2 | 58.5 | 1190.3 |
| | Percent Distribution | | | | | | |
| 57 | Direct Labor | | % | 14.5 | 5.2 | 13.0 | 12.4 |
| 58 | Indirect Labor | | % | 7.8 | 2.8 | 7.0 | 6.7 |
| 59 | Labor Overhead | | % | 39.1 | 14.1 | 35.0 | 33.4 |
| 60 | Parts Cost | | % | 9.0 | 3.3 | 27.0 | 8.6 |
| 61 | Inventory Cost | | % | 29.6 | 74.6 | 17.9 | 38.8 |
| 62 | Total | | % | 100.0 | 100.0 | 100.0 | 99.9 |
| 63 | Labor Cost | | % | 85.7 | 9.1 | 5.1 | 99.9 |
| 64 | Parts Cost | | % | 76.5 | 8.2 | 15.3 | 100.0 |
| 65 | Inventory Cost | | % | 56.0 | 41.7 | 2.3 | 100.0 |
| 66 | Total Cost | | % | 73.4 | 21.7 | 4.9 | 100.0 |

**Fixed Costs.** 27-29. We will take the point of view that total maintenance costs are the sum of certain fixed costs and of other costs which vary with the reliability and maintainability of the equipment—with MTBF and MTTR. In this very simple model, the fixed costs are then PM and inventory costs, and the variable costs are CM labor and parts costs. Lines 27 and 28 thus repeat lines 26 and 16, and line 29 is their sum.

**Incremental Cost.** 30. The incremental cost of a one percent increase in down time is the product of R and H, lines 19 and 9, divided by 100.

**Typical Cost.** 31-35. These lines show the possible maintenance parameters for a specific family of devices. Lines 31-33 are arbitrarily chosen, line 34 is the quotient of lines 32 plus 33 and 31, and line 35 is line 34 divided by line 1, multiplied by 100.

36-37. CM cost is the product of the incremental cost on line 30 and the percent CM time on lines 34 and 35.

38-39. Total cost is the sum of fixed and incremental costs. Line 38 is found by adding together lines 15, 25, and 36; line 39 by adding lines 29 and 37.

**System Values.** This section of the table shows costs for the system described by lines 1-3, and makes it possible to compute the parameters shown in the "System" column of the table.

40-42. These lines show the total fixed costs of a complete system. The inventory costs of peripherals in line 41, for example, is found by multiplying nine peripherals (line 2) by $28.8 per month (line 15). Line 42 is the sum of lines 40 and 41, and the entry in the "System" column on each line is the sum of the peripherals, processor, and terminal entries on that line. The total system fixed costs per $100K, shown in lines 27-29 above, were found by dividing the system figures on lines 40-42 by 5, the number of $100K in the total system (line 3).

43-44. The CM cost is similarly found by multiplying entries on line 36 by those on line 2. Total cost is the sum of CM and fixed costs, with the "System" figures in each case being the sum of figures in the three other columns. The "System" figures on lines 37 and 39 above were found by dividing the "System" figures on lines 43 and 44 by the ratio of $500K to $100K.

45-46. The number of unit failures per month is computed from lines 2, 9, and 31. For example, there are 350/750 = 0.47 failures per month for each peripheral, or 9x0.47 = 4.2 failures in total. The total repair time for those peripherals (line 46) is found by multiplying 4.2 by 1.5, the average repair time from line 32. "System" totals are the sum of peripherals, processor, and terminal failures and repair times. System MTBF on line 31 is found by dividing the 350-hour month by 5.95 failures; and system MTTR on line 32 is the quotient of 8.925 repair hours (line 46) and 5.95 failures. Percent system CM time, or lines 34 and 35, is computed from the system figures in lines 31-33.

System incremental cost, on line 30, is found by dividing the system CM Cost on line 36 by the percent CM time on line 34.

47-49. Total PM and CM hours per month are computed from PM and CM percentages on lines 24 and 35, taking into account operating hours on line 9 and the unit value per system on line 3.

50-53. The direct labor cost is the CE's salary cost for time actually spent on maintenance, and is found by multiplying line 49 by line 4. Indirect labor cost is also part of the CE's salary cost, and represents an allocation of the 35% of his time he spends on training, paperwork, etc. (Line 50 is 65% of the sum of lines 50 and 51.) Line 52 is the cost of the overhead applicable to the CE's salary, and is the product of the overhead rate on line 5 and the sum of lines 50 and 51. Line 53 is the sum of lines 50 through 52.

54-56. The parts cost is the product of the total CE hours on line 49 and the hourly parts cost on line 18. The inventory cost is copied from line 41. And total cost is the sum of lines 53 through 55.

57-66. These percentages are computed from lines 50 to 56. Note that the columns in lines 57 to 61 sum to 100%, while the rows in lines 63 to 66 sum to 100%.

### TABLE II.4.4.4 VARIATIONS IN SYSTEM MAINTENANCE COST—NOTES

The three sections of this table show how the fixed, incremental, and total "typical" cost of system and peripheral maintenance vary with variations in CE time available (f), operating hours, and percent PM time per month (H). The reference or "base case" is shown on the first line of each section of the table, and is the same as that for Table II.4.4.3.

The computations carried out can be deduced from the formula of Figure 4.4.8. Inventory costs remain constant throughout the table. PM and CM costs are inversely proportional to f, and directly proportional to H. PM costs are of course directly proportional to the percent PM time.

### TABLE II.4.4.5. ESTIMATED CHRONOLOGY OF MAINTENANCE COST—NOTES

This table describes a possible chronology of costs for maintaining a $500K system from 1956 to 1974. Fundamentally the estimate is based on fairly well-documented figures for CE hourly rate (line 1) and for computer lost time (line 18), and on my guesses on the changes which have occurred in other factors. The calculation and the format in general are the same as that for Table II.4.4.3.

**Cost Factors.** 1-4. The CE hourly rate is from Table II.1.4.3. The overhead factor is my guess, based on the fact that fringe benefits have increased over the years, and that the average CE has had to be supported by more and better tools and by more technical back up, especially for help on software. The CE fraction of time spent on CM, PM, and travel, line 3, has increased primarily because the increased concentration of computers has increased the equipment complement maintained by the average CE. Line 4 is computed from lines 1-3.

5-6. The inventory cost I estimate has remained fairly constant rising recently with the increased interest rates of the early 70's. Operating hours have increased over the years, and my estimate of that increase appears on line 6.

7-9. Inventories I estimate have recently dropped because of the increasing use of terminals, whose inventory rate per $100K I estimate as being lower than peripherals and processors (see Table II.4.4.3). The hourly parts cost I estimate has recently increased, again because of the increasing use of terminals.

**Fixed Cost.** 10-12. PM Costs have varied with the proportion of system cost devoted to peripherals, and have increased as the importance of PM was appreciated. The costs on line 10 are based on the PM hours per month shown on line 21 below. Line 11 is the same as line 8, and line 12 is the sum of 10 and 11.

**Incremental Cost.** This line is the product of operating hours per month on line 6 and burdened salary plus parts cost, line 4 plus line 9.

**Typical Cost.** 14-16. My estimates of MTBF, MTTR, and travel time are based on what seem to be reasonable figures in the light of maintenance history as described by the data of Tables II.23.6-8. My general supposition is that MTBF and MTTR improved substantially until the mid-60's and have since worsened slightly as system complexity increased and software problems became critical. Travel time meanwhile dropped as computer populations increased.

17-20. These figures were calculated in the same way that similar results were computed in Table II.4.4.3.

**CE Population.** 21-23. The PM hours per month I assumed, taking into account the increasing proportion of peripherals (up to the late 60's) and the increasing importance of PM. CM hours on line 22 are calculated from percent CM time on line 17 and total hours on line 6. Line 23 is the sum of 21 and 22.

24-25. The number of CE hours per month available for CM and PM assumes that the CE has always worked 190 hours per month (about 10% overtime), and takes into account the CE availability fraction on line 3. The number of CEs required per $1M of equipment is then ten times the quotient of lines 23 and 24.

**TABLE II.4.4.4**
**VARIATIONS IN SYSTEM MAINTENANCE COST**

| C.E. Availability f | Percent PM Time % | Operating Hours/mo. hrs. | Fixed Cost $/mo. | Incremental Cost $/mo./% | Typical Total Cost $/mo. |
|---|---|---|---|---|---|
| System | | | | | |
| 0.65 | 0.5 | 350 | 166.3 | 84.5 | 238.1 |
| 0.50 | 0.5 | 350 | 188.4 | 109.9 | 281.8 |
| 0.80 | 0.5 | 350 | 152.5 | 68.7 | 210.9 |
| 0.65 | 0.5 | 175 | 129.4 | 42.3 | 165.4 |
| 0.65 | 0.5 | 525 | 203.2 | 126.8 | 311.0 |
| 0.65 | 0.5 | 700 | 240.1 | 169.0 | 383.8 |
| Peripherals | | | | | |
| 0.65 | 0.5 | 350 | 232.4 | 81.9 | 323.4 |
| 0.65 | 0 | 350 | 95.9 | 81.9 | 186.9 |
| 0.65 | 0.25 | 350 | 164.2 | 81.9 | 255.2 |
| 0.65 | 0.75 | 350 | 300.7 | 81.9 | 391.7 |
| 0.65 | 1.0 | 350 | 368.9 | 81.9 | 459.9 |

**TABLE II.4.4.5 ESTIMATED CHRONOLOGY OF MAINTENANCE COSTS FOR A $500,000 SYSTEM**

| | | Units | 1956 | 1960 | 1965 | 1970 | 1974 |
|---|---|---|---|---|---|---|---|
| | **Cost Factors** | | | | | | |
| 1 | CE Hourly Rate | $/hr | 3.43 | 3.65 | 4.03 | 4.83 | 5.85 |
| 2 | Overhead Rate | | 1.30 | 1.50 | 1.65 | 1.75 | 1.80 |
| 3 | CE Fraction Available | | 0.40 | 0.52 | 0.60 | 0.65 | 0.70 |
| 4 | Burdened Salary | $/hr | 19.72 | 17.55 | 17.80 | 20.43 | 23.40 |
| 5 | Inventory Cost | %/mo | 3.5 | 3.5 | 3.5 | 3.5 | 4.5 |
| 6 | Operating Hours | hrs | 300 | 300 | 325 | 350 | 375 |
| | **Spare Parts** | | | | | | |
| 7 | Inventory per $100k | $k | 2.75 | 2.75 | 2.75 | 2.64 | 2.50 |
| 8 | Cost per Mo/$100k | $/mo | 96.3 | 96.3 | 96.3 | 92.5 | 112.5 |
| 9 | Hourly Parts Cost | $/hr | 3.0 | 3.0 | 3.0 | 3.8 | 5.0 |
| | **Fixed Costs/$100k** | | | | | | |
| 10 | PM | $/mo | 23 | 41 | 62 | 73.8 | 80 |
| 11 | Inventory | $/mo | 96.3 | 96.3 | 96.3 | 92.5 | 112.5 |
| 12 | Total | $/mo | 119.3 | 137.3 | 158.3 | 166.3 | 192.5 |
| | **Incremental Cost** | | | | | | |
| 13 | Per % Downtime | $/mo | 68.16 | 61.65 | 67.6 | 84.5 | 106.5 |
| | **Typical Costs** | | | | | | |
| 14 | MTBF | hrs | 28 | 42 | 65 | 58.8 | 55 |
| 15 | MTTR | hrs | 2.0 | 1.6 | 1.4 | 1.5 | 1.6 |
| 16 | CM Travel Time | hrs | 2.0 | 1.4 | 1.0 | 1.0 | 1.0 |
| 17 | Percent CM Time | % | 14.3 | 7.14 | 3.69 | 4.25 | 4.73 |
| 18 | Per $100k | % | 2.86 | 1.43 | 0.74 | 0.85 | 0.94 |
| 19 | CM Cost per $100k | $/mo | 194.9 | 88.2 | 50.0 | 71.9 | 100.1 |
| 20 | Total Cost per $100k | $/mo | 314.2 | 225.5 | 208.3 | 238.1 | 292.6 |
| | **CE Population** | | | | | | |
| 21 | PM Hours/Mo./$100k | hrs | 1.0 | 2.0 | 3.0 | 3.15 | 2.8 |
| 22 | CM Hours/Mo./$100k | hrs | 8.58 | 4.29 | 2.41 | 2.98 | 3.53 |
| 23 | Total CE Hrs/Mo./$100k | hrs | 9.58 | 6.29 | 5.41 | 6.13 | 6.33 |
| 24 | CE Hours/Mo. on CM/PM | hrs | 76 | 98.8 | 114 | 123.5 | 133 |
| 25 | No. of CE's per $1M | | 1.26 | .64 | .47 | .50 | .48 |

## II.4.5 Life Cycle Costs

### TABLE II.4.5.1. IBM LIFE CYCLE COSTS AND PROFIT—NOTES

Data in this table is from various exhibits made public as a result of the 1973 IBM-Telex trial. The particular reference document is cited as the first entry in the table as an Exhibit Number. Most of the exhibits are highly confidential "Greybacks" which provide a detailed management review of the expected life, costs, profit, and risks associated with a product or a family of products. They represent projections, not histories, though some include data on "status-to-date". All the data shown here is, I believe, for domestic revenues only, and does not include World Trade Corp. sales.

Unfortunately no definitions are provided for many of the terms used, and the numbers should therefore be interpreted with care. The figures generally represent the sum of a "to-date" entry, entries for seven specific years, and a "balance" entry.

**Revenue.** The revenue figures include lease and purchase income, apparently net of any discounts over the expected life of the product. The breakdown of lease and purchase revenue is also given.

**Costs.** All costs are given as a percent of revenue. Manufacturing cost includes a base figure plus an unexplained "Fourth Element" item. Field Engineering costs, detailed at the bottom of the table, include Labor, Parts, Training, and "Other". (An item labelled "ECP" I have included with "Other".) There is no indication as to whether labor is burdened or whether parts cost includes inventory costs or just replacement parts.

What I have called Manufacturing Engineering was labelled "SDD" and includes Development, Prog. (Project?) Engineering, Programming (shown at zero for both processors), SCR (presumed to be Scrap and Rework), and Product Test. "Other" included an item by that name, and another called "Plant and Field Reconditioning", which covers the cost of refurbishing returned equipment so it can be delivered to other customers.

Indirect costs include "Apportionments" and "Contingencies". Apportionment includes Sales, Development, and General and Administrative costs. For the tape units a partial breakdown was given (as shown), again without further definition. One might speculate that the "product cost" apportionment includes such things as QC, factory depreciation, and general Research and Development costs; and that the "Revenue" apportionment includes sales and G and A costs.

**Pre-tax Profit.** This figure is found by subracting total costs (Direct, apportionment, and contingencies) from 100%.

### TABLE II.4.5.2 THEORETICAL LIFE-CYCLE COSTS FOR A $100,000 PROCESSOR—NOTES

**Development Costs.** 1-2. We assume a "substantial" development effort for a new electronic technology, expended over a three-year period. The $2.153M total figure is from Table II.4.21.1, representing 1974 costs. We assume a family of five different processors will share this technology, so only one-fifth of the total cost is applicable to a single processor.

3-5. Hardware development costs are also from Table II.4.21.1 for the year 1974. The relative duration and timing of hardware and technology development are consistent with the schedule shown in Figure 4.21.3. Software development starts at the same time as hardware development, and the software is assumed to be written in a machine-oriented language, at a (1974) cost of $15.28 per instruction (Table II.4.22.3). We assume the five processors share 600,000 lines of code (Figure 1.25.5), and that the development effort stretches over six years, some of it not completed until after the first systems are shipped. The first fifth of the total cost is assumed applicable to this first model in the group of five.

**Shipments.** 6-9. The number of units shipped is arbitrary. The number in use is the cumulative number shipped. The number ordered is derived from the number shipped, assuming an order generally is delivered within 12 to 24 months of the order date. The number of units manufactured is also derived from the number shipped, but assumes equipment is generally delivered within a few months of the time it is shipped.

10-11. The sales value of shipments and orders is found by multiplying the number of units shipped and ordered by $100,000, the assumed price of the processor.

**Costs.** 12-13. Manufacturing costs are derived from line 9 by multiplying by $20,000, the assumed manufacturing cost of the processor. (The $20,000 figure was used in Table II.4.21.1.) Marketing costs are assumed to be 15% of the order value given on line 11.

14. Maintenance costs for the processor are estimated from Table II.4.4.3, which suggests processor and system maintenance costs for 1970, and Figure II.4.4.5, which gives system costs for 1970 and 1974. I assume the processor has a down time of 0.45% per $100k of sales price, and that 1974 fixed costs were $112 per month, variable costs $103 per month per percent down time. This gives a maintenance cost of $158 per month or $1900 per year for the processor. I further assume that all processors in use are maintained by the selling organization, so that total maintenance costs per year are found by multiplying the average number of units in use by $1900. The average number of units in use in a given year is estimated as the average of the number in use at year-end and the number in use at year-end in the previous year.

15-17. Engineers and programmers must be assigned to sustain the technology, the processor design, and the software. From Table II.4.21.1 we find the hardware development to be 530 man-months for the processor and 398 man-months for the technology. Since the development effort took about three years, there must have been about 26 engineers working on it. I assume the sustaining effort started at 10% of this staff, take into account the fact that the technology sustaining effort is divided among five processors, and assume the effort drops off to one percent. In a similar way, we compute that about sixty programmers were at work on new software during the peak development period, and assume the software sustaining effort starts at 20% of that figure and trails off to two percent. It drops more slowly than does the hardware effort because new software development is not completed until the seventh year. The software sustaining personnel applicable to this particular processor are assumed to amount to one-fifth of the total sustaining effort, but weighted toward the early part of the project when this processor is the only member of the family to have been shipped.

18-19. Sustaining costs are found by multiplying the number of personnel, on lines 15 and 17, by the 1974 total costs, including overhead, of engineers (from Table 4.21.1) and supplier programmers (from Table 4.22.1).

**Revenues.** 20-23. Three possible revenue scenarios are shown. Line 20 is computed assuming each system shipped (line 6) is sold for $100,000. If all systems are leased at a price of $27,000 per year, which corresponds to a 44.4:1 ratio of purchase price to monthly rent, and if we assume the lease revenue for a given year is found by multiplying the average number of systems in use at the end of successive years by $27,000, the result is lease revenue as shown in line 21. Lines 22 and 23 show the revenue assuming 70% of the systems in use are leased, the other 30% purchased. Note also that it assumes purchased and leased systems exist in the same relative proportions over the entire period. In practice, the purchased systems might begin to predominate in the later years.

24-25. The above lease price includes a payment for maintenance. However, users who have purchased systems must pay a separate price for maintenance. Line 24 shows the maintenance revenue received if all systems are sold, and line 25 the revenue if only 30% are sold. The maintenance price is assumed to be $220 per month, which covers costs and includes a 15% allowance for general and administrative expenses and a profit of 20%.

**Summary.** 26. Total costs is the sum of development costs (lines 2,3, and 5), manufacturing costs (line 12), marketing expenses (line 13), maintenance costs (line 14), and sustaining costs (lines 18 and 19).

27-30. These lines show the calculations used in determining cumulative gross profit under the assumption all systems are sold. Total revenue, on line 27, is the sum of sales and maintenance revenues, lines 20 and 24. Annual gross profit on line 28 is then the difference between revenue on line 27 and costs on line 26. (Numbers in parenthesis are negative.) This gross profit does not, however, include interest costs. Interest rates, assumed to be 10% per year, are applied each year to half the gross profit for that year and to the full cumulative gross profit at the end of the previous year. The cumulative gross profit for that year is then the sum of the previous cumulative gross profit, the gross profit for that year, and interest charges. For example, in year 4 the interest charge on line 29 is 10% of the sum of $5.46M (the cumulative loss at the end of year 3), and half of $5.31M, the loss for year 4. The cumulative gross profit for year 4 is then the sum of $5.46M, $5.31M, and $0.81M. Note that, when the product becomes profitable, the gross profit is assumed to *earn* interest.

31-37. Lines 31-33 provide cumulative gross profit calculations for the all-processors-leased case, and lines 34-37 for the 70%/30% leased/purchased case.

38-39. Development costs is the sum of lines 2,3, and 5, and sustaining costs the sum of lines 18 and 19.

40-44. These lines are computed by dividing individual costs by the total cost on line 26.

45-52. These lines give the present value, computed with interest at 10% compounded annually, of the revenue and cost data on earlier lines in the table. (I used 5% for the first year, to take into account the fact that costs are incurred more or less uniformly through the year.) The present value of total revenues is $77.2M; of total costs $32.5M.

**Cumulative Data.** The last column in the table shows cumulative expenses and revenues for selected items. It is generally computed by adding together all the items on a given line. However, the cumulative distributions on lines 40-44 show the distribution of individual cumulative costs over total cumulative costs—the "cum." entry on line 40, for example, is the ratio of "cum." entries on lines 38 and 26.

**TABLE II.4.5.1 LIFE CYCLE COSTS AND PROFIT FOR SELECTED IBM EQUIPMENT**

| | | 370 Processors | | Line Printer | Magnetic Tape | | Moving-Head File | | Data Cell |
|---|---|---|---|---|---|---|---|---|---|
| | | /135 | /145 | 3211 | 2401 | 2415 | 2311 | 3330 | 2321 |
| **Reference** | | | | | | | | | |
| IBM-Telex Exhibit Number | | 115 | 116 | 122 | 225 | 225 | 132* | 121 | 132* |
| **Revenue-Total** | $M | 1568 | 2293 | 304 | 1086 | 334 | 802 | 1639 | 83 |
| Lease | % | 84.5 | 75.7 | 81.4 | 78.7 | 90.0 | 93.3 | 80.4 | 93.4 |
| Purchase | % | 15.5 | 24.3 | 18.6 | 21.3 | 10.0 | 6.7 | 19.6 | 6.6 |
| **Costs** | | | | | | | | | |
| Manufacturing | % | 14.1 | 15.5 | 14.2 | 12.3 | 17.7 | 8.9 | 17.6 | 17.3 |
| Field Engineering | % | 7.1 | 10.1 | 13.3 | 11.7 | 20.5 | 4.0 | 7.2 | 10.1 |
| Mfg. Engineering | % | 1.4 | 1.7 | 1.7 | 0.2 | 0.8 | | 1.6 | |
| Other | % | 0.3 | 0.5 | 1.0 | 0.2 | 0.5 | 1.1 | 1.3 | 1.9 |
| Total Direct Costs | % | 22.9 | 27.8 | 30.3 | 24.5 | 39.6 | 14.0 | 27.7 | 29.3 |
| Apportionment-Total | % | 43.1 | 32.3 | 34.7 | 33.6 | 36.3 | 33.0 | 38.5 | |
| Product Cost | % | | | | 7.2 | 10.4 | | | |
| Engineering | % | | | | 0.1 | 0.6 | | | |
| Revenue | % | | | | 26.3 | 25.3 | | | |
| Contingencies | % | 0 | 4.8 | 2.1 | 1.2 | 1.9 | | 0 | |
| Total Costs | % | 66.0 | 64.9 | 67.1 | 59.5 | 77.7 | 47.0 | 66.2 | 64.0 |
| **Pre-Tax Profit** | % | 34.0 | 35.1 | 32.9 | 40.5 | 22.3 | 53.0 | 33.8 | 36.0 |
| **Field Engineering Detail** | | | | | | | | | |
| Labor | % | 5.9 | 7.8 | 11.3 | 9.6 | 15.6 | 3.1 | 5.4 | 4.8 |
| Parts | % | 0.5 | 0.9 | 1.3 | 1.9 | 3.9 | 0.7 | 1.4 | 4.7 |
| Training | % | 0.5 | 1.3 | 0.3 | 0.2 | 1.1 | 0.3 | 0.2 | 0.5 |
| Other | % | 0.2 | 0.1 | 0.3 | - | - | - | 0.2 | - |

* World Trade Corporation Product Pricing. "Manufacturing" Costs are designated "depreciation".

## TABLE II.4.5.2 THEORETICAL LIFE-CYCLE COSTS FOR A $100,000 PROCESSOR

| Line | Item | Figure | Units | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | Cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Development Costs** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Technology Devel.—Total | | $k | 550 | 903 | 700 | | | | | | | | | | | | | | | | | 2153 |
| 2. | Applicable | | $k | 110 | 181 | 140 | | | | | | | | | | | | | | | | | 431 |
| 3. | Hardware Development | | $k | | 700 | 1300 | 867 | | | | | | | | | | | | | | | | 2867 |
| 4. | Software Development—Total | | $k | | 500 | 1500 | 2200 | 2200 | 1768 | 1000 | | | | | | | | | | | | | |
| 5. | Applicable | | $k | | 500 | 1500 | 834 | | | | | | | | | | | | | | | | 2834 |
| | **Shipments** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Number of Units Shipped | 4.5.1 | | | | | 20 | 200 | 300 | 280 | 150 | 50 | | | | | | | | | | | 1000 |
| 7. | Number in Use | 4.5.1 | | | | | 20 | 220 | 520 | 800 | 950 | 1000 | 1000 | 950 | 800 | 600 | 400 | 225 | 75 | 30 | 25 | 20 | |
| 8. | Number of Units Ordered | | | | | 40 | 280 | 300 | 230 | 125 | 25 | | | | | | | | | | | | 1000 |
| 9. | Number of Units Manufactured | | | | | | 60 | 220 | 300 | 250 | 170 | | | | | | | | | | | | 1000 |
| 10. | Sales Value—Shipments | | $M | | | | 2 | 20 | 30 | 28 | 15 | 5 | | | | | | | | | | | 100 |
| 11. | Orders | | $M | | | 4 | 28 | 30 | 23 | 12.5 | 2.5 | | | | | | | | | | | | 100 |
| | **Costs** | | | | | | | | | | | | | | | | | | | | | | |
| 12. | Manufacturing Costs | 4.5.3 | $k | | | | 1200 | 4400 | 6000 | 5000 | 3400 | | | | | | | | | | | | 20,000 |
| 13. | Marketing Expenses | 4.5.3 | $k | | | 600 | 4200 | 4500 | 3450 | 1875 | 375 | | | | | | | | | | | | 15,000 |
| 14. | Maintenance Costs | 4.5.3 | $k | | | | 19 | 228 | 703 | 1254 | 1663 | 1853 | 1900 | 1853 | 1663 | 1330 | 950 | 594 | 285 | 100 | 52 | 43 | 14,490 |
| 15. | Sustaining Personnel—Hardware | | | | | | 1.5 | 2 | 1.5 | 1 | .5 | .5 | | | | | | | | | | | |
| 16. | Software—Total | | | | | | 3 | 12 | 12 | 10 | 8 | 6 | 4 | 3 | 2 | 2 | 1 | 1 | 1 | | | | |
| 17. | Applicable | | | | | | 3 | 2 | 2 | 2 | 2 | 1 | 1 | | | | | | | | | | |
| 18. | Sustaining Costs—Hardware | | $k | | | | 97 | 130 | 97 | 65 | 32 | 32 | | | | | | | | | | | 453 |
| 19. | Software | | $k | | | | 121 | 80 | 80 | 80 | 80 | 40 | 40 | | | | | | | | | | 521 |
| | **Revenues** | | | | | | | | | | | | | | | | | | | | | | |
| 20. | All Systems Sold | | $M | | | | 2 | 20 | 30 | 28 | 15 | 5 | | | | | | | | | | | 100 |
| 21. | All Systems Leased | | $M | | | | .27 | 3.24 | 9.99 | 17.82 | 23.63 | 26.33 | 27.00 | 26.33 | 23.63 | 18.90 | 13.50 | 8.44 | 4.05 | 1.42 | .74 | .61 | 205.90 |
| 22. | Thirty Percent Sold | 4.5.2 | $M | | | | .60 | 6.00 | 9.00 | 8.40 | 4.50 | 1.50 | | | | | | | | | | | 30.00 |
| 23. | 70%Leased | 4.5.2 | $M | | | | .19 | 2.27 | 6.99 | 12.47 | 16.54 | 18.43 | 18.90 | 18.43 | 16.54 | 13.23 | 9.45 | 5.91 | 2.84 | .99 | .52 | .43 | 144.13 |
| 24. | Maintenance—All Sold | | $M | | | | .03 | .32 | .98 | 1.74 | 2.31 | 2.57 | 2.64 | 2.57 | 2.31 | 1.85 | 1.32 | .83 | .40 | .14 | .07 | .06 | 20.14 |
| 25. | 30% Sold | | $M | | | | .01 | .10 | .29 | .52 | .69 | .77 | .79 | .77 | .69 | .56 | .40 | .25 | .12 | .04 | .02 | .02 | 6.04 |
| | **Summary** | | | | | | | | | | | | | | | | | | | | | | |
| 26. | Costs-Total | 4.5.2 | $k | 110 | 1381 | 3540 | 7338 | 9338 | 10330 | 8274 | 5550 | 1925 | 1940 | 1853 | 1663 | 1330 | 950 | 594 | 285 | 100 | 52 | 43 | 56,596 |
| 27. | All Sold-Total Rev. | | $M | | | | 2.03 | 20.32 | 30.98 | 29.74 | 17.31 | 7.57 | 2.64 | 2.57 | 2.31 | 1.85 | 1.32 | .83 | .40 | .14 | .07 | .06 | 120.14 |
| 28. | Gross Profit | | $M | (.11) | (1.38) | (3.54) | (5.31) | 10.98 | 20.65 | 21.47 | 11.76 | 5.65 | 0.70 | .72 | .65 | .52 | .37 | .24 | .11 | .04 | .02 | .02 | 63.56 |
| 29. | Interest | | $M | (.01) | (.08) | (.34) | (.81) | (.61) | .91 | 3.11 | 5.08 | 6.46 | 7.42 | 8.24 | 9.13 | 10.10 | 11.15 | 12.30 | 13.55 | 14.91 | 16.40 | 18.05 | |
| 30. | Cum. Gross Profit | 4.5.4 | $M | (.12) | (1.58) | (5.46) | (11.58 | (1.21) | 20.35 | 44.93 | 61.77 | 73.88 | 82.00 | 90.96 | 100.74 | 111.36 | 122.88 | 135.42 | 149.08 | 164.03 | 180.45 | 198.52 | |
| 31. | All Leased—Gross Profit | | $M | (.11) | (1.38) | (3.54) | (7.07) | (6.10) | (.34) | 9.55 | 18.08 | 24.40 | 25.06 | 24.48 | 21.97 | 17.57 | 12.55 | 7.85 | 3.76 | 1.32 | .69 | .57 | 157.31 |
| 32. | Interest | | $M | (.01) | (.08) | (.34) | (.90) | 1.65) | (2.14) | (1.89) | (.70) | 1.36 | 3.97 | 6.84 | 9.85 | 12.81 | 15.60 | 18.18 | 20.58 | 22.89 | 25.28 | 27.87 | |
| 33. | Cum. Gross Profit | 4.5.4 | $M | (.12) | (1.58) | (5.46) | (13.43 | (21.18 | (23.66 | (16.00 | 1.38 | 27.14 | 56.17 | 87.49 | 119.31 | 149.69 | 177.84 | 203.87 | 228.21 | 252.42 | 278.39 | 306.83 | |
| 34. | 70/30—Total Rev. | | $M | | | | .80 | 8.37 | 16.28 | 21.39 | 21.73 | 20.70 | 19.69 | 19.20 | 17.23 | 13.79 | 9.85 | 6.16 | 2.96 | 1.03 | .54 | .45 | 180.17 |
| 35. | Gross Profit | | $M | (.11) | (1.38) | (3.54) | (6.54) | (.97) | 5.95 | 13.12 | 16.18 | 18.78 | 17.75 | 17.35 | 15.57 | 12.46 | 8.90 | 5.57 | 2.67 | .93 | .49 | .41 | 131.59 |
| 36. | Interest | | $M | (.01) | (.08) | (.34) | (.87) | (1.34) | (1.22) | (.39) | 1.04 | 2.89 | 5.00 | 7.26 | 9.63 | 12.00 | 14.26 | 16.41 | 18.47 | 20.49 | 22.61 | 24.92 | |
| 37. | Cum. Gross Profit | 4.5.4 | $M | (.12) | (1.58) | (5.46) | (12.87 | (15.18 | (10.45 | 2.28 | 19.50 | 41.17 | 63.92 | 88.53 | 113.73 | 138.19 | 161.35 | 183.33 | 204.47 | 225.89 | 248.99 | 274.32 | |
| 38. | Development Costs | 4.5.3 | $k | 110 | 1381 | 2940 | 1701 | | | | | | | | | | | | | | | | 6132 |
| 39. | Sustaining Costs | 4.5.3 | $k | | | | 218 | 210 | 177 | 145 | 112 | 72 | 40 | | | | | | | | | | 974 |
| | Present Values | | | | | | | | | | | | | | | | | | | | | | |
| 45. | Sales Revenue (30%) | | $k | | | | 429 | 3903 | 5322 | 4516 | 2199 | 666 | | | | | | | | | | | 17,035 |
| 46. | Lease Revenue (70%) | | $k | | | | 136 | 1477 | 4134 | 6704 | 8083 | 8188 | 7634 | 6767 | 5521 | 4015 | 2607 | 1482 | 647 | 205 | 98 | 74 | 57,772 |
| 47. | Maintenance Rev. | | $k | | | | 7 | 65 | 171 | 280 | 337 | 342 | 319 | 283 | 230 | 170 | 110 | 63 | 27 | 8 | 4 | 3 | 2419 |
| 48. | Development Costs | | $k | 95 | 1196 | 2314 | 1217 | | | | | | | | | | | | | | | | 4822 |
| 49. | Manufacturing Costs | | $k | | | | 859 | 2862 | 3548 | 2688 | 1662 | | | | | | | | | | | | 11,619 |
| 50. | Marketing Costs | | $k | | | 472 | 3005 | 2927 | 2040 | 1008 | 183 | | | | | | | | | | | | 9635 |
| 51. | Maintenance Costs | | $k | | | | 14 | 148 | 416 | 674 | 813 | 823 | 767 | 680 | 555 | 403 | 262 | 149 | 65 | 21 | 10 | 7 | 5807 |
| 52. | Sustaining Costs | | $k | | | | 156 | 137 | 105 | 78 | 55 | 32 | 16 | | | | | | | | | | 579 |

# Supplement
## Part I

## 1.1a Background

Inflation has become our most serious national problem. What one could buy for $1 in 1958 cost over $2 in 1977 (see Figure 1.1.1a). Nevertheless telephone revenues and electronics industry sales per capita, in uninflated dollars, have more than doubled during that period (Figure 1.1.6b).

In the early Seventies integrated circuits overtook both vacuum tubes and other semiconductor devices in annual sales. Figures 1.1.9a and 1.1.10a show how these sales are distributed. Note that the dollar value of MOS IC's surpassed that of bipolar IC's in 1975. (Note also the discontinuity in data between 1972 and 1973, when the Electronic Industry Association stopped collecting data and the Semiconductor Industry Association began.)

**The Information Economy.** In 1962 Princeton University Press published Fritz Machlup's *The Production and Distribution of Knowledge in the U.S.*, which for the first time identified and tried to quantify that portion of the economy which has to do with the collection, processing, storage, and distribution of information. Many studies, books, and papers have since appeared, stimulated by Machlup's imaginative and pioneering example.

One of the most recent, and surely the most quantitative of these studies (PoraM76), employs U.S. Department of Commerce statistics to measure what the author, Marc Porat, calls the Information Economy. He analyzes the U.S. National Income, and breaks it into two parts. The primary sector, as shown in Table 1.1.1a, consists of those industries whose function is to sell information services or to produce and distribute information machines. And the secondary sector consists of the public and private bureaucracy—the white-collar workers who deal primarily with information. (Note there is no overlap between sectors; the bureaucrats of the secondary sector are those *outside* the primary sector industries). Figure 1.1.11a traces the growth of the information sector since 1929. Since 1965 more than half the National Income has come from the two information sectors. Comparing this figure with the National Income percentages shown in Figure 1.1.4, we observe that the growth of the information economy is associated with growth of the financial, service, and government sectors.

The bulk of the money spent in the information sectors goes for employee compensation (the other components are proprietor's income, corporate profits, and net interest). In Table 1.1.2a we see how that compensation was divided between information workers and non-information workers (the rows), and the information and non-information sectors (the columns). Note that employee compensation in the information sectors accounted for 58.5% of all U.S. compensation, and that the compensation of the information workers alone (leaving out the $26.7B paid to non-information workers in the primary sectors—people like assemblers on a computer manufacturing line, or furniture-makers working on office furniture) was 52.8% of the total or $248.8B.

In Table 1.1.3a these information workers are identified,

**TABLE 1.1.1a THE PRIMARY INFORMATION SECTOR**

| Category | Examples |
|---|---|
| Knowledge Production and Invention Industries | R & D Laboratories<br>Legal, Engineering, Architectural Services<br>Management Consulting Services<br>Accounting and Bookkeeping Services |
| Information Distribution and Communications Industries | Education<br>Libraries<br>Radio and TV Broadcasting<br>Newspaper, Magazine and Book Publishing<br>Motion Picture Production |
| Search and Coordination Industries | Employment Agencies<br>Advertising Industries<br>Political, Business and Labor Organizations |
| Risk Management Industries | Insurance Industries<br>Commercial and Savings Banks<br>Security Brokers |
| Information Processing and Transmission Services | Typesetting<br>Engineering Printing<br>Data Processing Services<br>Telecommunication Industry |
| Information Goods Manufacturing Industries | Paper Industry<br>Photo Equipment and Supplies<br>Pencils, Pens and Other Marking Devices<br>Paper Industry Machinery<br>Printing Industry Machinery<br>Optical Instruments and Lenses<br>Phonograph Records<br>Electronic Components<br>Computers<br>Radio and TV Sets<br>Laboratory and Scientific Instruments<br>Construction of Office, School, and Communications Buildings<br>Furnishings for Office Buildings |
| Trade in Information Goods | Bookstores<br>Camera Stores<br>Radio and TV Stores<br>Motion-Picture Theaters |

**TABLE 1.1.2a EMPLOYEE COMPENSATION DISTRIBUTION IN 1967 ($B)**

| | Information Sectors | | | Non-Info | Tot. Empl. |
|---|---|---|---|---|---|
| | Primary | Second. | Total | Sectors | Compen. |
| Information Workers' Income | 109.4<br>(23.2%) | 139.4<br>(29.6%) | 248.8<br>(52.8%) | 0* | 248.8<br>(52.8%) |
| Non-Information Workers' Income | 26.7<br>(5.7%) | 0 | 26.7<br>(5.7%) | 195.6<br>(41.5%) | 222.3<br>(47.2%) |
| Total Income | 136.1<br>(28.9%) | 139.4<br>(29.6%) | 275.5<br>(58.5%) | 195.6<br>(41.5%) | 471.1<br>(100%) |

*The Information Workers in the Non-Information sectors of the economy are included in the secondary sector.

Notes to Table 1.1.3a on opposite page:

(1) Includes personnel and labor relations, draftsmen and designers, lawyers and judges, social workers and one-half of physicians' compensation

(2) Includes editors, reporters, writers, artists, public-relations

(3) Includes only one-half the compensation of *retail* sales persons

(4) Includes cashiers, bank tellers, billing clerks, and ticket agents

(5) Excludes military workers, who earned $7.8B in 1978

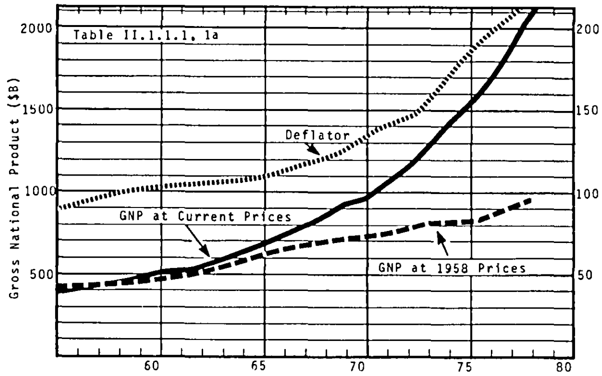



FIGURE 1.1.1a GROSS NATIONAL PRODUCT AND DEFLATOR

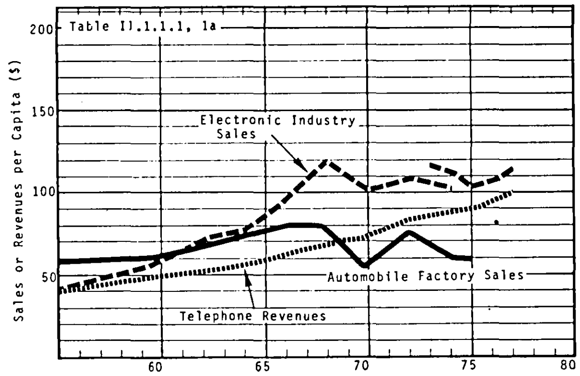



FIGURE 1.1.6b SELECTED INDUSTRIES PER CAPITA SALES IN 1958 DOLLARS

## TABLE 1.1.3a INFORMATION WORKERS AND THEIR COMPENSATION—1967

| Category | Compensation ($B) | Pct. of Tot. Info. Workers |
|---|---|---|
| Markets for Information | 75.3 | 31.0 |
| Knowledge Producers | 47.0 | 19.3 |
| Scientific and Technical Workers | 18.8 | |
| Engineering | 13.0 | |
| Other | 5.7 | |
| Private Inf. Service Providers | 28.2 | |
| Counselors and Advisors (1) | 14.6 | |
| Computer Specialists | 2.7 | |
| Financial Specialists | 10.9 | |
| Knowledge Distributors | 28.3 | 11.6 |
| Educators | 23.7 | |
| Librarians | 1.2 | |
| Communication Workers (2) | 3.3 | |
| Information in Markets | 154.7 | 63.6 |
| Market Search & Coord. Specialists | 93.4 | 38.4 |
| Information Gatherers | 6.1 | |
| Search & Coord. Specialists | 28.3 | |
| Buyers | 3.0 | |
| Brokers | 7.2 | |
| Salesmen (3) | 18.1 | |
| Planning and Control Workers | 59.0 | |
| Administrators & Managers. | 53.1 | |
| Process Control Workers | 5.9 | |
| Information Processors | 61.3 | 25.2 |
| Non-Electronic Based | 55.6 | |
| Secretaries and Typists | 17.3 | |
| File, Statist. & Misc. Clerks | 8.8 | |
| Bookkeepers | 6.9 | |
| Sales Clerks, Retail (3) | 8.2 | |
| Other | 14.4 | |
| Electronic Based (4) | 5.7 | |
| Information Machine Workers | 13.2 | 5.4 |
| Non-Electronic Machine Operators | 4.2 | |
| Electronic Machine Operators | 3.7 | |
| Computer and Keypunch Oper's and Repairmen | 2.7 | |
| Other | 1.0 | |
| Telecommunication Workers | 5.3 | |
| Total Information Workers (5) | 243.1 | 100.0 |
| Total Employee Compensation | 454.3 | |
| Information as % of Total | 53.5% | |

See Notes on preceding page.

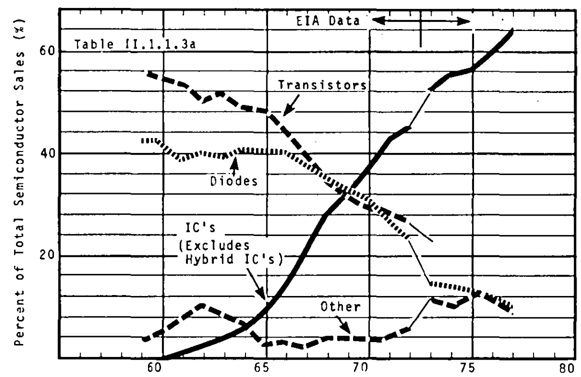



FIGURE 1.1.9a DISTRIBUTION OF SEMICONDUCTOR SALES

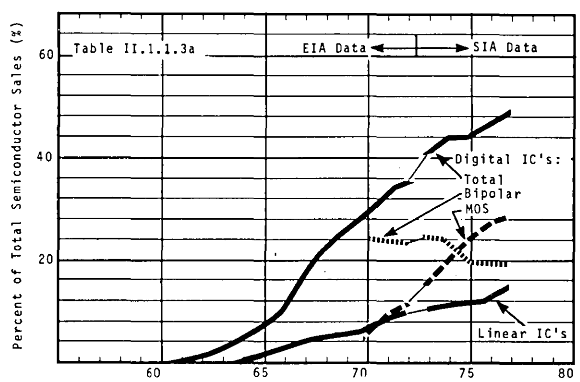



FIGURE 1.1.10a DISTRIBUTION OF IC SALES

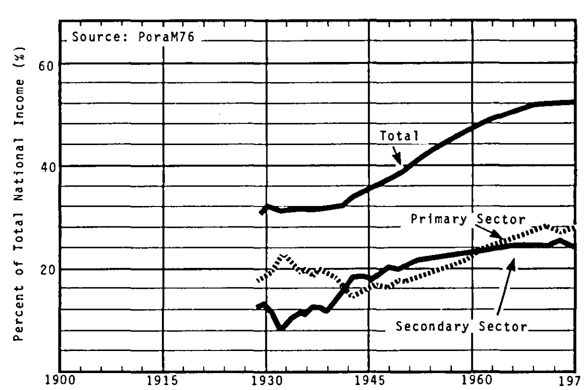



FIGURE 1.1.11a PRIMARY AND SECONDAY INFORMATION SECTORS -- AS PERCENT OF TOTAL NATIONAL INCOME

and are classified in three groups: those whose job it is basically to provide information in the marketplace–the knowledge producers and distributors; those who *serve* the marketplace with the help of information; and those who work with information machines. Of the $243.1B in compensation shown in the table, only $5.7B was earned by individuals working directly with computers–the computer specialists (mostly programmers and system analysts) in the first category, and the computer operators in the last category. But note also that many other job categories are directly or indirectly affected by computer technology.

As the information sector has grown, so also, of course, has the population of information workers. Figure 1.1.12a traces the history of the four major employment categories since the middle of the last century. Porat suggests the United States has proceeded through three stages. In the first, which ended in 1906, agricultural workers predominated; in the second, industrial occupations were in the majority; and since 1954 information occupations have been preponderant.

But is all this information, collected, analyzed, processed, stored, acted on, and distributed, by so many people, at such great expense, really worthwhile? Are we becoming more efficient by virtue of the existence of all the information workers? The productivity of manufacturing workers–the hours of labor taken to assemble a car or to print a book–*has* improved over the years, though it has leveled off during the past decade. But the dollars spent on the bureaucracy have *not* paid off our investment in that bureaucracy. Porat computed the share of National Income spent in the non-information sector, added to it the non-bureaucratic portion of the primary information sector (e.g. the share of National Income devoted to manufacturing computers), and divided the result by the National Income devoted to the bureaucracy–the secondary information sector plus the bureaucratic portion of the primary information sector. The resulting ratio is plotted in Figure 1.1.13a (solid line) along with the Production Productivity Index (dotted line). In the heart of the Depression, with all firms–and the Government–forced to economize, there was almost $12 real output for every dollar spent on the bureaucracy. In 1974 there was only $3 of real output.

The increase in information workers has of course benefitted us all in many ways. Some of the increase in production productivity undoubtedly can be attributed to money spent on the bureaucracy–on research into new production techniques, for example, or on programs written to operate machine tools. In addition, the growing bureaucracy has presumably improved the quality of our lives, by doing such things as attempting to reduce smog, or supplying more television programs, or helping the poor and aged. But Porat's analysis should make us all wonder how much farther we should go in enlarging our public and private bureaucracies.

## 1.2a Data Processing Industry Sales

### 1.20a OVERVIEW

The industry has continued to grow faster than the economy in general, as is indicated in Figure 1.20.1a: shipments of computer systems have represented an increasing percentage of the Gross National Product. The total value of such shipments, plus revenues from the sales of related goods and services, has also grown remarkably, exceeding $35B in 1978–see Figure 1.20.2a. Of the $35B, half came from worldwide shipments of computer systems

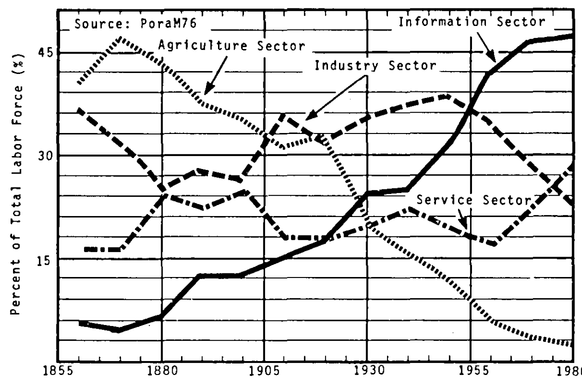



FIGURE 1.1.12a DISTRIBUTION OF U.S. WORK FORCE

(Figure 1.20.3a); and almost half of *that* $18B represented overseas sales.

**Hardware Shipments.** In recent years hardware shipments and revenues have settled down at about 60% of total U.S. shipments and revenues, as shown in Figure 1.20.4a. The decline in GP shipments, as a proportion of the total, has just about been made up by an increase in shipments and revenues by the independent peripheral manufacturers, and by shipments of minicomputers and Small Business Computers (SBC's–which will be discussed in Section 1.21a). The growth of the independent peripherals business (Figure 1.20.5a) is particularly noteworthy; it grew at an average rate of 25% per year between 1968 and 1978. There are three component parts to this business. The first is plug-compatible peripheral equipment, mostly moving-head files, tapes, and internal memory for IBM systems. (IBM plug-compatible CPU's are included with GP system shipments). The second is peripherals, memory, and terminals shipped to system manufacturers who incorporate the units into their own products. These OEM shipments are in effect counted twice in the data behind Figure 1.20.2a, for the revenue for a tape unit is counted once when it is shipped to, and again when it is shipped by, the system manufacturer. The third part of the independent peripheral market is shipments direct to end users, of non-plug-compatible equipment, mostly terminals. In fact, terminals of all kinds comprised almost half of 1977 shipments by the independents.

**Non-Hardware Revenues.** Revenues from services and software have continued to increase their share of the total DP market, representing over a quarter of the total for the past four years (see Figure 1.20.6a). Supplies costs have declined as a fraction of the total, in part because the widespread use of terminals for data entry has finally led to a reduction in the shipments of tabulating cards. Meanwhile data communications revenues have increased, to support the carriage of data from an ever-increasing population of terminals.

Finally, Figure 1.20.8a shows that there was over $60B worth of data processing hardware in use by the end of 1978, and that GP systems still accounted for over three-quarters of the total–though the GP share has been shrinking. Keyboard data entry hardware (i.e. keypunches, key-to-tape, and key-to-disk systems) have also declined as a percentage of the total, again reflecting the increasing use of terminals for data entry.

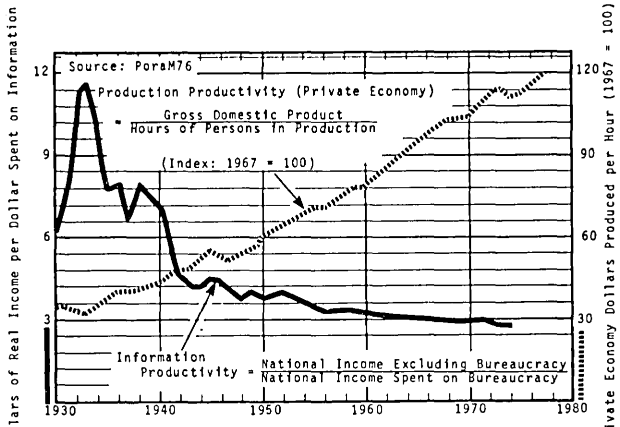



FIGURE 1.1.13a TWO PRODUCTIVITY MEASURES

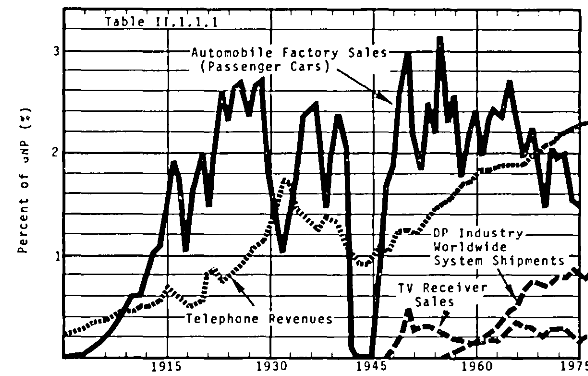



FIGURE 1.20.1a SELECTED INDUSTRIES SALES AS PERCENT OF GROSS NATIONAL PRODUCT

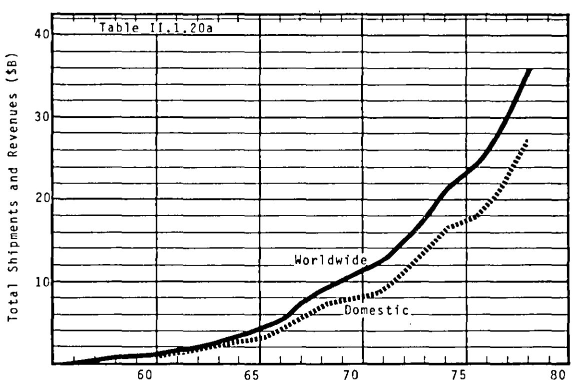



FIGURE 1.20.2a DATA PROCESSING INDUSTRY--DOMESTIC & WORLDWIDE TOTAL SHIPMENTS AND REVENUES BY U.S. FIRMS

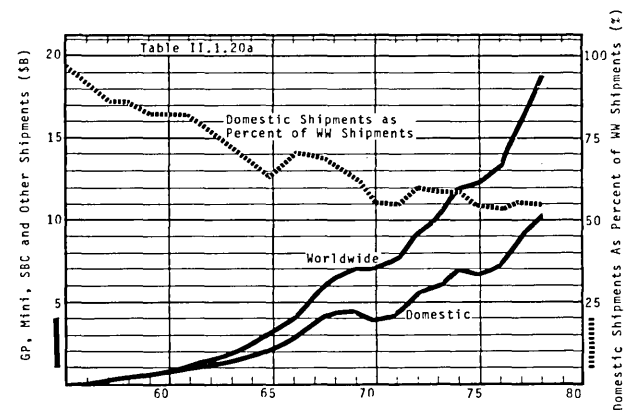



FIGURE 1.20.3a DATA PROCESSING SYSTEM SHIPMENTS DOMESTIC AND WORLDWIDE SHIPMENTS OF GP, MINI, SBC, AND OTHER SYSTEMS

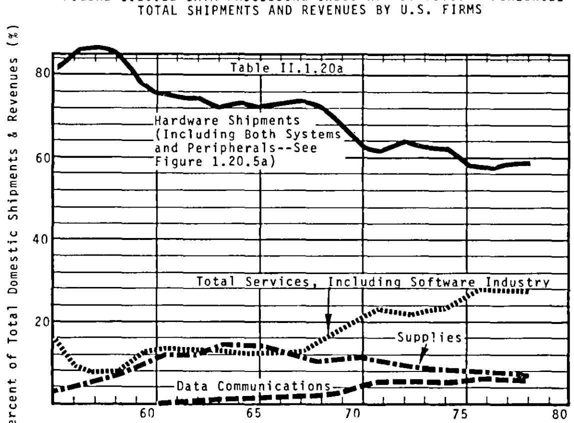



FIGURE 1.20.4a D.P. INDUSTRY DOMESTIC SHIPMENTS & REVENUES I PROPORTIONS OF PRINCIPAL COMPONENTS TO TOTAL

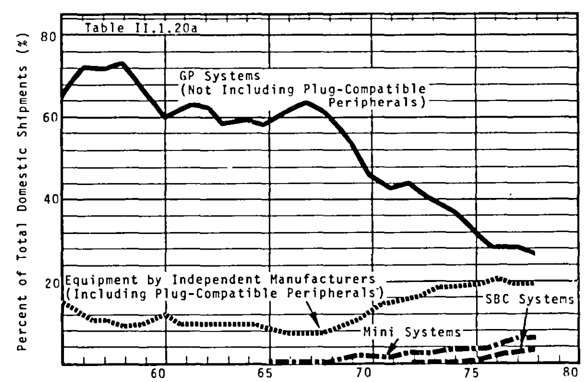



FIGURE 1.20.5a DATA PROCESSING INDUSTRY DOMESTIC SHIPMENTS II. PROPORTIONS OF HARDWARE SHIPMENTS TO TOTAL

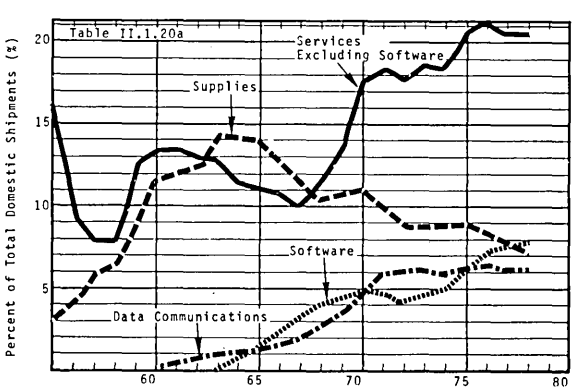



FIGURE 1.20.6a DATA PROCESSING INDUSTRY DOMESTIC SHIPMENTS III. PROPORTIONS OF OTHER REVENUES TO TOTAL

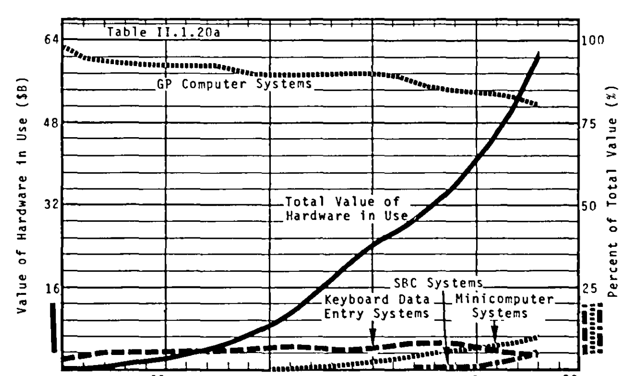



FIGURE 1.20.8a TOTAL DP HARDWARE IN USE IN THE U.S. GP, MINI, AND SBC SYSTEMS, AND DATA ENTRY EQUIPMENT

## 1.21a SYSTEMS

**Shipments and Installations.** During the past five years, technology has continued to drive the cost of computing downward, and new low-cost systems aimed at the small-business market have been developed and have become the fastest-growing segment of the market. Figures 1.21.1a through 1.21.4a show the growth in numbers and in value of GP, mini-, and small business computer (SBC) systems. Comments:

1. GP computers, ranging in size from $1500/month System/3's to $300,000/month supercomputers, still dominate the market in terms of dollar value, though their number in use was passed by minicomputers in 1973 and by SBC's in 1978. Note that the number of GP systems in use has been fairly constant for the past six years, though their value has continued to increase. We will discuss this phenomenon in connection with Figure 1.21.5b and 1.21.5c below, and again in Section 3.27 when we review market elasticity.

2. SBC's are defined (by International Data Corp., on whose statistics these curves are based) as "small general-purpose computers marketed by the major mainframe manufacturers and their competitors to smaller businesses and first-time users." The definition is quite arbitrary, and SBC's on the IDC list overlap the IDC's GP system list in price and performance. Furthermore, SBC's are used by large organizations which have larger GP systems—not *solely* by "smaller business and first-time users." However, the reason for the rapid growth in sales of SBC's is the existence of a large number of business locations which have data to process and can justify system hardware costs of less than $1500/month. The SBC is really simply a low-cost GP system—an extension, at the low end, of the GP product line. This can be seen most clearly in Figure 1.21.6c, which plots the distribution of systems by size and shows that most SBC's fall in the price range of $15.6k to $62.5k, while GP systems lie in the range $62.5k and larger.

3. The data plotted here excludes two new and rapidly-growing computer-based markets: word processing and personal computers. Word processing systems are stand-alone (as opposed to time-sharing) text editing and storage systems, aimed at improving the productivity of office personnel. Personal computers are general-purpose computers in the under-$5000 price range, marketed to individuals for hobby, education, entertainment, and other personal use. Table 1.21.1a provides an estimate of the number of such systems in use. Some minis and SBC's are used in word-processing applications, and many personal computers are beginning to be used in business applications—so there is once again a potential overlap. Note that the number of personal computers in use exceeded the number of GP's in use during 1978. However, note also that the *value* of these computers is so low it would hardly show if plotted on Figure 1.21.2a.

4. There are some matters of definition and overlap which deserve mention in connection with these graphs. First is the fact that the definition of minicomputers has been changed from that employed in DPT&E. The new IDC definition states that "minis are general-purpose in design but are sold as tools, not just solutions; are available from the makers as complete systems, not just boards; are available to OEM'S and are usually discounted in volume buys; and are part of a family that has at least one product in the $2000 to $2500 price range and comes with at least 4K RAM." Once again the definition is arbitrary. And it arbitrarily excludes widely-used systems like the LGP-30, G-15, and CDC 160 (all pre-1965) and IBM's System/7. These four computers, and others included in the earlier DPT&E inventories of what were then called minicomputers, are now lumped together in a category called "other," not plotted here explicity, *but included in each graph's "total"*. Finally, it is important to note that some SBC's contain minicomputers. Thus there is some overlap between the SBC and mini lines on the graph. However, that overlap is taken into account in computing the totals. In summary, for each graph Total = GP's + Minisystems + SBC's + Other - (Minisystems in SBC's).

**Average System Price** Average mini and SBC price trends are shown in Figure 1.21.5a, and average GP system price trends appear in Figure 1.21.5b. The 1970-1974 SBC prices are very gross estimates— the peak shown may not have occurred, or may have been much smaller.

The recent increase in average GP system price, as shown in Figure 1.21.5b, is spectacular. As was mentioned above and as is shown in Figure 1.21.5c, the number of GP systems in use in the U.S. has been relatively constant since year-end 1973 (the number of such systems in use abroad has also levelled off). But despite the fact that the number of systems in use has not changed, GP system dollar shipments have continued strong (compare Figure 1.21.4a and 1.21.5c for the 1974-1978 period) for two reasons: because users have been upgrading, exchanging one system for a more powerful one; and because users have been adding to and thus increasing the size of their systems. Table 1.21.2a presents evidence for the latter statement, showing how average system prices increased from end-1973 to end-1978. We will explore the reasons for this increase in GP system price in Section 1.22.

**System Size.** The changes in GP system size distribution are shown in Figure 1.21.6a, which confirms what we have

**TABLE 1.21.1a PERSONAL COMPUTERS AND WORD PROCESSORS**

| | Number in Use (000) | | | | Shipments | |
|---|---|---|---|---|---|---|
| | '75 | '76 | '77 | '78 | No. (000) | Value ($M) |
| **Personal Computers** | | | | | | |
| Total in Use | 10 | 25 | 50 | 250 | | |
| Shipment Year | | | | | 1978 | 1978 |
| Shipments | | | | | | |
| Radio Shack | | | | | 100 | 105 |
| Commodore | | | | | 25 | 20 |
| Apple | | | | | 20 | 30 |
| Other | | | | | 55 | 345 |
| Total | | | | | 200 | 500 |
| **Word Processors** | | | | | | |
| Keystations in Use | 200 | 242 | 275 | 300 | | |
| Shipment Year | | | | | 1976 | 1976 |
| Shipments | | | | | | |
| Single, Printing | | | | | 44. | 340 |
| Single, Display | | | | | 2.5 | 40 |
| Clusters | | | | | 1. | 10 |
| Total | | | | | 47.5 | 390 |

Sources:
1. For personal computers, a study by Dataquest Corp. (Menlo Park, CA) reported in *Electronic News*, Jan. 29, 1979.
2. For Word Processors, IDC's 1979 Annual Briefing together with IDC report 1768 "The Word Processing Marketplace" dated February 1977.

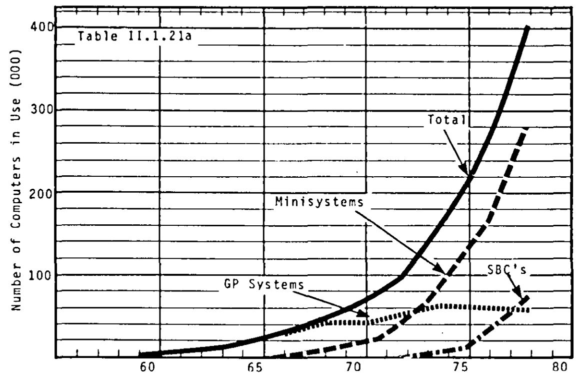



FIGURE 1.21.1a TOTAL NUMBER OF COMPUTERS IN USE IN THE U.S.

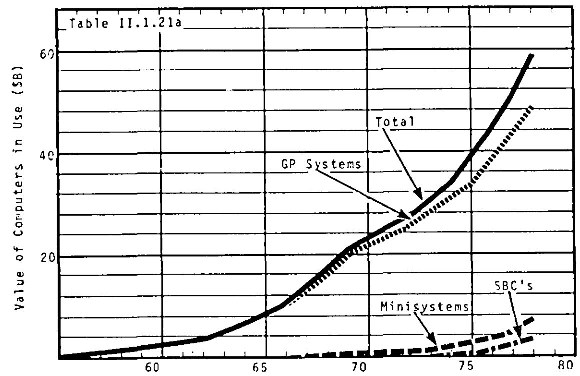



FIGURE 1.21.2a TOTAL VALUE OF COMPUTERS IN USE IN THE U.S.

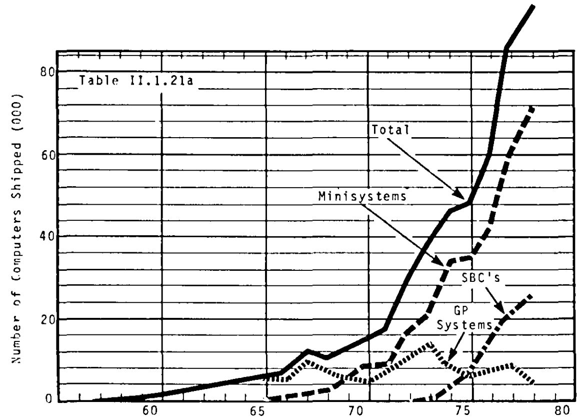



FIGURE 1.21.3a TOTAL NUMBER OF COMPUTERS SHIPPED IN THE U.S.

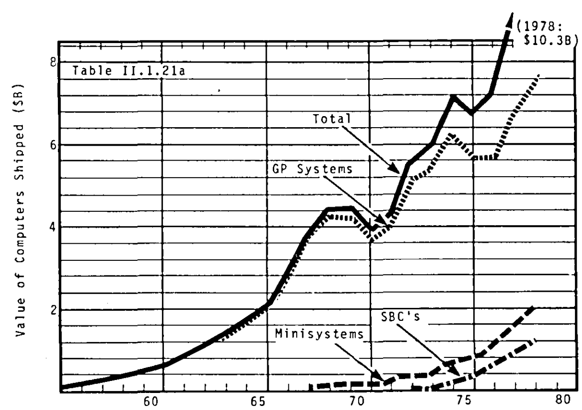



FIGURE 1.21.4a TOTAL VALUE OF COMPUTERS SHIPPED IN THE U.S.

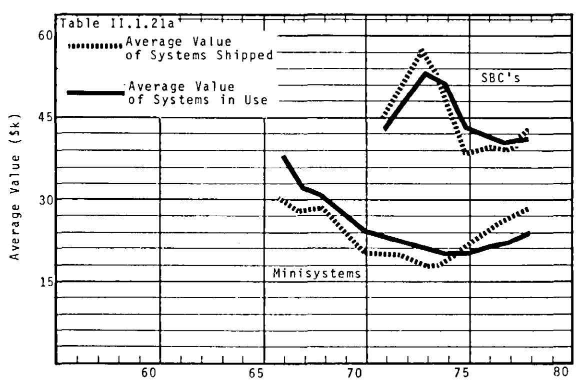



FIGURE 1.21.5a AVERAGE VALUE OF MINI AND SBC SYSTEMS IN THE U.S.

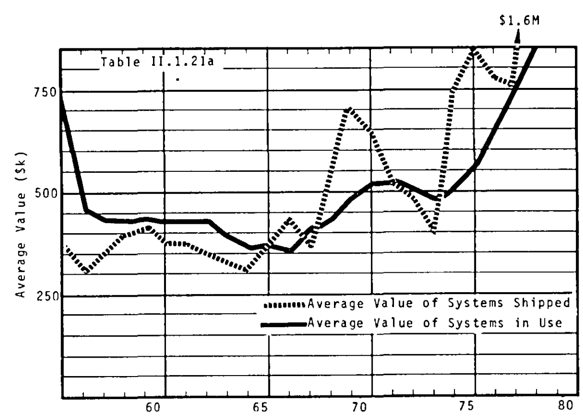



FIGURE 1.21.5b AVERAGE VALUE OF GP SYSTEMS IN THE U.S.

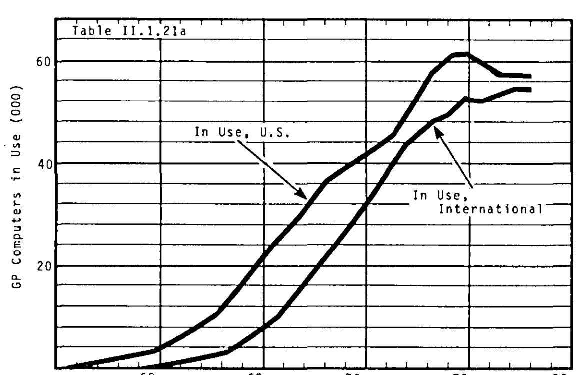



FIGURE 1.21.5c TOTAL NUMBER OF GP SYSTEMS IN USE

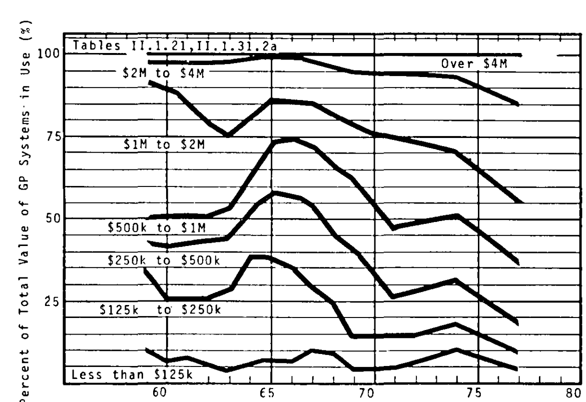



FIGURE 1.21.6a DISTRIBUTION OF TOTAL VALUE OF GP SYSTEMS IN USE, BY SYSTEM SELLING PRICE

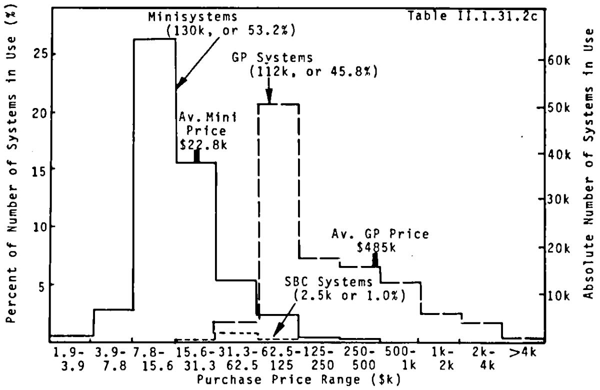



FIGURE 1.21.6b DISTRIBUTION OF U.S.-BUILT SYSTEMS IN USE, WW BY NUMBER, in 1974

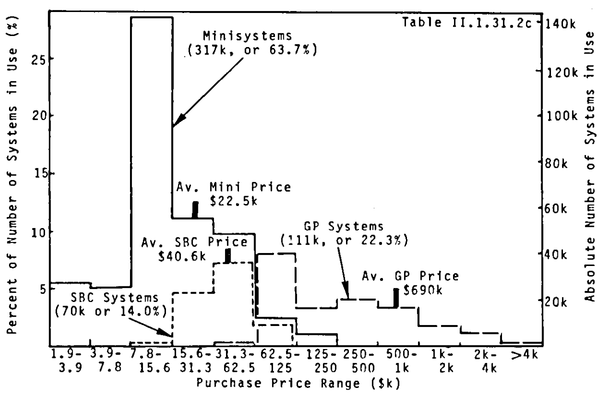



FIGURE 1.21.6c DISTRIBUTION OF U.S.-BUILT SYSTEMS IN USE, WW BY NUMBER IN 1977

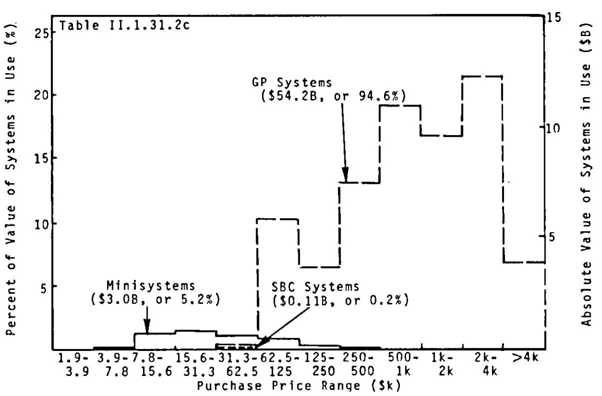



FIGURE 1.21.6d DISTRIBUTION OF U.S.-BUILT SYSTEMS IN USE WORLDWIDE BY VALUE IN 1974

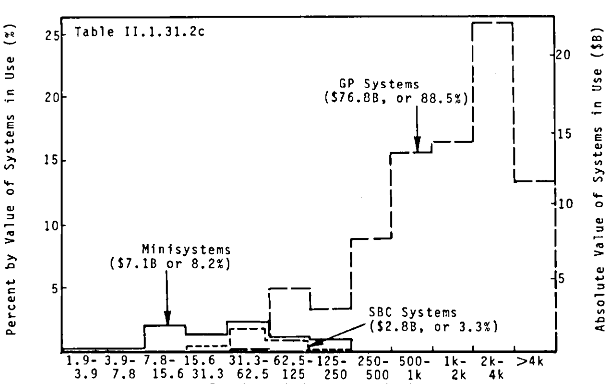



FIGURE 1.21.6e DISTRIBUTION OF U.S. BUILT SYSTEMS IN USE, WW BY VALUE IN 1977

been saying about the trend toward increasing system size. Figures 1.21.6b to 1.21.6e provide additional detail for the years 1974 and 1977, and include minisystems and SBC's as well as GP systems. The figures show very neatly the interplay between number in use and value in use, and the relative importance of the three categories of computers. (The data sources are the IDC censuses for 1974 and 1977, and IDC has subsequently modified its estimates. Thus the data shown here is not quite consistent with that of Figures 1.21.1a to 1.21.5c.)

**System Life.** GP System retirements are cyclical, and peaked in 1962, 1966, and 1972 as first-, then second-, and finally third-generation systems were replaced (see the solid line in Figure 1.21.7a). Meanwhile, the life of a dollar's worth of GP equipment continues to increase, and reached the age of five years in 1977. The age of equipment retired each year (computed assuming that the oldest equipment is always retired first) also increased over the past five years, as retirements dropped. When the industry reaches the point where shipments, on the average, are a fixed percentage of value in use each year, the "average life shipped to date" will stabilize at a value equal to the reciprocal of that percentage. If the market saturates and annual shipments equal annual retirements, the average life of systems retired will converge to the same value as average system life. And if shipments and value in use increase at the same uniform annual rate (which might be expected because of inflation), average retirement age will converge to a value somewhat higher than system life.

**TABLE 1.21.2a INCREASES IN SYSTEM SIZE**

| Computer System | Avg. Price ($/mo) 12/31/73 | Avg. Price ($/mo) 12/31/78 | Percent Increase |
|---|---|---|---|
| Burroughs 2700 | 8,700 | 10,700 | 23.0 |
| CDC 3300 | 28,800 | 34,500 | 19.8 |
| DEC 1040/1050 | 13,300 | 17,300 | 30.1 |
| Honeywell 2020 | 2,350 | 3,700 | 57.4 |
| IBM System/3-10 | 2,420 | 2,700 | 11.6 |
| IBM 370/125 | 9,800 | 13,000 | 32.7 |
| 370/135 | 16,225 | 20,500 | 26.3 |
| 370/145 | 27,800 | 39,000 | 40.3 |
| 370/158 | 59,200 | 104,000 | 75.7 |
| 370/168 | 110,200 | 194,000 | 76.0 |
| NCR 101 | 2,750 | 4,100 | 49.1 |
| Univac 1110 | 79,000 | 145,000 | 83.5 |
| Average | | | 43.8 |

Source: *EDP/IR* Annual Review and Forecast.

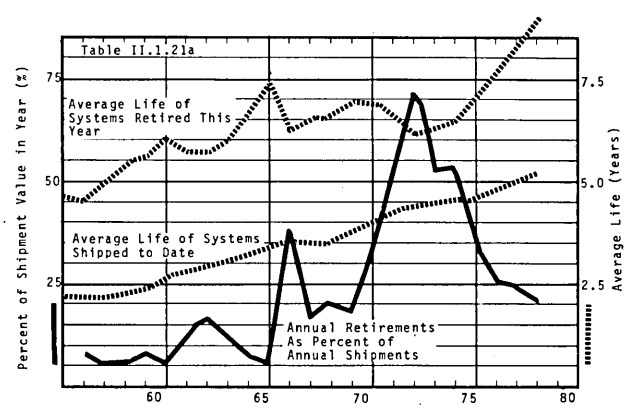



FIGURE 1.21.7a GP SYSTEM LIFE (U.S.) ANNUAL RETIREMENTS, AND AVERAGE SYSTEM LIFE

## 1.22a GP SYSTEM COMPONENTS

**Summary.** We saw in Figure 1.21.5b that the average value of a GP system in use rose from \$468k to \$840k between 1973 and 1978. Figures 1.22.1a through 1.22.6c show how the four principal component parts of a GP system are distributed and how the distribution has changed with time. Note (Figure 1.22.6b) that during the past five years all the components of an average system have increased in value, but that the value of terminals and of "processors, etc." have grown most vigorously. The growth in the numbers and types of terminals in use we will review in Section 1.24a below. "Processors, etc." is the remainder when the value of other listed components are subtracted from system value. It thus includes the central processor, input-output processors, communications processors, and miscellaneous peripherals such as COM or paper tape units. (It also, of course, includes somehow the summation of the errors made in estimating system and component values). I have seen no statistics on the number and value in use of these auxiliary processors and peripherals. But it seems safe to presume that the addition of peripherals and terminals has lead to corresponding additions of I/O processors and communications interfaces. And we will see in Section 2.11a that IBM, in introducing the 370 family in the early seventies, revised system pricing structure by increasing the price of CPU's and reducing the incremental price of memory (Figures 2.11.9a to 2.11.11a). Thus as System/360's were traded in for equivalent System/370's, the average CPU value increased.

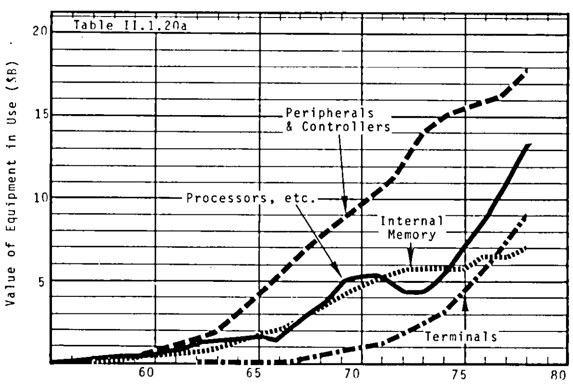


FIGURE 1.22.1a GP SYSTEM VALUE IN USE IN THE U.S. I

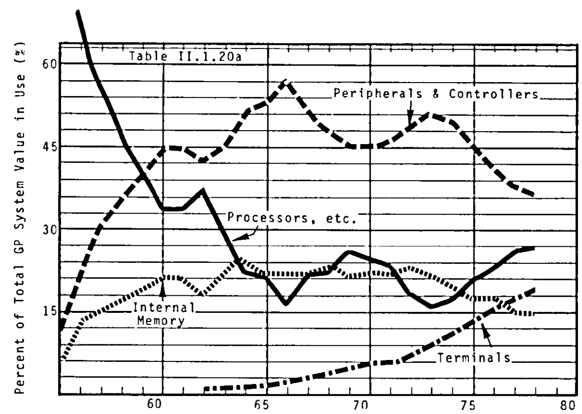


FIGURE 1.22.2a GP SYSTEM VALUE IN USE IN THE U.S. II
PROPORTIONS OF MAJOR EQUIPMENT CATEGORIES

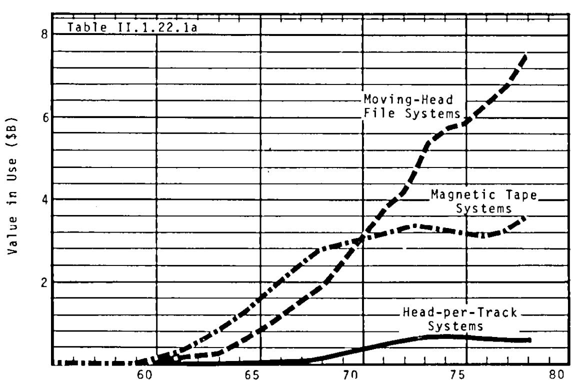


FIGURE 1.22.3a INSTALLED VALUE OF PERIPHERALS I. MEMORY EQUIPMENT

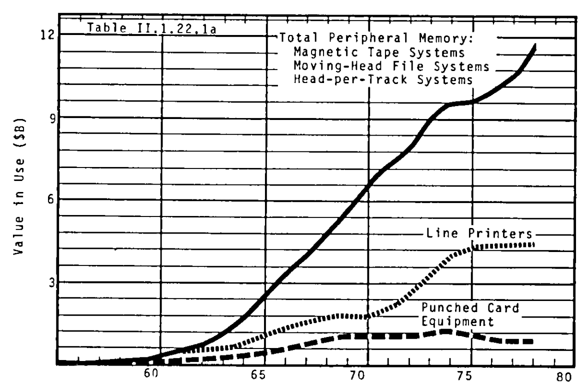


FIGURE 1.22.4a INSTALLED VALUE OF PERIPHERALS II.

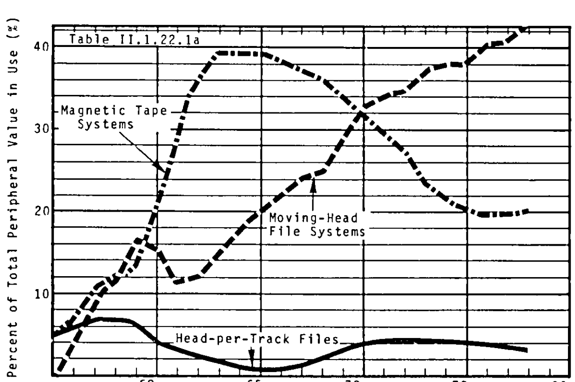


FIGURE 1.22.5a INSTALLED VALUE OF PERIPHERALS III
MEMORY EQUIPMENT AS PROPORTION OF ALL PERIPHERALS

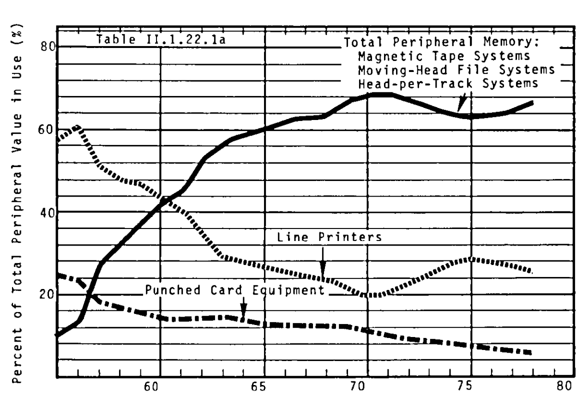


FIGURE 1.22.6a INSTALLED VALUE OF PERIPHERALS IV
AS PROPORTION OF ALL PERIPHERALS

**Peripherals.** Figures 1.22.3a to 1.22.14a summarize the history of the unit record and memory peripherals. The moving-head file has emerged, in the seventies, as the leading peripheral, with the line printer a surprising second—line printer value exceeded magnetic tape value in the mid-seventies, for the first time since about 1962, as shown in Figure 1.22.6c. The downturn in tape unit usage has come about largely because of the increasing proportion of System/3-type systems, which rely more on disks than on tape. The increase in line printer value comes about both because the average number of printers per system has increased, and because average printer price has increased, as users moved up to faster printers. The surge in moving-head file installations since 1975 is largely due to the increasing use of the very large disks—like the double-density IBM 3330, and the 3350.

Head-per-track files and punched card equipment are less important today than they were five years ago. The former has been affected by the introduction of head-per-track platters in some moving-head files (IBM 3350, and plug-compatible products manufactured by Memorex and Storage Techonology Corp.), and by the increased use of large internal memory. The decline in the use of punched-card equipment is a result of the increased use of terminals and other non-card-oriented systems for data entry.

Tape unit and MHF on-line storage capacity has of course continued to increase, as shown in Figures 1.22.9a and 1.22.11a. Note that, at year-end 1978, MHF capacity was almost ten times that of tape units (But see Figure 1.27.8a for a comparison of off-line capacity.) The distribution of MHF capacity among MHF's on IBM systems is shown in Figure 1.22.12b. Note that it only takes two or three years after first shipment for a new technology to supplant an old one in this very fast-moving field.

Although this section is primarily devoted to GP system components, Figures 1.22.9a, 1.22.11a, and 1.22.14a show that minisystems and small business computers between them make extensive use of magnetic tape, moving-head-file, and printing peripherals. The total number of peripherals in each category on these smaller systems exceeds the number on GP systems, but of course the units generally have less capacity (measured by data transfer rates, storage capacity, or printing speeds) and are much less costly per unit. Many of these mini and SBC components are supplied to small system manufacturers by the independent peripheral manufacturers, and help account for the growth of the OEM sector of that business.

**Internal Memory.** The introduction of the IC memory, in the early seventies, made it possible for manufacturers to supply larger and larger memories at lower and lower prices. Cache, or buffer memories made it feasible even for large, powerful systems to employ low-cost, relatively slow IC memory. The result has been that minimum memory configurations are much larger today than they were ten years ago (see Figures 2.11.9a to 2.11.11a), and the average number of bytes per GP system has increased from 50,000 to over 400,000, while the average price per byte in use fell from $1.95 to $0.29. Figures 1.22.17a to 1.22.20a display these facts, and show how the value and size of memory in use has been distributed among IBM generations and families.

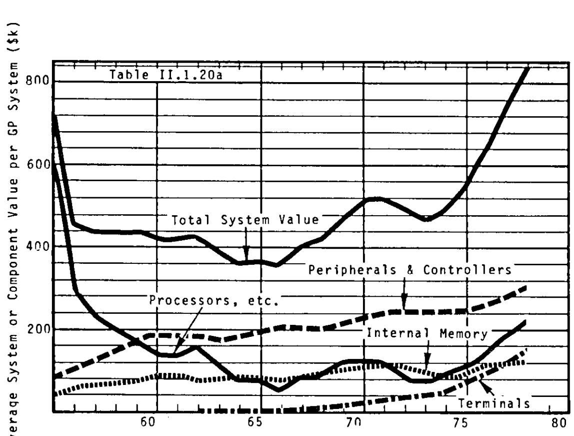



FIGURE 1.22.6b INSTALLED VALUE OF PERIPHERALS V
COMPONENTS OF AN AVERAGE SYSTEM

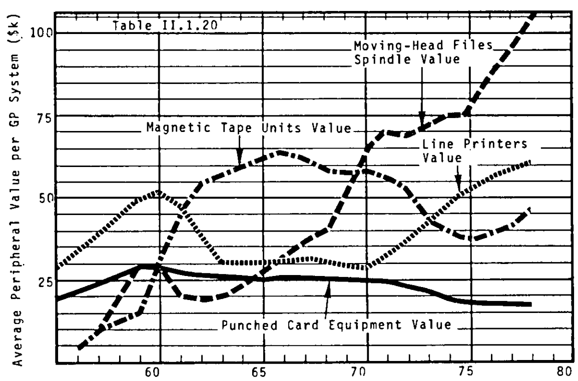



FIGURE 1.22.6c INSTALLED VALUE OF PERIPHERALS VI
PERIPHERAL VALUE ON AN AVERAGE SYSTEM

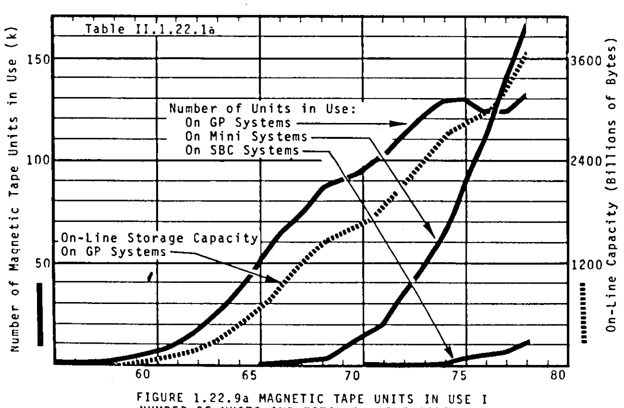



FIGURE 1.22.9a MAGNETIC TAPE UNITS IN USE I
NUMBER OF UNITS AND TOTAL ON-LINE CAPACITY

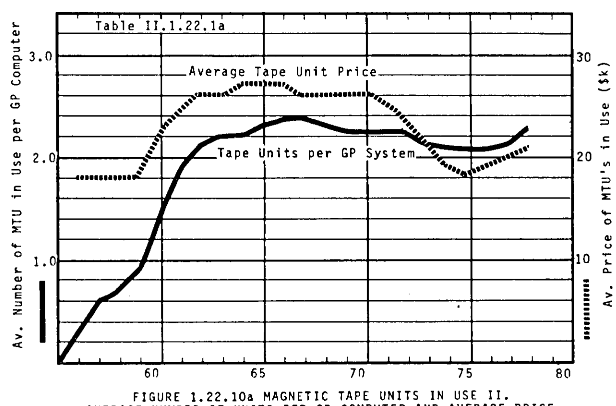



FIGURE 1.22.10a MAGNETIC TAPE UNITS IN USE II.
AVERAGE NUMBER OF UNITS PER GP COMPUTER AND AVERAGE PRICE

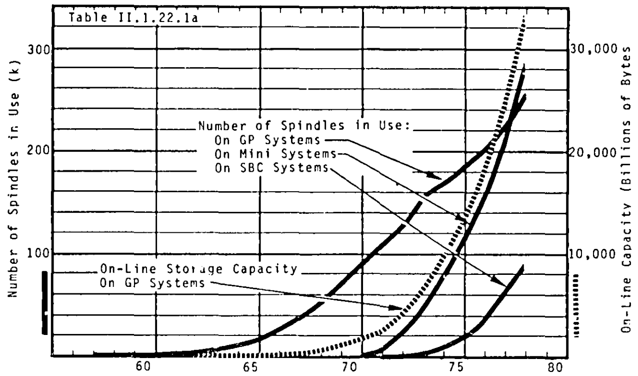



FIGURE 1.22.11a MOVING-HEAD FILES IN USE I
NUMBER OF UNITS AND TOTAL ON-LINE CAPACITY

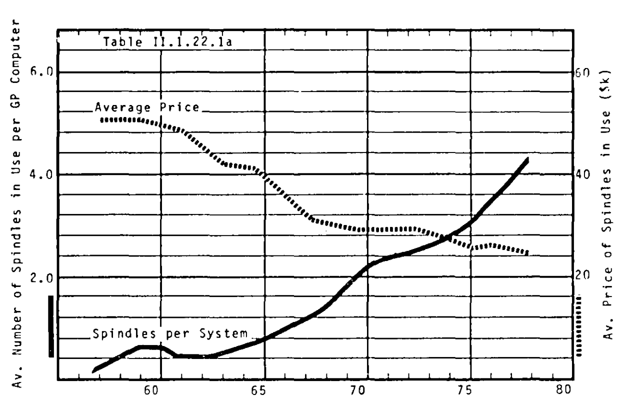



FIGURE 1.22.12a MOVING-HEAD FILES IN USE II.
AVERAGE NUMBER OF UNITS PER GP COMPUTER AND AVERAGE PRICE

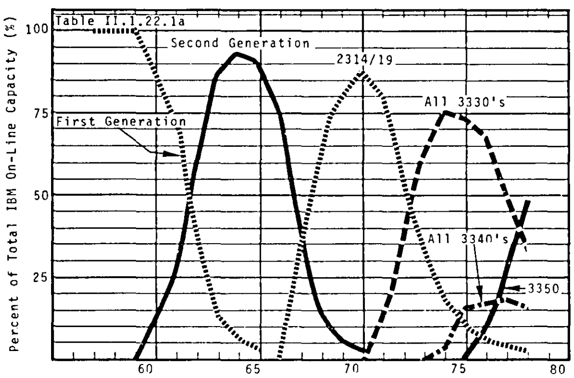



FIGURE 1.22.12b MOVING-HEAD FILES IN USE III
DISTRIBUTION OF IBM ON-LINE CAPACITY

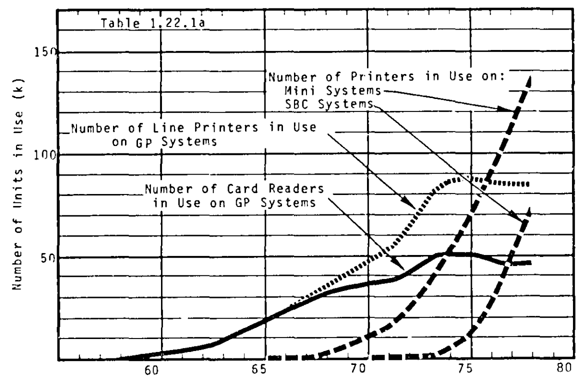



FIGURE 1.22.14a UNIT RECORD DEVICES IN USE
NUMBER OF PUNCHED-CARD UNITS AND LINE PRINTERS

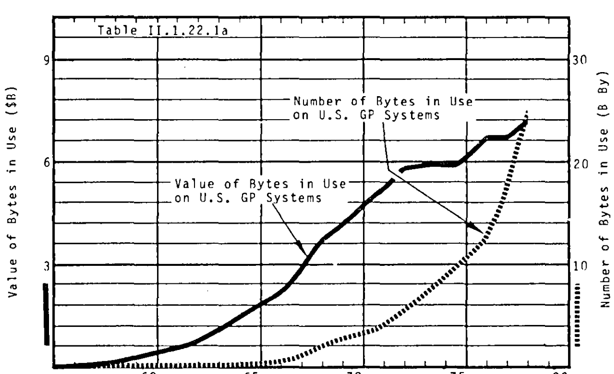



FIGURE 1.22.17a INTERNAL MEMORY I.
NUMBER AND VALUE OF BYTES IN USE ON U.S. GP SYSTEMS

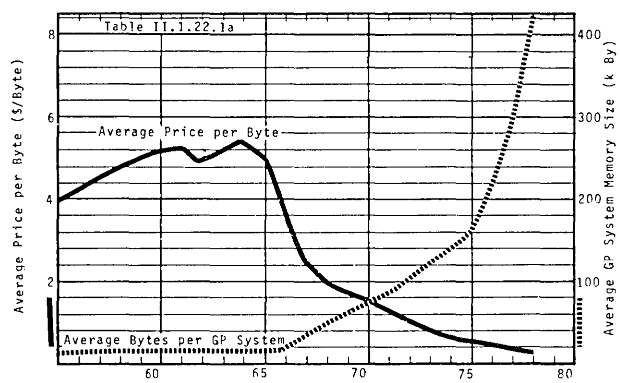



FIGURE 1.22.18a INTERNAL MEMORY II.
AVERAGE PRICE AND SIZE OF SYSTEMS IN USE IN U.S.

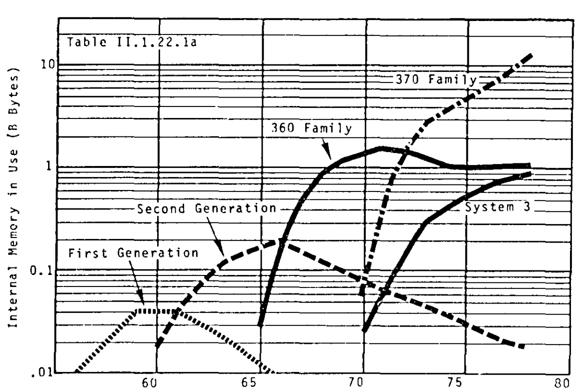



FIGURE 1.22.19a INTERNAL MEMORY III
IBM SYSTEMS -- BYTES IN USE

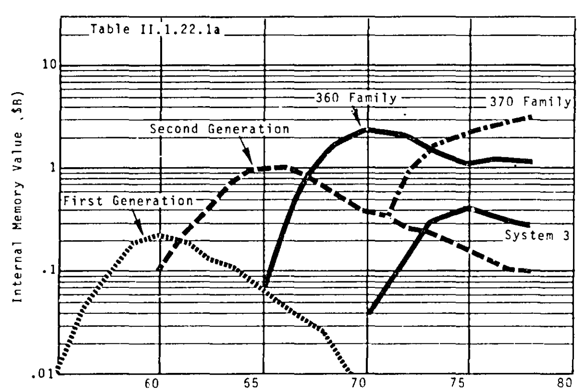



FIGURE 1.22.20a INTERNAL MEMORY IV.
IBM SYSTEMS--VALUE OF MEMORY IN USE

## 1.23a DATA ENTRY EQUIPMENT

Three developments seem worth mentioning.

1. The population of keypunches and verifiers, still the most important of the equipments designed solely for data entry, has finally started to shrink, as is shown in Figure 1.23.1a.

2. The key-to-diskette system, introduced by IBM in 1974, has become the fastest-growing data entry component, and has displaced both keypunches and the old key-to-tape devices. (See Figures 1.23.1a and 1.23.2a)

3. Remote terminals (not shown here, but discussed in Section 1.24a) have been used increasingly for data entry, and undoubtedly account for the leveling off in total keyboards in use, shown in Figure 1.23.3a. An IDC report published in December, 1976 (IDC 1765.76) estimated that there were 240,000 terminals used for local and remote data entry on GP systems in December, 1976—compared with the 463,000 data entry keyboards used on all systems, shown in Figure 1.23.3a.

## 1.24a DATA COMMUNICATIONS AND TERMINALS

The population of terminals (which are connected to communication lines, according to the definition in DPT&E) and keyboard-oriented, terminal-like devices has continued to increase during the Seventies, as new applications made use of terminal equipment, and as terminals have supplanted keypunches (and other related devices) for system data entry.

Figure 1.24.1a indicates how the number of systems having terminals, or terminal-like devices, and the number of systems connected to communications lines, have increased with time. The data has a large probable error, but apparently the proportion of GP systems containing terminals or connected to communication lines has remained fairly constant at 20-25%. However, minisystems have increasingly been used as communication or data entry controllers, and by 1978 an estimated 12% of the minisystem population had communication connections. An additional 10% of the GP and minisystem populations contained some kind of "terminal" connected locally to the system. And 10% of the SBC's contained "terminals", though apparently very few of them, so far, are connected to communication lines. (In this and some other figures presented later in this section, note there is a discontinuity between 1971 and 1972. 1971 and earlier figures were based on communication connections to GP systems only; 1972 and later dates include non-GP systems).

**Data Communication Revenues.** The estimated cost of data communications to GP users is shown as the solid line in Figure 1.24.2a. The dotted line there shows "Data service revenue" as given in 1972 in AT&T's Annual Report. The other points shown in the figure are also given in Table 1.24a. In 1976 some AT&T executives discussed, in public conferences, the result of "AT&T studies" which broke data communications into three parts, and estimated revenue for those three parts in the years shown in the table. These three parts were:

1. Data Transmission. The movement of bits over a communication channel.

2. Media Conversion. The transformation of human-readable input into bits and vice-versa.

3. Communications Processing. Rearrangement or interpretation of communicated information. Includes such things as formatting of data for CRT display, speed conversion, error control, and polling.

The totals shown in Table 1.24a, and plotted as points (mostly off the chart) in Figure 1.24.2a were described as "total user expenditures" by one AT&T speaker and as "Bell System Revenues" by another, according to reports in the technical press. AT&T now states the studies referred to "total industry revenues." Note that the 1965 figure of $550 million for data transmission is more than twice as big as the "Data Service Revenue" given in AT&T's 1972 Annual report—the unlikely implication being that AT&T provided less than half of U.S. data transmission services in that year.

Actual data transmission revenues undoubtedly lie somewhere above the solid line in Figure 1.24.2a. The GP "user budget" which is the basis for the curve may include some minisystem data communication cost, where a mini, or network of minis, connects to a GP system *and* the budget for that network is managed by the GP user. But increasingly, communications budgets are being decentralized, and do not appear in any computer-related budget. And of course, some datacom costs are incurred by minisystems not connected to GP equipment and thus are not included in the plotted data.

The new terms (media conversion, communications processing) discussed by the AT&T representatives have not, to my knowledge, been concisely defined. They were introduced, apparently, as part of an AT&T campaign designed to explore the prospects of entering the data processing market. Does "formatting of data for CRT display" include, for example, sorting a group of records received in random order so they may be displayed in

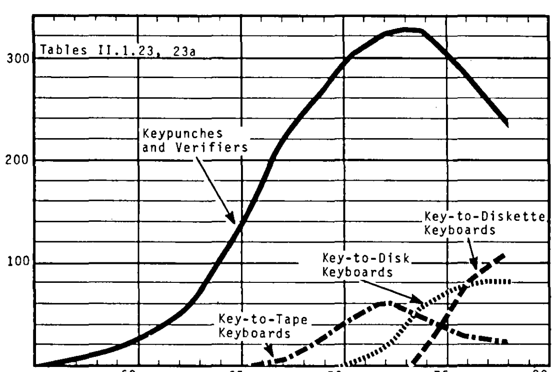



FIGURE 1.23.1a DATA ENTRY EQUIPMENT I
NUMBER OF KEYBOARDS IN USE IN THE U.S.

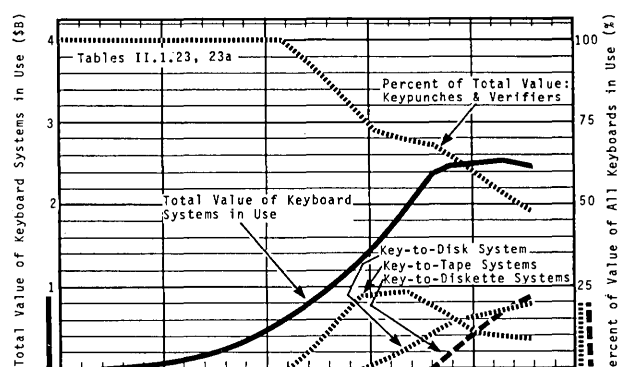



FIGURE 1.23.2a DATA ENTRY EQUIPMENT II
VALUE OF KEYBOARD SYSTEMS IN USE IN THE U.S.

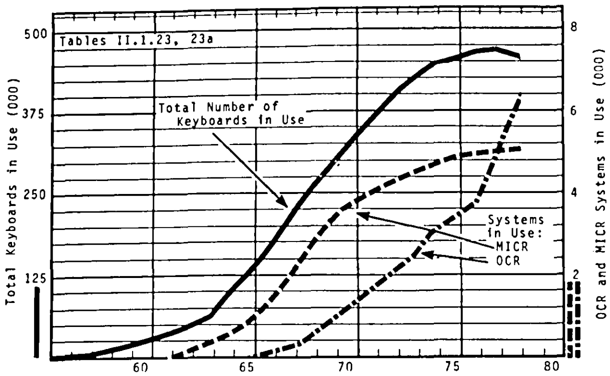



FIGURE 1.23.3a DATA ENTRY EQUIPMENT III
NUMBER OF OCR, MICR, AND KEYBOARDS IN USE IN THE U.S.

## TABLE 1.24a ESTIMATES OF DATACOM EXPENSES

| | 1965 | 1975 | 1980 | 1985 |
|---|---|---|---|---|
| Data Transmission | $0.55B | $1.7B | $3.2B | $5.5B |
| Percent | 55% | 31% | 27% | 24% |
| Media Conversion | $0.30B | $2.1B | $5.3B | $10.0B |
| Percent | 30% | 38% | 44% | 44% |
| Commun. Processing | $0.15 | $1.7B | $3.5B | $7.0B |
| Percent | 15% | 31% | 29% | 31% |
| Total | $1.0B | $5.5B | $12.0B | $22.5B |

Sources: *EDP/IR* 7/31/78, *Datamation*, June, 1976, p. 117. AT&T was given as the original source by both publications. The 1965 total was given in *EDP/IR* as $1.5B. However, in a private communication from AT&T dated 7/5/79, I was told the correct estimate, for total industry datacom revenues in 1965, was $1.0B.

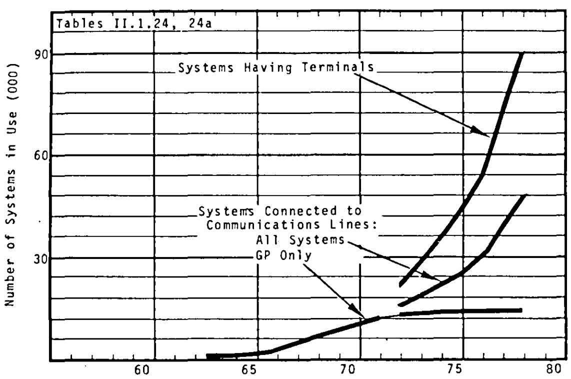



FIGURE 1.24.1a SYSTEMS IN USE IN THE U.S.
HAVING TERMINALS AND CONNECTED TO COMMUNICATIONS LINES

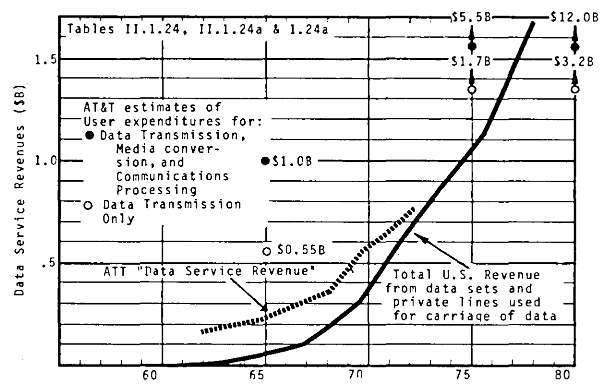



FIGURE 1.24.2a DATA COMMUNICATIONS REVENUES

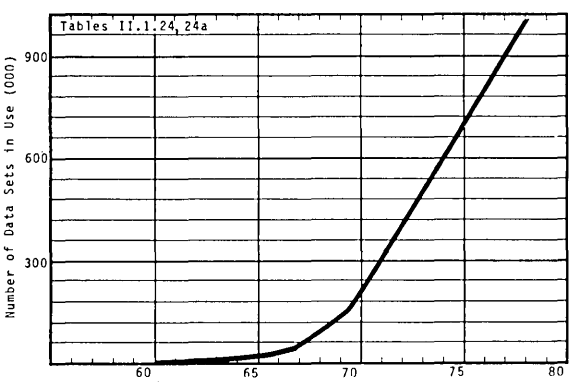



FIGURE 1.24.3a DATA SETS IN USE IN THE U.S.

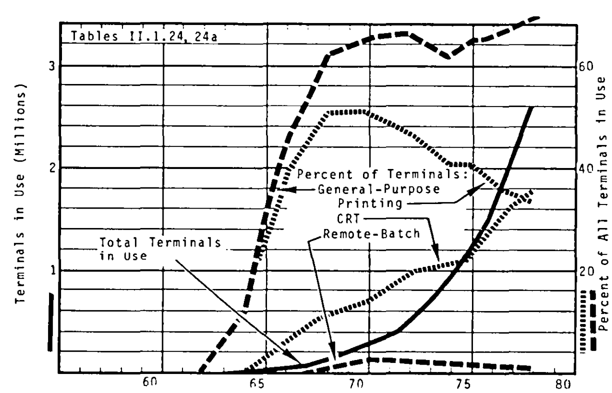



FIGURE 1.24.5a TERMINALS IN USE IN THE U.S. I
TOTAL NUMBER AND DISTRIBUTION BY NUMBER

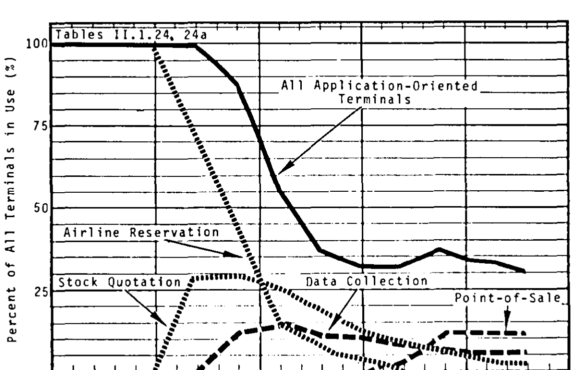



FIGURE 1.24.5b TERMINALS IN USE IN THE U.S. II
DISTRIBUTION OF APPLICATION-ORIENTED TERMINALS

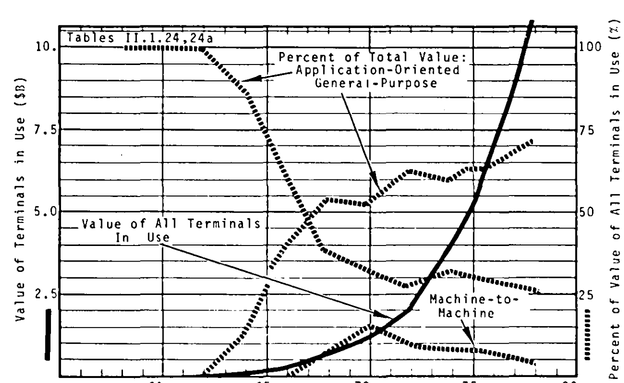



FIGURE 1.24.6a TERMINALS IN USE IN THE U.S. III
TOTAL VALUE AND DISTRIBUTION BY VALUE

alphabetical order? Does "error control" include checking a data item against pre-stored limits and rejecting it if it lies outside those limits? AT&T did not answer such questions. But if we agree that a communication consists of two parts, an address and a message, we might reasonably argue that a data communicator reads, interprets, and employs the address to deliver the message, but does not read the message (the telephone company may not listen to our phone calls, and the post office may not open our letters, without a court order). A data *processor* reads, interprets, and manipulates the message. Given this understanding of data communications, we might argue that data transmission is the heart of the data communications business, that media conversion is another business altogether, and that some of what AT&T seems to call "communication processing" is clearly part of data communications (e.g. polling, speed conversion, store and forward), while other parts (sorting, checking against limits) are not.

The number of data sets (modems) in use in the U.S. is estimated in Figure 1.24.3a.

**Terminals** By the end of 1978 there were over 2.5 million terminals and terminal-like devices in use in the U.S., and the growth does not yet appear to be slowing (solid line in Figure 1.24.5a). Almost three-quarters of them were general-purpose, divided fairly evenly between CRT and printing terminals. These general-purpose terminals are the ones most often used for inquiries and for data entry.

The distribution of special, application-oriented terminals is shown in Figure 1.24.5b. The point-of-sale terminals, replacing cash registers in department stores and supermarkets, became the most widely-used application-oriented terminal during the mid-Seventies. Special banking terminals, originally used mostly for savings institutions but increasingly applied by commercial banks, are also widely used though they are not shown on the graph–they would plot nearly on top of the Factory Data Collection Terminals. For the past five years, POS, Data Collection, and Banking Terminals have each held a fixed proportion of total terminals in use, which means, of course, that their populations have been growing rapidly. By the end of 1978, the U.S. terminal population was worth over $10 billion, as shown in Figure 1.24.6a.

**Terminals, Data Sets, and Systems.** The number of terminals per data set (solid line in Figure 1.24.7a) has increased in recent years as an increasing number of terminals have found use in systems with no communication lines. The number of terminals per system having terminals has remained fairly constant or perhaps increased slightly (dashed lines in Figure 1.24,7a). There seem to be no reliable statistics on the distribution of terminals between GP and other systems, though it seems likely that the average GP system with terminals has more than the average minisystem. The annual cost of data communication lines and data sets, and the dollar investment in terminals, is shown on a per-system basis in Figure 1.24.8a. Note that the communication line cost is undoubtedly low, because it is based on the costs from Figure 1.24.1a, which we have already noted are unrealistically low.

## 1.25a SOFTWARE EXPENSES

Software expenses passed the $20B per year mark in about 1978, though the expenses estimated here are, for the most part, associated with general-purpose computers only. The total is made up of three components: revenue from the software industry; expenses by GP system manufacturers; and burdened costs of programmers and systems analysts working for organizations which have GP computers. The growth in total expenses is shown in Figure 1.25.1a, and the growth of users' costs, still the largest component by far, in Figure 1.25.2a.

**The Software Industry.** Standard software packages have generated more revenue per year than has custom software since 1975, as the effects of unbundling made themselves felt, and users had to pay for programs they had previously received "free" from the hardware manufacturers. The revenues shown in Figure 1.25.3a are from both system manufacturers and the independent software houses, and, though both parts are growing, that collected by the manufacturers is growing faster and amounted to about 55% of the total in 1978.

I could not find a breakdown of the sources of software revenue from the systems manufacturers, but Table 1.25.1a shows an analysis of the independent's revenues. Systems software includes system resource management, communications, performance measurement, and operating systems and compilers. Utility software includes Data Management systems, report generators, program support, security, and design aids. Applications programs include "horizontal" applications like payroll and accounting, and "vertical" ones for industries like insurance or manufacturing. As one might expect, applications software is the fastest-growing of the three revenues.

**Manufacturers' Software.** I have found little new data on the nature or magnitude of the system manufacturers' software development efforts. Table 1.25.2a provides one fragment I did run across: a measure of the size of two of IBM's operating systems. The striking feature of this data (and of Belady's paper from which it came) is the enormous amount of effort which obviously goes into "maintenance" (i.e. correcting errors and adding features) of these complex products.

**TABLE 1.25.2a IBM OPERATING SYSTEM STATISTICS**

| System | Release Number | System Age (Years) | Statements (Millions) | Modules (k) | Av. Statements per Module | Modules Modified per Release (% of Total) |
|---|---|---|---|---|---|---|
| OS 360 | 21 | 6.5 | 3.46 | 6.3 | 550 | 14 |
| DOS 360 | 27 | 6.0 | 8.9 | 2.3 | 390 | 38 |

Source: BelaL77. "Modules modified per release" was computed from Belady's figure of 11 and 6 modules changed per day (for OS and DOS), and the assumptions that all the releases occurred during the system's life, and that a year contains 260 working days.

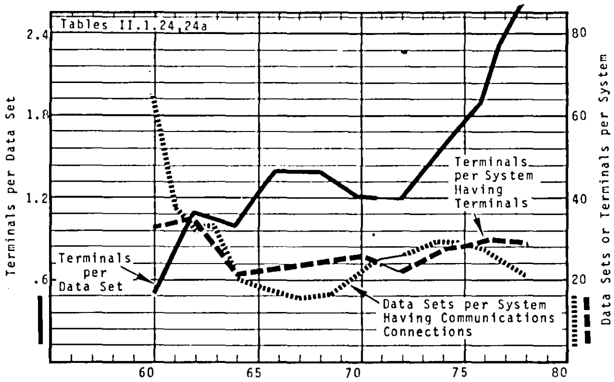


FIGURE 1.24.7a DATA SETS AND TERMINALS IN USE SOME RATIOS

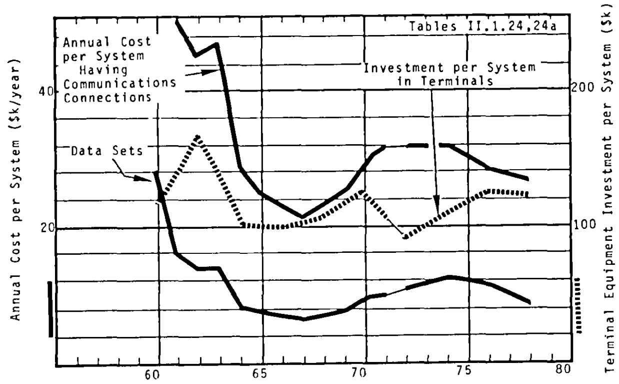


FIGURE 1.24.8a COMMUNICATIONS AND TERMINAL COSTS

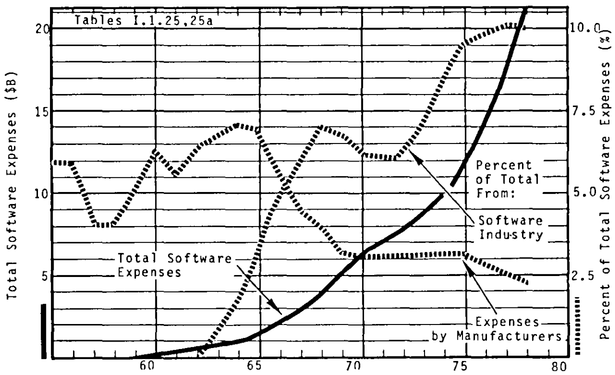


FIGURE 1.25.1a DOMESTIC SOFTWARE EXPENSES TOTAL, AND MANUFACTURERS' AND INDEPENDENTS' SHARE OF THE TOTAL

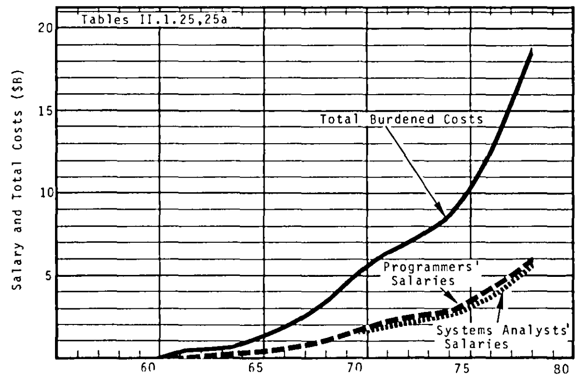


FIGURE 1.25.2a COMPUTER USERS' DIRECT SOFTWARE COSTS SALARY AND BURDENED TOTAL COSTS OF APPLICATIONS PROGRAMS

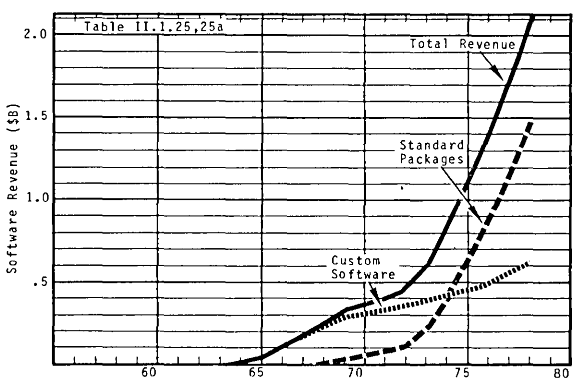


FIGURE 1.25.3a SOFTWARE INDUSTRY REVENUE CUSTOM SOFTWARE AND STANDARD PACKAGES

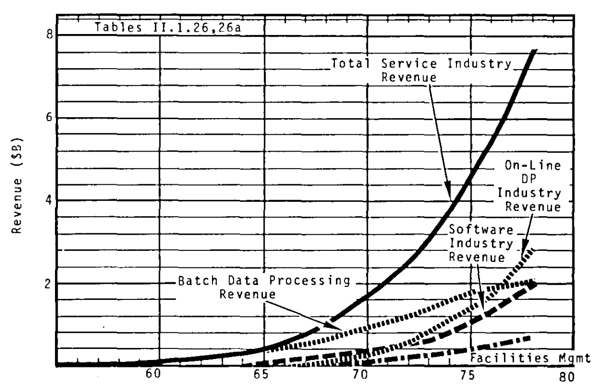


FIGURE 1.26.1a SERVICE INDUSTRY REVENUE I PRINCIPAL COMPONENTS OF REVENUE

## TABLE 1.25.1a PACKAGED SOFTWARE REVENUES FOR INDEPENDENT SOFTWARE COMPANIES

| | 1976 ($M) | 1977 ($M) | 1978 ($M) | Growth Rate (% per year) |
|---|---|---|---|---|
| Systems Software | 70 | 85 | 102 | 20.7 |
| Utility Software | 132 | 180 | 243 | 35.7 |
| Application Software | 168 | 235 | 325 | 39.1 |
| Total | 370 | 500 | 670 | 34.6 |

Source: IDC1968.79, as reported in *Computer Business News*, June 18, 1979

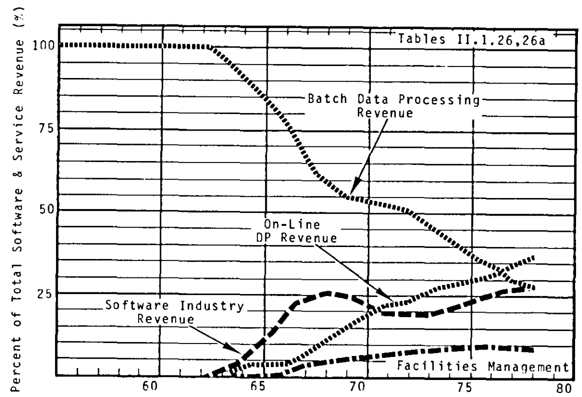


FIGURE 1.26.2a SERVICE INDUSTRY REVENUE II DISTRIBUTION OF PRINCIPAL COMPONENTS

## 1.26a THE DATA PROCESSING SERVICE INDUSTRY

Whereas packaged software has been the fastest-growing component of the software industry, the provision of on-line services has been the outstanding service component, as shown in Figures 1.26.1a and 1.26.2a. Note that the growth of the Facilities Management business has levelled off, as that industry has found it difficult to add new customers in the near-saturated GP computer marketplace.

If we delete software and facilities management, and look at the remaining data processing service components, we find the "interactive," keyboard-oriented applications and the remote batch operations continuing to grow faster than batch data processing. Figure 1.26.2b shows this relationship, and Figure 1.26.3a shows the growth in the interactive component and its parts. Finally, Table 1.26.1a shows how the nine components of DP services looked in 1978. Comparing it with Table 1.26.1 (p. 29 of DPT&E), which gives comparable data for 1971, we note that components which might be called "packaged on-line services" (performing regular calculations, on-line, with vendor's software) have grown the fastest—from $60M in 1971 to over $1B in 1978.

The advent of the Small Business Computer promises to have a major impact on the service industry. Most of its customers are small organizations; as shown in Table 1.26.2a, the average customer of these service firms only paid $7500 in 1976 (up from $4900 in 1971—see Table 1.26.2, p. 29 of DPT&E), and the average customer of the smaller firms paid only $2400. Customers with small DP workloads are potential buyers of SBC's, and in fact some service firms have begun offering SBC products which their customers can "move up" to when they feel they can save money, or get better service with their own computer.

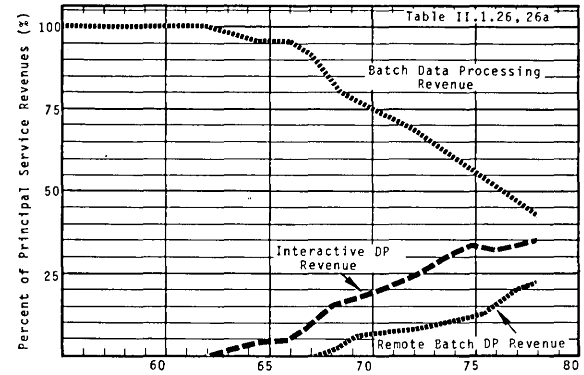



FIGURE 1.26.2b SERVICE INDUSTRY REVENUE III -- DISTRIBUTION OF PRINCIPAL COMPONENTS, EXCLUDING SOFTWARE AND FACILITIES MANAGEMENT

### TABLE 1.26.1a DP SERVICE REVENUES (1978)

| Computer Use | Computer Access Means | | | Total Revenue |
|---|---|---|---|---|
| | Messenger or Mail (Batch) | Computer Terminal (On-Line) | | |
| | | Remote Batch | Keyboard (Interactive) | |
| Raw Power | $60M (1.2%) | $505M (10.3%) | $770M (15.7%) | $1335M (27.2%) |
| Reg. Calc. | $1995M (40.5%) | $555M (11.3%) | $530M (10.8%) | $3080M (62.7%) |
| Com. Files | $45M (0.9%) | $17M (0.3%) | $438M (8.9%) | $500M (10.2%) |
| Total | $2100M (42.7%) | $1077M (21.9%) | $1738M (35.4%) | $4915M (100%) |

Source: IDCBrief79

### TABLE 1.26.2a DP SERVICE FIRMS (1976)

| | Size of Service Firm | | | |
|---|---|---|---|---|
| | Large | Medium | Small | Total |
| Number of Firms | 46 | 145 | 1365 | 1556 |
| Average Revenue | $42M | $4.8M | $0.71M | $2.31M |
| Number of Customers | | | | |
| Average | 1538 | 210 | 295 | 324 |
| Minimum | 300 | 2 | 14 | 2 |
| Maximum | 6000 | 700 | 2000 | 6000 |
| Revenue per Customer | $27.3k | $22.9k | $2.4k | $7.15k |
| Total Customers | 70,748 | 30,450 | 402,675 | 503,873 |

Source: Eleventh Annual ADAPSO. Report, *1977 Annual Report. The Computer Services Industry.* International Data Corp., Sept.77.

## 1.27a DATA PROCESSING SUPPLIES

Annual shipments of supplies for GP computers in the U.S. reached almost $1.7B in 1978, as shown in Figure 1.27.1a, and total supplies shipments, worldwide, by U.S. firms was over $2.1B. (I have drastically revised much of the original DPT&E data here. See Notes to Table II.1.27a for sources.)

**Continuous Forms and Tabulating Cards.** Inflation has driven up the cost of paper, and thus, the price of printer forms and punched cards. Users have found it difficult to cut back on forms usage, and so the paper cost per printer has increased during the past five years (see Figure 1.27.2a). But meanwhile, the increasing use of terminals, for data entry among other purposes, and the reduction in the number of keypunches in use (documented in Sections 1.24a and 1.23a) have made it possible to cut back on card usage with the result shown in Figure 1.27.1a. (The number of cards shipped per year actually declined between 1972 and 1977, though the price per card more than doubled.)

**Magnetic Tape and Disk Packs.** Tape and disk pack revenues have been increasing since the early seventies (Figure 1.27.4a) despite the continuing fall in unit prices (Figure 1.27.5a). In part, the increased sales are due to tape and disk (or more properly, cartridge) use by minicomputers and SBC's, and in Figure 1.27.4a I have estimated how the market is split between these two classes of users.

The average number of tapes on hand per drive continues to increase as users apparently add to their tape archives. The number of disks on hand per spindle has, however, been falling off with each new generation of disk packs. (Figure 1.27.6a displays both disk and tape trends.) As is indicated in Figure 2.16.1a, off-line tape storage is much cheaper than disk storage, and that is surely one factor which influences the decline of disk usage. Another is the fact that the individual disk pack itself has been more expensive with each succeeding generation (see Figure 1.27.5a). Until the advent of the 3340, each new disk pack provided lower cost storage per byte (off-line) than did its predecessor. However, the 3340 pack contains expensive read/write heads, and costs more per byte stored than the old 2314/19 pack. With newer generation MHF drives (3350, 3310, 3370) IBM has

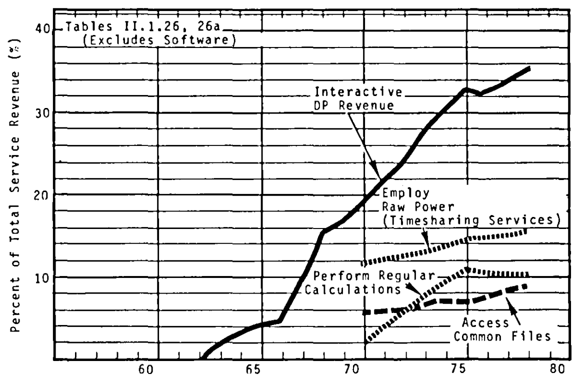



FIGURE 1.26.3a SERVICE INDUSTRY REVENUE IV
DISTRIBUTION OF COMPONENTS OF INTERACTIVE DP REVENUES

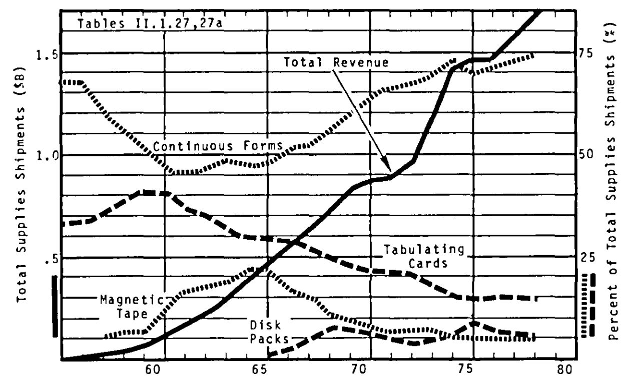



FIGURE 1.27.1a SUPPLIES INDUSTRY REVENUES I
TOTAL DOMESTIC SHIPMENTS FOR GP SYSTEMS

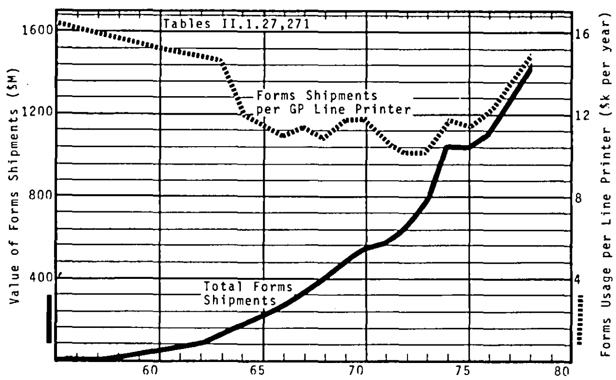



FIGURE 1.27.2a SUPPLIES INDUSTRY REVENUES II.
CONTINUOUS FORMS FOR EDP PRINTERS

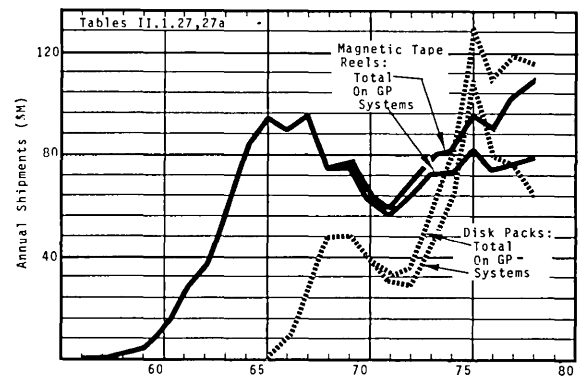



FIGURE 1.27.4a SUPPLIES INDUSTRY REVENUES IV.
MAGNETIC TAPE AND DISK PACK SHIPMENTS

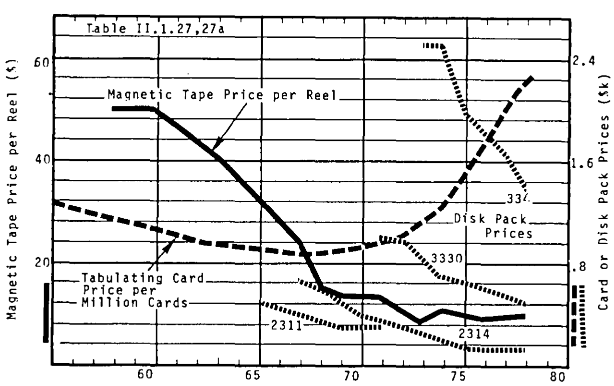



FIGURE 1.27.5a PRICES OF SUPPLIES
MAGNETIC TAPE, TABULATING CARDS, AND DISK PACKS

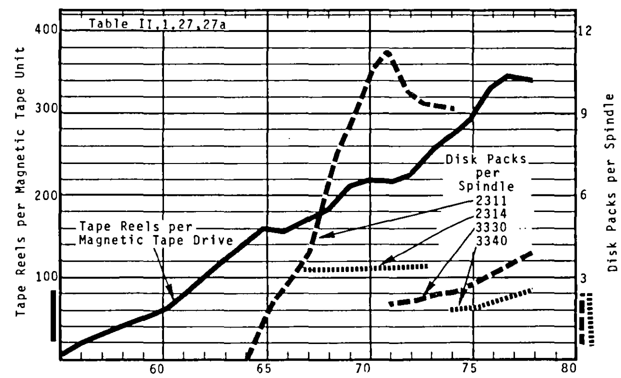



FIGURE 1.27.6a MAGNETIC TAPE AND DISK-PACK INVENTORIES I
TAPES PER DRIVE AND DISKS PER SPINDLE

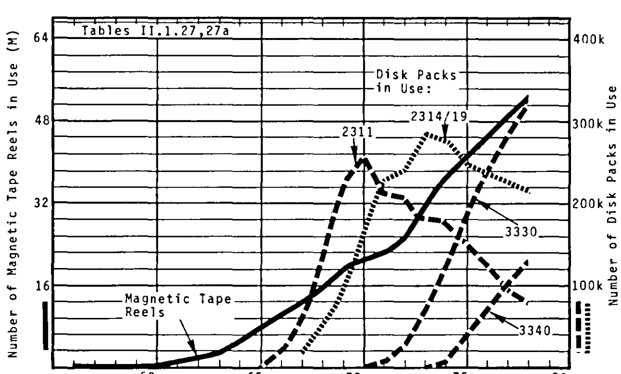



FIGURE 1.27.7a MAGNETIC TAPE AND DISK PACK INVENTORIES II
TOTAL TAPES AND DISK PACKS IN USE

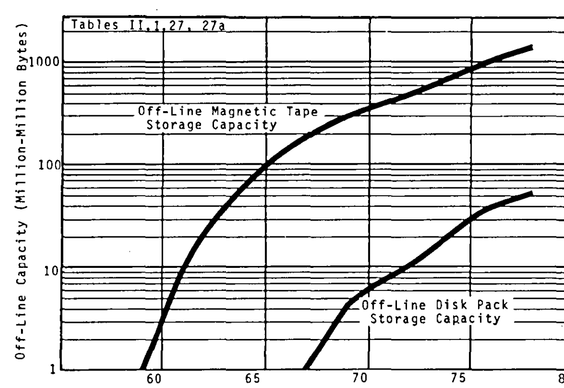



FIGURE 1.27.8a OFF-LINE STORAGE CAPACITY
OF MAGNETIC TAPE AND DISK PACK MEDIA

concluded that off-line disk storage is not necessary, as well as being uneconomic, and has designed fixed-pack units.

Total off-line storage capacity, on disks and tape, is shown in Figure 1.27.8a. Note disk capacity has been increasing relative to tape; in 1969 only 1.3% of off-line data was on disks; by 1978 the figure was 3.6%. Presumably the trend will reverse as the new fixed-pack disks are more widely used.

## 1.3a Companies

### 1.31a SYSTEMS COMPANIES

We have seen (Section 1.21a) that the GP market has leveled off in terms of number of systems in use, that minisystems are continuing to find new applications, and that a small business computer market has sprung up and is growing rapidly. We have also seen that, despite the fact there are far more minis and SBC's shipped than GP systems, GP systems shipment value is far larger than the total of mini and SBC shipment value. This section shows how the business is split among the systems manufacturers.

**Systems in Use.** GP market share is given in Figures 1.31.1a to 1.31.4a, and mini- and SBC system shares in Figures 1.31.6a and 1.31.6b. Comments:

1. IBM's share of the GP market has increased slightly during the past ten years—from 61% of GP systems in use in 1968 to over 66% in 1978. The Systems/32 and /34 were relatively late entries in the SBC market, but immediately made IBM the most successful company there. IBM's minicomputer, the Series/1, has however, been relatively unsuccessful so far—at year-end 1978 it represented only about 1% of the number of minis in use in the U.S.

2. DEC continues to dominate the minicomputer market, and has a respectable position in the SBC market as well. DEC's GP products are comparable to IBM's minis: they represent a small, though growing, proportion of the total.

3. The still-rapidly-growing SBC and mini markets are supplied by a large number of companies: there were 61 active SBC suppliers at year-end 1978, 36 mini suppliers (up from only 21 at year-end 1969), but only 11 GP suppliers. As the markets begin to saturate, the number of competing companies will drop off—some will fail, some will be merged into other companies.

4. Only three companies, IBM, DEC, and Univac, have products in all three markets. Burroughs and NCR have SBC products as well as GP's; Control Data and Honeywell have mini's as well as GP's.

Total value of equipment in use gives us another measure of the relative success of different companies, and Figures 1.31.9a to 1.31.14b show how the market is split. (Note the curves cover the worldwide market *for U.S. manufacturers*, and exclude systems marketed by Japanese and European firms.) Comments:

1. The pre-1974 data and the post-1972 data is not quite comparable in these four figures. The early data is from Table II.1.31.1, and includes 1975-1976 estimates of the value of GP and mini systems as then defined. The later data, from Table II.1.31.1a, takes into account an IDC revision which increased the estimated value in use of GP systems worldwide without changing the number in use. It also includes new-definition GP, mini, and SBC systems

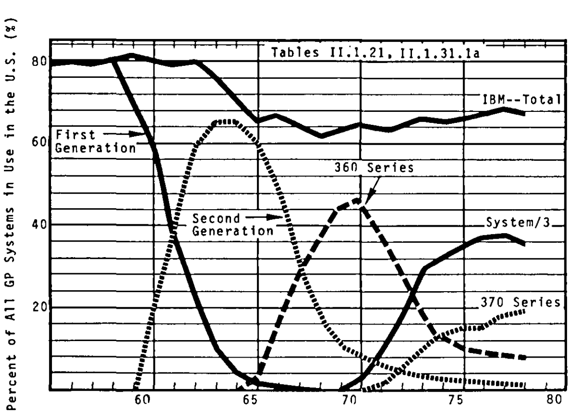



FIGURE 1.31.1a MANUFACTURERS' SHARES OF U.S. GP MARKET I
PERCENT OF NUMBER OF SYSTEMS IN USE--IBM

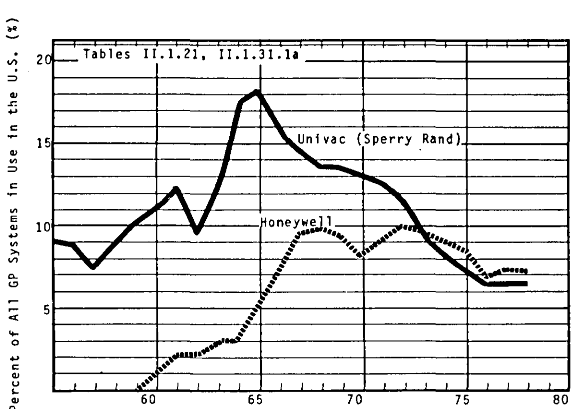



FIGURE 1.31.2a MANUFACTURERS' SHARES OF U.S. GP MARKET II
PERCENT OF NUMBER OF SYSTEMS IN USE--UNIVAC & HONEYWELL

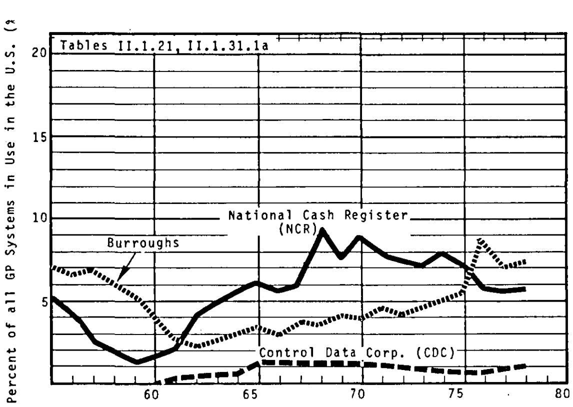



FIGURE 1.31.4a MANUFACTURERS' SHARES OF U.S. GP MARKET III
PERCENT OF NUMBER OF SYSTEMS IN USE--BURROUGHS, NCR, CDC

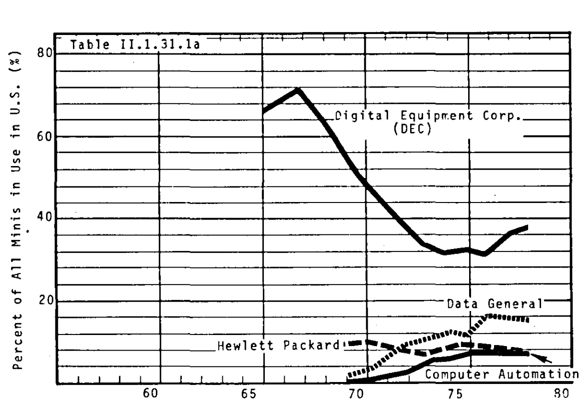



FIGURE 1.31.6a MANUFACTURERS' SHARES OF U.S. MINI MARKET
PERCENT OF NUMBER OF SYSTEMS IN USE

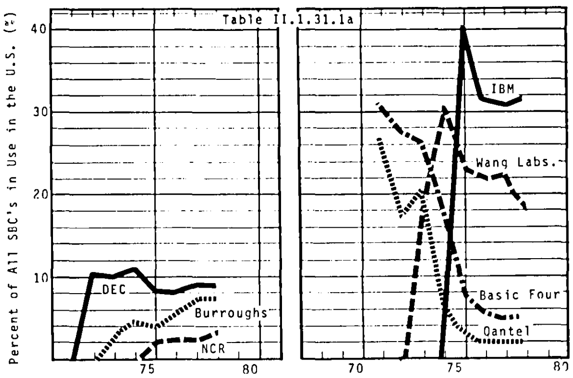



FIGURE 1.31.6b MANUFACTURERS' SHARE OF U.S. SBC MARKET PERCENT OF NUMBER OF SYSTEMS IN USE

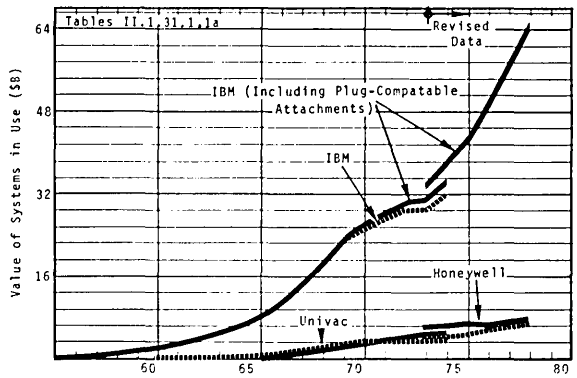



FIGURE 1.31.9a MANUFACTURERS' SHARE OF TOTAL WORLDWIDE MARKET I VALUE OF GP, MINI, AND SBC SYSTEMS IN USE

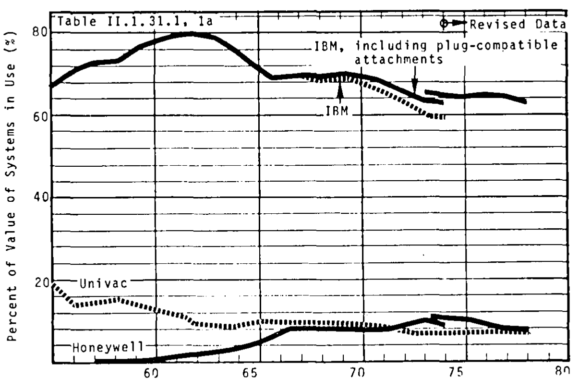



FIGURE 1.31.10a MANUFACTURERS' SHARES OF TOTAL WW MARKET II PERCENT BY VALUE OF GP, MINI, AND SBC SYSTEMS IN USE

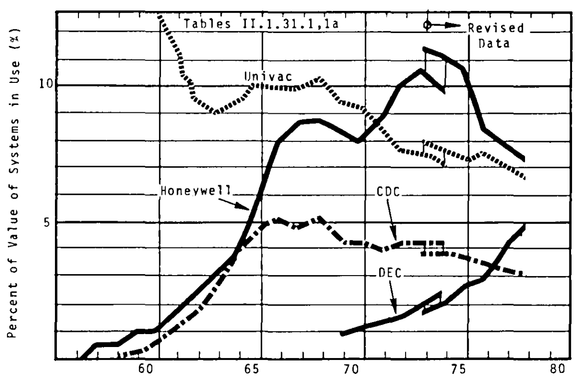



FIGURE 1.31.14a MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET III PERCENT BY VALUE OF GP, MINI, AND SBC SYSTEMS IN USE

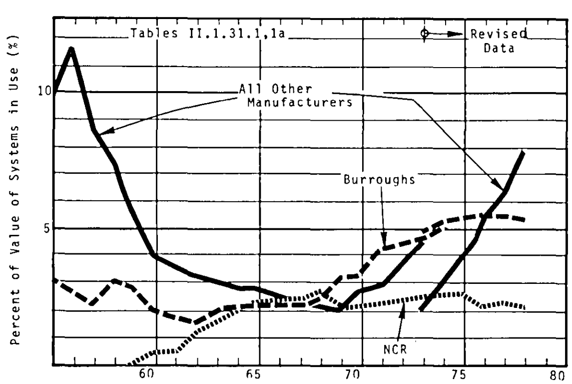



FIGURE 1.31.14b MANUFACTURERS' SHARES OF TOTAL WORLDWIDE MARKET IV - PERCENT BY VALUE OF GP, MINI, & SBC SYSTEMS IN USE

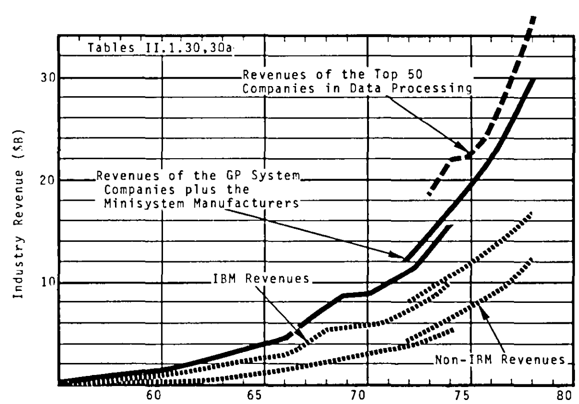



FIGURE 1.31.25a DATA PROCESSING INDUSTRY REVENUES

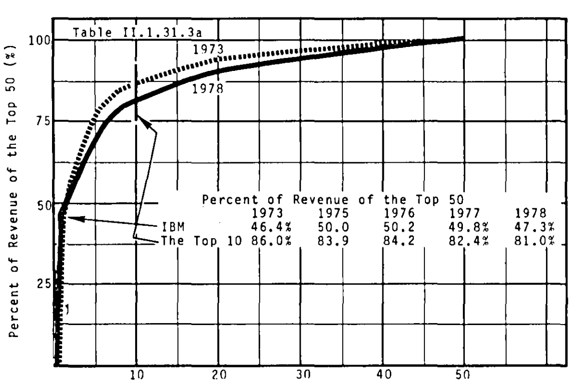



FIGURE 1.31.25b DISTRIBUTION OF REVENUES THE TOP 50 COMPANIES IN THE DP INDUSTRY

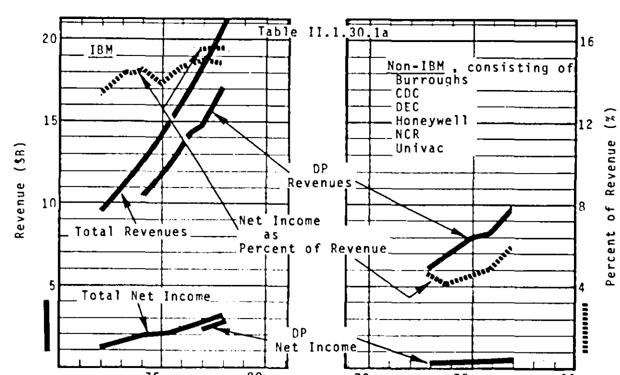



FIGURE 1.31.26a DATA PROCESSING INDUSTRY REVENUES IBM AND NON-IBM REVENUES AND PROFITS

while omitting those classified as "other". A two-year overlap for each curve shows the effect of the changes.

2. Since 1970 Burroughs and DEC have been the only major companies able to increase their market share. Univac and Honeywell have lost ground; NCR has remained static.

3. The miscellaneous manufacturers not explicitly identified, who had a significant share of the market when the GP business was new (Figure 1.31.14b), have again become important: taken together, they grew much faster even than DEC in the past five years.

**Revenues.** Because so many companies supply data processing goods and services, it is difficult to identify them all, or to estimate their total revenues. Figure 1.31.25a shows two different estimates. The first (solid and dotted lines) summarizes revenues from the GP and mini system manufacturers, and breaks the total into IBM and non-IBM portions. (Actually there are two slightly different estimates here. The 1955-1974 data is from DPT&E and is an estimate of hardware revenue only. The 1972-1978 data is from IDC, and includes hardware, software, services, and some supplies revenue.) The other estimate— the dashed line—estimates the revenue of the top 50 firms in the industry. It covers hardware, software, and service firms having DP products, and includes their DP revenue only. Figure 1.31.25b illustrates Pareto's Law: the top 20% of the companies do 80% of the business.

IBM remains by far the most profitable company among the major manufacturers. Figure 1.31.26a shows that IBM's after-tax profit is around 15% of revenue (note that the DP profit rate is higher than that for the company as a whole), and that the other major manufacturers averaged around 5% during the same period. Of these, DEC and Burroughs were the most profitable, with average rates approaching 10%. Honeywell and CDC were the least profitable.

All the data in this section emphasizes and reiterates the fact of IBM's dominance and power.

## 1.310a THE MIDDLE FOUR

Figures 1.310.1a to 1.310.8a show recent results for Burroughs, Honeywell, NCR, and Sperry-Rand. Comments:

1. Honeywell's dip in revenues in 1976 was caused by their divesture of an interest in the French firm Honeywell-Bull—their ownership share fell from 66% to 47%. There was a corresponding drop in percent of revenue from Information Systems, and from International business. The divesture also resulted in an increase in net income as a percent of sales.

2. The proportion of NCR's revenues derived from Retail Systems had fallen from 23% to 17% between 1967 and 1975. However, since the mid-seventies electronic cash registers and systems have reversed the trend as the mechanical cash register is phased out.

3. The Middle Four, along with IBM and CDC, have historically devoted most of their resources to the GP computer market. Figures 1.310.9a and 1.310.10a demonstrate the already-discussed fact that the GP market in the U.S. has saturated, so these manufacturers are fighting over a limited market. (The number of non-IBM systems in use has probably not fallen as sharply as is indicated—probably the "peak" showing at 1973-1975 in Figure 1.21.5c is an estimation error.)

## 1.311a INTERNATIONAL BUSINESS MACHINES

Since the early Fifties, IBM had distinguished three revenue categories: data processing systems, other regular products, and special products. Starting with the 1977 annual report, IBM provided a different breakdown, still having three components: data processing (including machines, programs, programming and systems analysis, education, and related services and supplies), office products (including typewriters, magnetic media typewriters, information processors (sic), document printers, copiers, and related supplies and services), and other (including special information handling products and services for the Federal Government, and educational, training and testing materials and services for school, home, and industrial use.) The percentage of revenues attributed to "data processing" increased slightly with this change, though it is not clear why. (See Figure 1.311.4a).

IBM has sold an increasing proportion of its equipment in the years since 1970, as can be seen from the drop in the proportion of rental and service revenue (Figure 1.311.5a), and in the proportion rental machines and parts are to total IBM property (see Tables II.1.311 and II.1.311.a, line 124). Revenues from data processing equipment rental and services fell below 50% of total IBM revenue for the first time in 1976, and dp equipment sales were over 25% in 1977. (See Figure 1.311.4a)

IBM's after-tax earnings have continued to increase as a percent of revenue, reaching 15% in 1977 (Figure 1.311.8a). However, if we look at IBM's operating income before interest charges (revenue minus direct costs and indirect expenses) as a percent of revenues, we find it has fallen slightly since the mid-sixties—see the dotted line in Figure 1.311.8a. The *increase* in earnings has come about simply

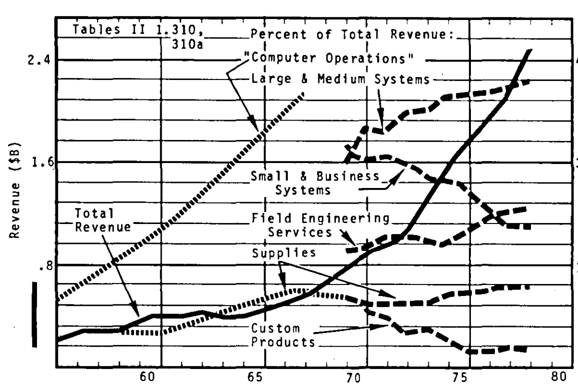



FIGURE 1.310.1a BURROUGHS CORPORATION I
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

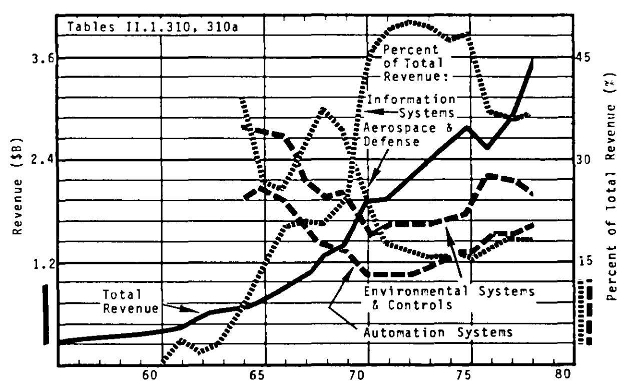



FIGURE 1.310.3a HONEYWELL, INC. I
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

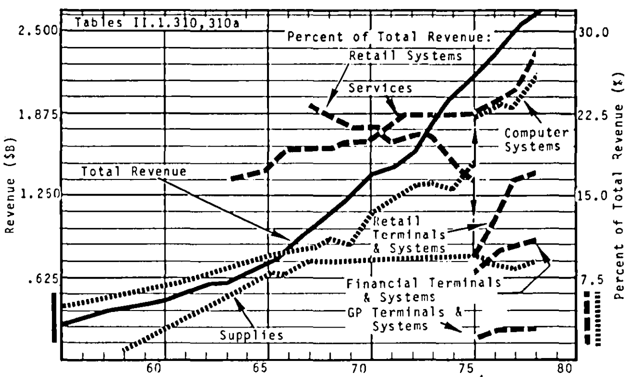


FIGURE 1.310.5a NATIONAL CASH REGISTER (NCR) I
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

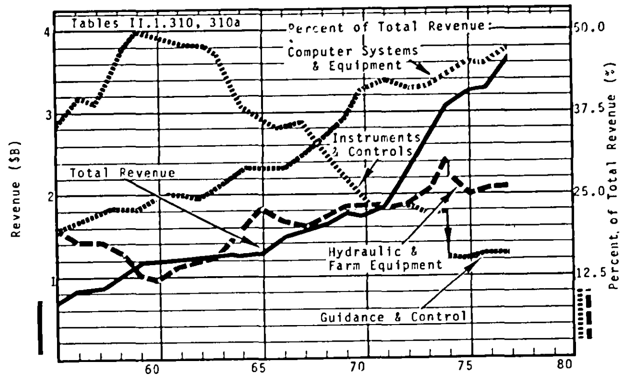


FIGURE 1.310.7a SPERRY-RAND (UNIVAC) I
TOTAL REVENUE AND ITS PRINCIPAL COMPONENTS

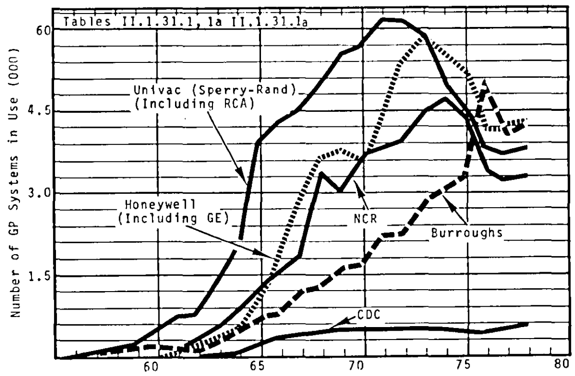


FIGURE 1.310.9a MANUFACTURERS' SHARES OF U.S. GP MARKET
GP SYSTEMS IN USE -- NON-IBM

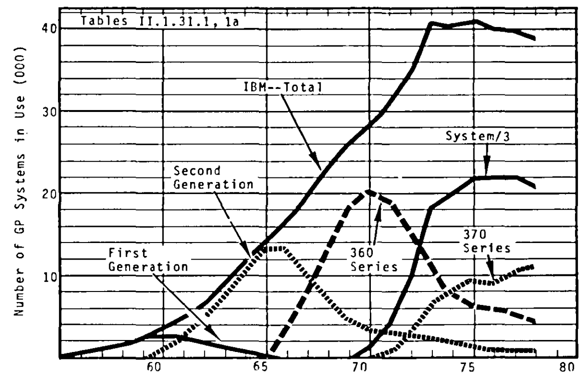


FIGURE 1.310.10a IBM SHARE OF THE U.S. GP MARKET
GP SYSTEMS IN USE

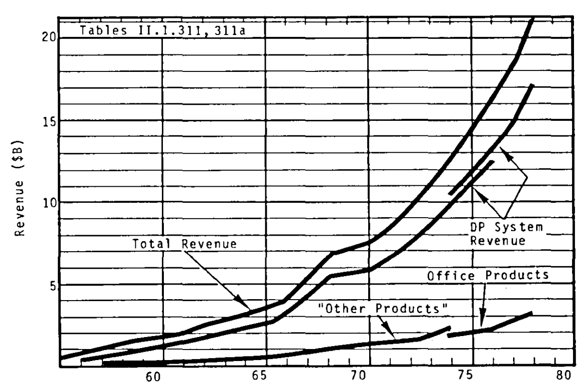


FIGURE 1.311.3a IBM WORLDWIDE REVENUES I
WORLDWIDE REVENUE AND ITS PRINCIPAL COMPONENTS

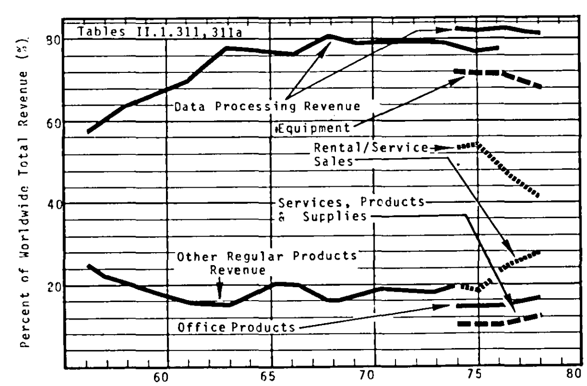


FIGURE 1.311.4a IBM WW REVENUES II
PERCENTAGE DISTRIBUTION TO MAJOR CATEGORIES

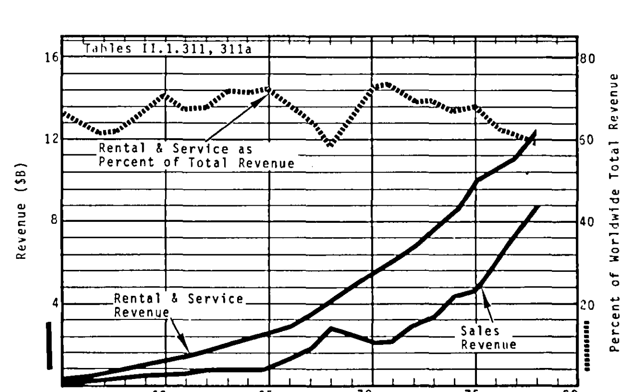


FIGURE 1.311.5a IBM WW SALES AND SERVICE REVENUE

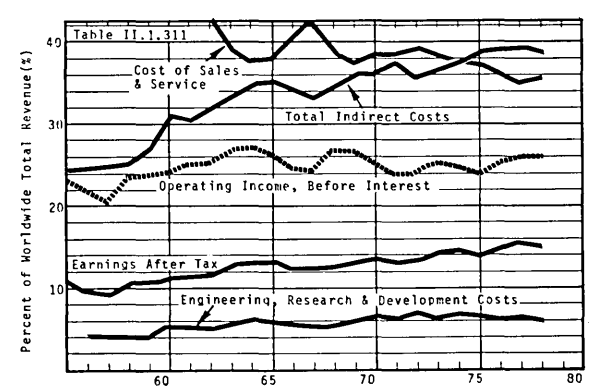


FIGURE 1.311.8a IBM WW COSTS & EARNINGS II
AS PERCENT OF TOTAL WW REVENUE

because of IBM's wealth: the net interest income has increased more than enough to compensate for the drop in operating income. The problem appears to be that IBM's indirect costs are on balance increasing slightly faster than its cost of sales and services are decreasing.

In 1975 IBM's non-U.S. revenue exceeded domestic revenue for the first time, as shown in Figure 1.311.9a. Overseas revenues have grown faster than U.S. revenues ever since IBM started reporting them, and it seems likely that the gap between foreign and U.S. sales will increase.

More than 300,000 people work for IBM world-wide. In 1965, when IBM stopped breaking down employment into its U.S. and WTC components, the revenue per employee was higher in the U.S. The situation had reversed by 1975, when non-U.S. employment data again was available. Only 45% of IBM's employees work outside the U.S., but they produce more than half the revenue (Figure 1.311.15a).

### 1.4a PERSONNEL

U.S. industry continues to find jobs for new employees, and the labor force continues to increase. It should reach 100 million by the end of 1980, and perhaps by the end of 1979. And despite (or perhaps because of) the increasing use of computers, professional and clerical personnel continue to increase as a percentage of the total—see Figure 1.4.1a.

Computer-related occupations have of course grown faster than the total work force, and the population of user personnel (Figure 1.4.2a) has grown fastest. However, the numbers shown are conservative, for two reasons: they only include people working with GP and mini computers, ignoring the operators, programmers, and others who work with SBC's; and they make no attempt at estimating the increasing number of people who work at least part-time at computer terminals. We have seen (Figure 1.24.5a) there were more than 2.5 million of these terminals in use in the U.S. at the end of 1978. Thus, if we were to assume that there was a full-time "computer terminal operator" at each terminal, the number of user personnel at year-end 1978 would more than double. Certainly that would not be fair, for many terminals are in use only part-time, by people (e.g. department store sales clerks, stock brokers, airline ticket salesmen, bank tellers) who have other responsibilities. But the recent levelling off of the population of keypunch operators (see Fig. 1.4.2a) is certainly due largely to the fact that more and more data entry is being accomplished through terminals, and the upper curve of Figure 1.4.2a doesn't include that new manpower.

The population growth of GP system supplier personnel is summarized in Figures 1.4.3a and 1.4.4a, and the total is shown as a solid line in Figure 1.4.5a. Comments:

1. The population of manufacturing direct labor personnel, shown by the solid line in Figure 1.4.3a, fluctuates with fluctuations in system shipments. It has remained in the range 40,000 to 60,000 over the past ten years, in part because of the levelling off of GP shipments, and in part because of increased manufacturing productivity: in 1969, direct labor cost 9.8% of shipments; by 1973, the figure was less than 6.8%.

2. The population of customer engineers first exceeded that of sales people during the mid-seventies (see Figure 1.4.4a). The evidence available indicates that sales and maintenance productivity have not improved, as manufacturing productivity has, so these populations have continued to increase— sales populations reflecting fluctuations in annual sales, and CE populations reflecting the continuing increase in value of equipment in use.

3. Once again, the figures shown are conservative, because they do not count personnel involved in the development, manufacture, and, distribution of mini and SBC systems or of peripheral and memory equipment provided by the "independents." (They also do not include the many clerical, administrative, and management personnel in the companies which supply GP systems). One measure of total industry employment is provided by the Department of Commerce's analysis of the Electronic Computing Equipment manufacturing industry (SIC code 3573 and its predecessor 3571, which included calculators and accounting machines as well as computers). The dashed line in Figure 1.4.5a shows the Department of Commerce data. The growing population difference between the solid and dashed lines undoubtedly reflects, in part at least, the fact that the mini, SBC, and peripheral equipment business have in recent years grown faster than the GP business.

4. The SIC code employment figures include only the employees of plants which are primarily engaged in manufacturing computing equipment. It does not include R&D, management, sales, or service people in other plants (offices) of the manufacturing companies. The points connected by dotted lines at the top of Figure 1.4.5a include estimates of these auxiliary people, and also estimates of people engaged in supplying computer software and services. Note, however, that even this large population is only a fraction of the user population shown in Figure 1.4.2a.

The last three figures bring the data on computer-related salaries up to date.

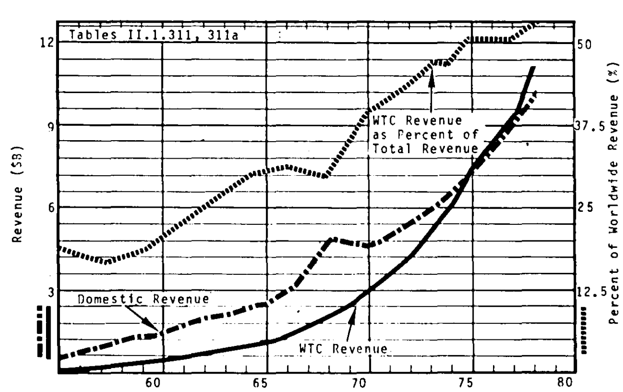



FIGURE 1.311.9a IBM DOMESTIC AND WTC REVENUE I

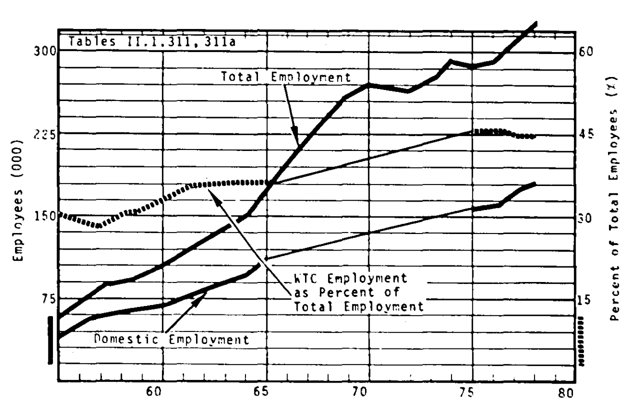



FIGURE 1.311.15a IBM EMPLOYMENT

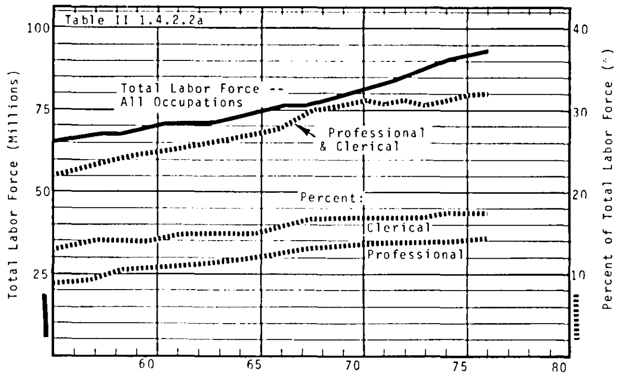



FIGURE 1.4.1a THE U.S. LABOR FORCE
ENUMERATION OF SOME WHITE-COLLAR WORKERS

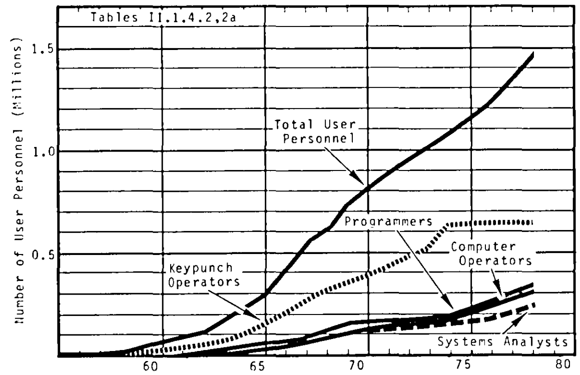



FIGURE 1.4.2a COMPUTER SYSTEM USERS' PERSONNEL

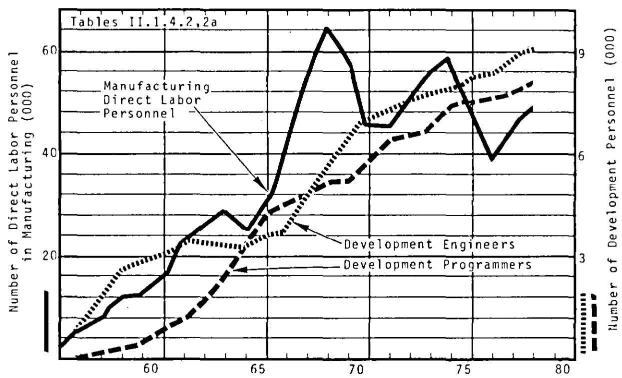



FIGURE 1.4.3a COMPUTERS EQUIPMENT SUPPLIERS' PERSONNEL I
MANUFACTURING AND DEVELOPMENT PEOPLE

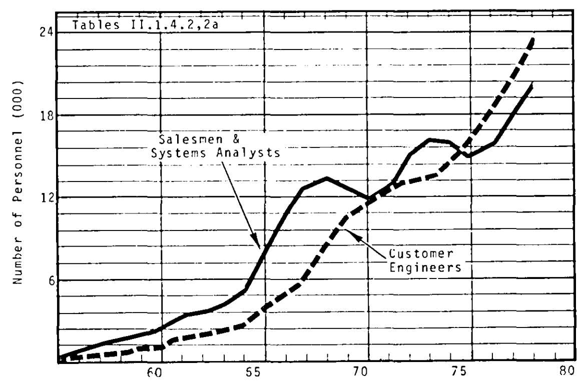



FIGURE 1.4.4a COMPUTER EQUIPMENT SUPPLIERS' PERSONNEL II
SALES AND MAINTENANCE PEOPLE

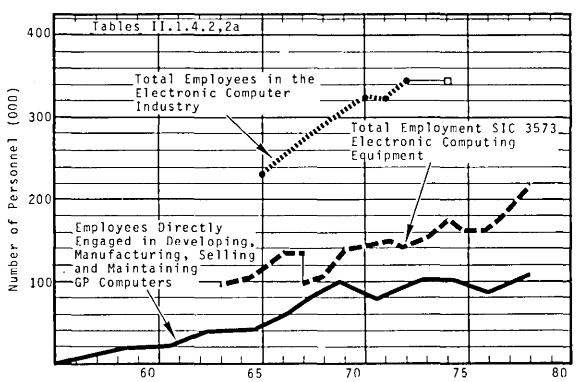



FIGURE 1.4.5a COMPUTER EQUIPMENT SUPPLIERS' PERSONNEL

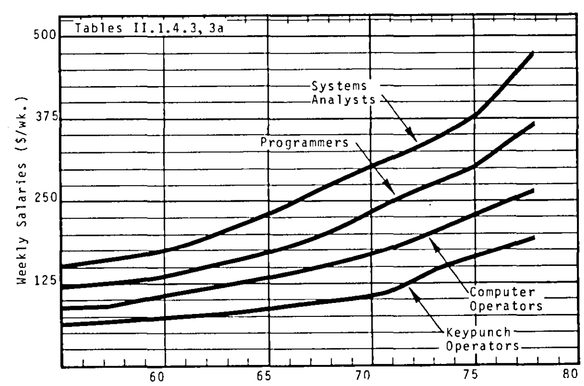



FIGURE 1.4.6a SOME KEY SALARIES I

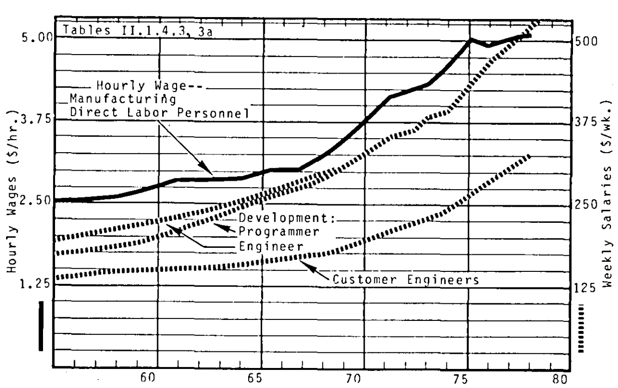



FIGURE 1.4.7a SOME KEY SALARIES II
SUPPLIER PERSONNEL (WEEKLY) AND HOURLY PAY

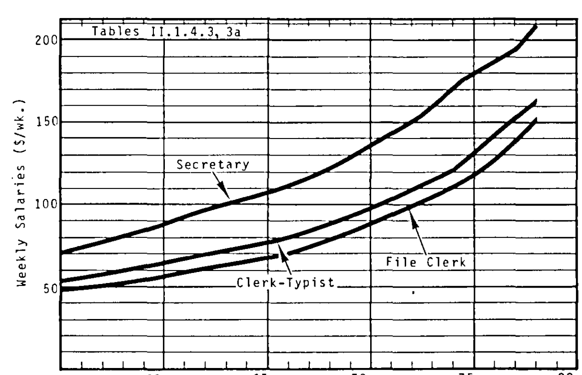



FIGURE 1.4.8a SOME KEY SALARIES III
WEEKLY PAY OF CLERICAL PERSONNEL

# 2.0 PRODUCTS

## 2.1 Unit Performance and Price

### 2.11 PROCESSORS AND THEIR INTERNAL MEMORIES

**Important Products.** Figures 2.10.1a to 2.10.7a show that the most important computer products, defined by numbers, value or computer power in use at any time, continue to be systems designed and manufactured by IBM. The exception is in the minicomputer marketplace, where IBM's entry, the System 1, has had little impact: by year-end 1978, more than two years after the first system was installed, there were only about 3000 in use in the U.S. The minicomputer marketplace (defined to include "other" computers, as was done in developing Figure 2.10.3 on page 59; or employing IDC's new definition, as plotted here in Figure 2.10.3a) is dominated by DEC, and DEC machines continue to be the most important in terms of number and (though the data is not shown here) value and computing power, as well.

In the SBC market, IBM's System 32 was a late entry, but now leads the field. In fact, if we look on the SBC as simply the low-price part of the GP marketplace, we would have to say that IBM's System 3 had been the leading small business computer until about 1977, when the System 32 took over—by the end of 1977 there were more 32's than System 3/10's. IBM's low-entry products seem always to be priced at the high end of the price range in which they compete, and other manufacturers, able to offer comparable systems at prices lower than the cheapest System 3, were able to enter what we now call the SBC business. When IBM finally responded, the lower-cost Systems 32 and 34 immediately captured a dominant position.

**Raw Performance** Trends in add times, arithmetic speeds, and memory cycle times and data rates appear in Figures 2.11.1a to 2.11.5a. Comments:

1. The pairs of dotted lines in Figures 2.11.1a to 2.11.7a connect points representing IBM computers in comparable price ranges. In each figure, one line connects the 650, 1401, 360/30, 370/115, and 4331, all in the $4k to $8k per month price range; the other line connects the 709, 7090, 360/65, 370/155, and 3031, all roughly in the $40k to $64k per month price range. Looking at the trends, we observe the improvements in elementary operation times have slowed. The very fastest of today's computers (the Cray 1, the CDC Star) have reached the point where designers must take into account the speed-of-light limit on signal speeds, and while that limitation does not seriously affect the design of the main-line products we are discussing here, it indicates the kinds of problems designers must face as they keep pressing for better performance. The rapid gains achieved in the fifties and early sixties came about first because improvements in technology made it economically and technically feasible to build memories and arithmetic-logic units which operated in parallel, where early systems had been serial. Later increases in raw speed came from improvements in circuits and core memory technology. Future improvements will come from improvements in semiconductor electronics.

2. In the mid-sixties, the Burroughs 5500, the CDC 6600, and the Univac 1108 all provided exceptional performance

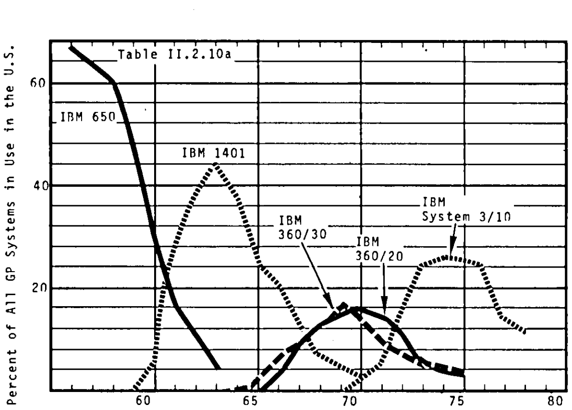



FIGURE 2.10.1a THE IMPORTANT COMPUTERS I
GP SYSTEMS HAVING THE GREATEST NUMBER IN USE IN THE U.S.

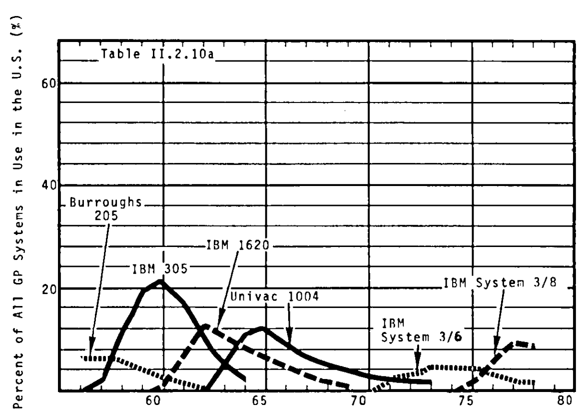



FIGURE 2.10.2a THE IMPORTANT COMPUTERS II
GP SYSTEMS HAVING THE SECOND GREATEST NUMBER IN USE IN THE U.S.

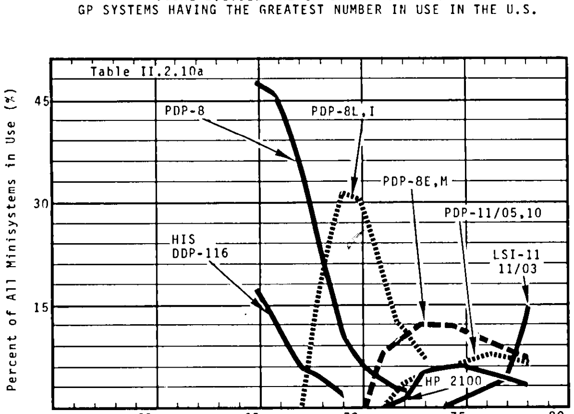



FIGURE 2.10.3a THE IMPORTANT COMPUTERS III
MINISYSTEMS HAVING THE GREATEST NUMBER IN USE IN THE U.S.

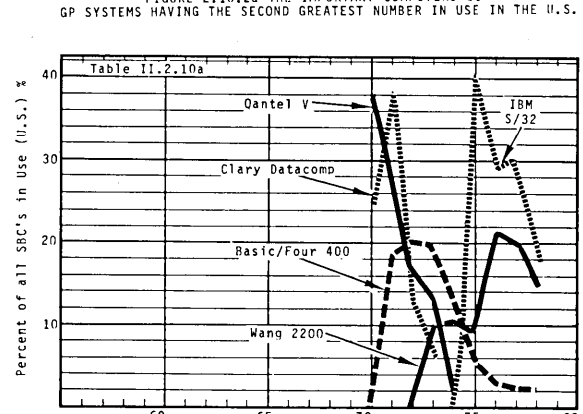



FIGURE 2.10.3b THE IMPORTANT COMPUTERS IV.
SBC'S HAVING THE GREATEST NUMBER IN USE IN THE U.S.

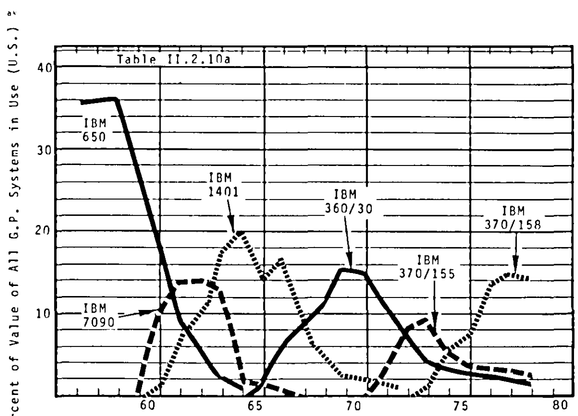


FIGURE 2.10.4a THE IMPORTANT COMPUTERS V
GP SYSTEMS HAVING THE GREATEST VALUE IN USE IN THE U.S.

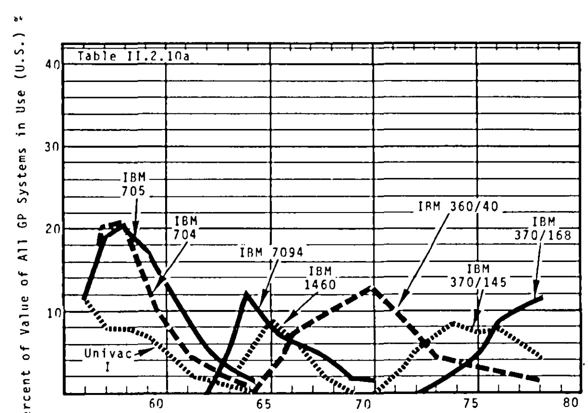


FIGURE 2.10.5a THE IMPORTANT COMPUTERS VI
GP SYSTEMS HAVING THE SECOND GREATEST VALUE IN USE IN THE U.S.

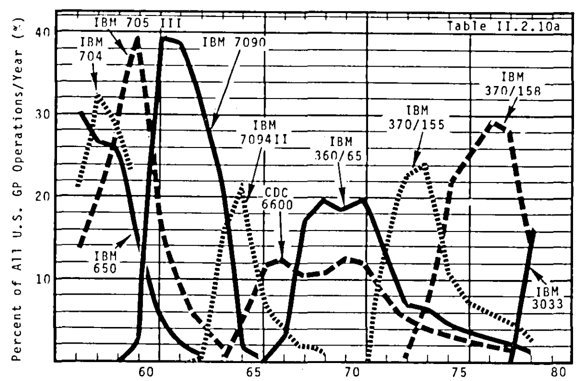


FIGURE 2.10.6a THE IMPORTANT COMPUTERS VII
GP SYSTEMS PERFORMING MOST OPERATIONS PER YEAR IN THE U.S.

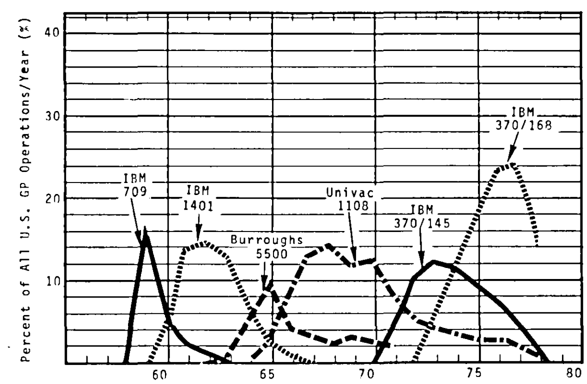


FIGURE 2.10.7a THE IMPORTANT COMPUTERS VIII
GP SYSTEMS PERFORMING SECOND MOST OPERATIONS PER YEAR IN U.S.

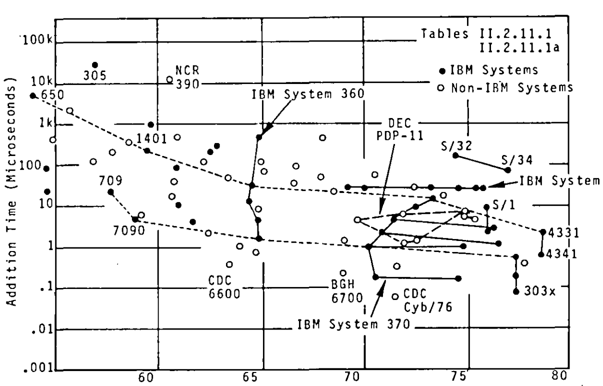


FIGURE 2.11.1a PROCESSOR PERFORMANCE I
ADDITION TIME

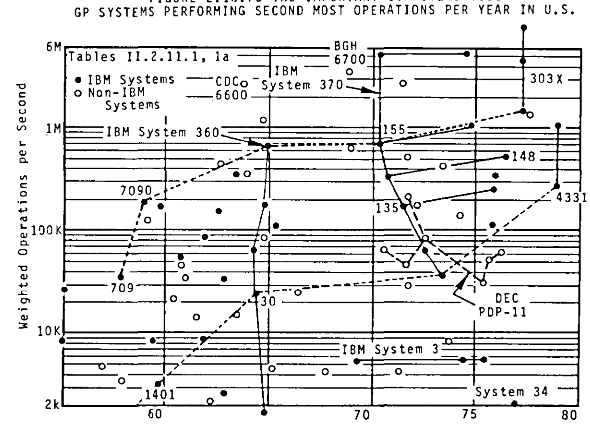


FIGURE 2.11.2a PROCESSOR PERFORMANCE II
WEIGHTED ARITHEMETIC SPEED

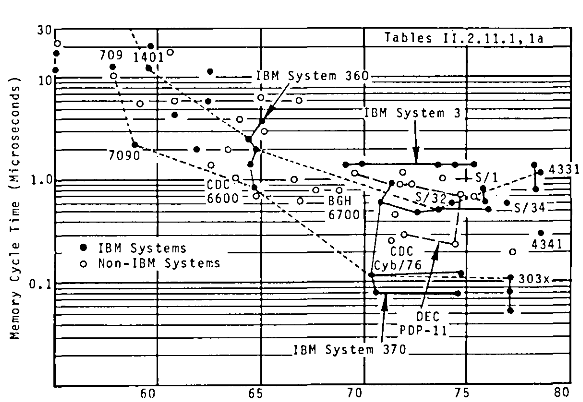


FIGURE 2.11.4a PROCESSOR PERFORMANCE IV
MEMORY CYCLE TIME

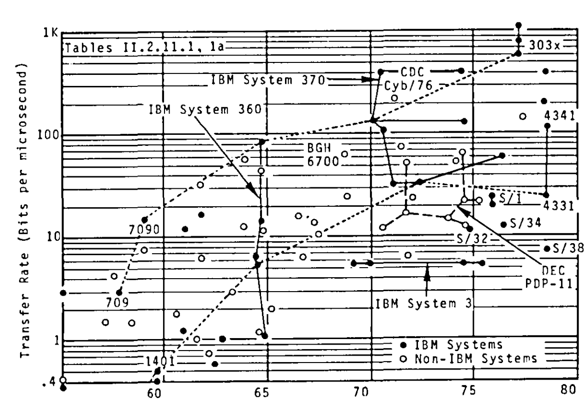


FIGURE 2.11.5a PROCESSOR PERFORMANCE V
MEMORY DATA TRANSFER RATES

per dollar—far better than that supplied by IBM 360's (see Figures 2.11.6a and 2.11.7a). IBM tried to counter by offering the cut-rate 360/44. But customers generally recognized the superior products offered by IBM's competitors, and the three computers were very successful—as we saw in Section 2.10. None of the three has been nearly as successful with their follow-on products—though perhaps Burroughs came closest with the 6700.

3. Examining Figure 2.11.7a, we observe that there was little or no improvement in operations per dollar between IBM's 360 and 370 family. The 360/65 provided 28 million operations per dollar spent on processor rental; so did the 370/155. The 360/30 provided 13 million; the 370/115 only 8.7 million. These strange results (strange because a new generation and new technology apparently brought no improvement in performance per unit cost) stem from a change in IBM's pricing strategy. With its second and third generation systems, IBM established a relatively low price for the processor and a relatively high price for core memory increments. Competition from suppliers of add-on memory led IBM to change that strategy when introducing the System 370 (see discussion, pp. 63-64). As a result, the *processor-alone* prices of the 370 systems are much higher than those for comparable 360 Systems—compare the 360/30 in Figure 2.11.9a with the 370/115 in Figure 2.11.10a, for example.

One set of "raw performance" measurements have been recently made at Kolence's Institute for Software Engineering, (see Kolek76,79). Kolence has designed and has been conducting a series of carefully-described, reproducable experiments aimed at measuring CPU performance. There are two kinds of experiments. In the first, a system is dedicated to the measurement, one or more program "kernels" are loaded, each kernel is timed for short runs to be sure the system software is quiescent, and finally the CPU is run for 50 to 200 seconds while the number of executions of the kernel is counted. Three different kernels have been used, and for a given machine the measurements are quite reproducable—within 1% of one another on two 370/158-3 systems, for example. The kernels are small enough that they fit within the system cache memory, so the results are independent of cache "hit rate", and represent the highest possible processor speed.

The second kind of experiment is run while the system is in normal use, and requires the use of special test hardware and "probes" connected to the system under measurement. The hardware measures total elapsed time, and samples and records data on the characteristics of every millionth instruction executed; and that data is later analyzed to determine processor performance. In order for the samples to be numerous enough to be statistically significant, the experiment may be run for hours. It does not, of course, give reproducable results, for performance will be a function of the job mix over the period of time the experiment is conducted. In addition, it obviously measures total instruction rates including execution of the operating system instructions; and it is affected by CPU idle times, if the system is not kept busy.

The results of a first set of measurements are shown in Table 2.11.1a. Comments:

1. The user runs (hardware measurements) on the 168-3 gave results almost as good as the fastest kernel, despite the fact that they were presumably affected by CPU waits and

**TABLE 2.11.1a CPU PERFORMANCE MEASUREMENTS**

| Processor | CPU Millions of Instructions/Second Benchmark Using Kernels | | | | Ratios Assuming the 168-3 = 124 |
|---|---|---|---|---|---|
| | C05 Moves & Compares | S01 Engineer. Calcs. | C01 Decimal Arith. | Average* | |
| **IBM** | | | | | |
| 360/65 | 0.135 | 0.562 | 0.208 | 0.241 | 27.0 |
| 370/168-3 | 0.781 | 2.400 | 0.840 | 1.106 | 124.0 |
| 370/158-3 | 0.314 | 0.822 | 0.341 | 0.433 | 48.5 |
| 370/148 | 0.153 | 0.240 | 0.067 | 0.112 | 12.6 |
| 3033 | 1.677 | 5.200 | 1.287 | 1.963 | 220.1 |
| 3032 | 0.779 | 2.403 | 0.839 | 1.104 | 123.8 |
| 3031 | 0.408 | 0.897 | 0.394 | 0.510 | 57.2 |
| **Amdahl** | | | | | |
| 470-V7 | 1.777 | 6.209 | 1.884 | 2.552 | 286.1 |
| 470-V6 | 1.426 | 5.090 | 1.454 | 2.012 | 225.6 |
| 470-V5 | 0.806 | 4.112 | 1.085 | 1.388 | 155.6 |

The instruction mix in the kernels was chosen to give a range of memory accesses per instruction 32.4 bytes per instruction for C05, 5.8 for S01, and 12.6 for C01.

Hardware monitor measurements of a 370/168-3 running user jobs disclosed a speed of 2.35 MIPS at 6.15 bytes per instruction.

*The Average is computed by dividing total number of instructions executed by the three benchmarks by the total time required to complete them. The Ratios in the last column are computed from the Averages.

Source: KoleK79

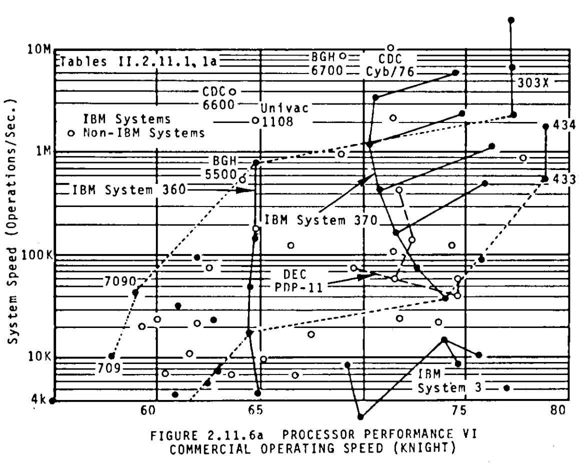



FIGURE 2.11.6a PROCESSOR PERFORMANCE VI
COMMERCIAL OPERATING SPEED (KNIGHT)

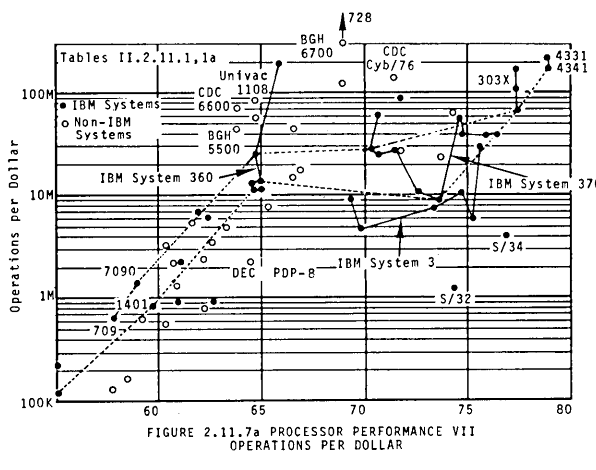



FIGURE 2.11.7a PROCESSOR PERFORMANCE VII
OPERATIONS PER DOLLAR

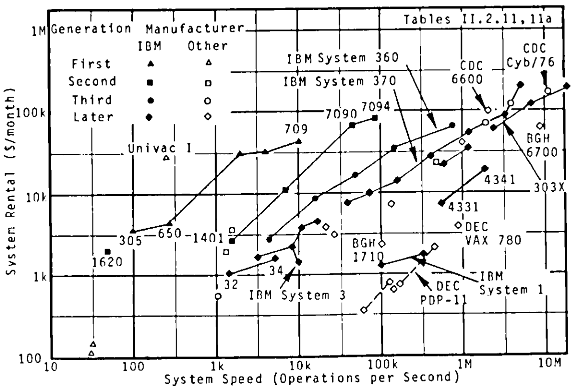



FIGURE 2.11.8a PROCESSOR PERFORMANCE VIII
COMMERCIAL OPERATING SPEED VS. SYSTEM RENTAL

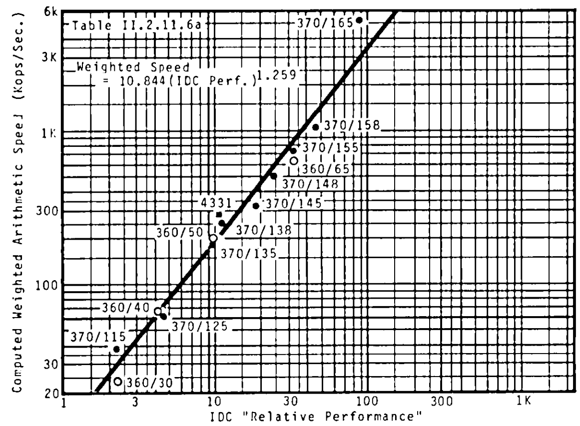



FIGURE 2.11.8b PROCESSOR PERFORMANCE IX
RELATIVE PERFORMANCE VS. WEIGHTED ARITHMETIC SPEED

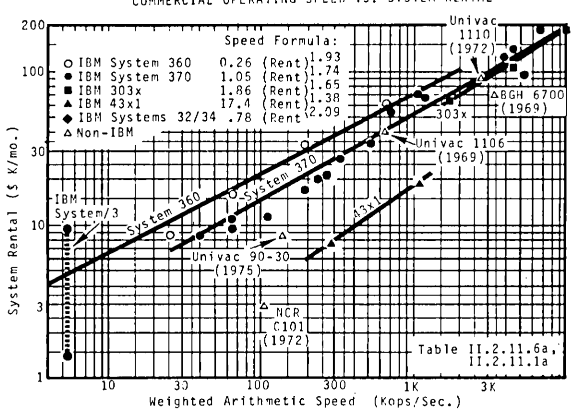



FIGURE 2.11.8c PROCESSOR PERFORMANCE X
SOME EVIDENCE FAVORING GROSCH'S LAW

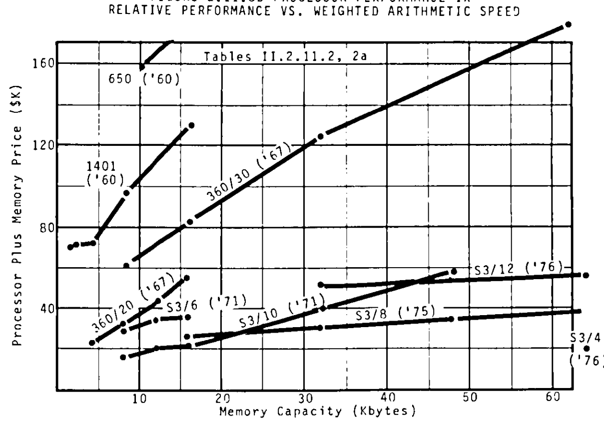



FIGURE 2.11.9a SYSTEM MEMORY CAPACITY AND PRICE I

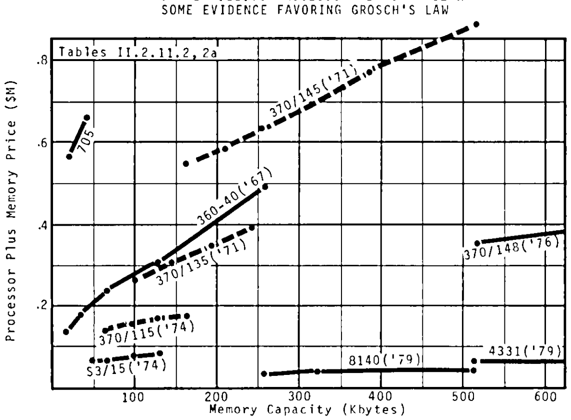



FIGURE 2.11.10a SYSTEM MEMORY CAPACITY AND PRICE II

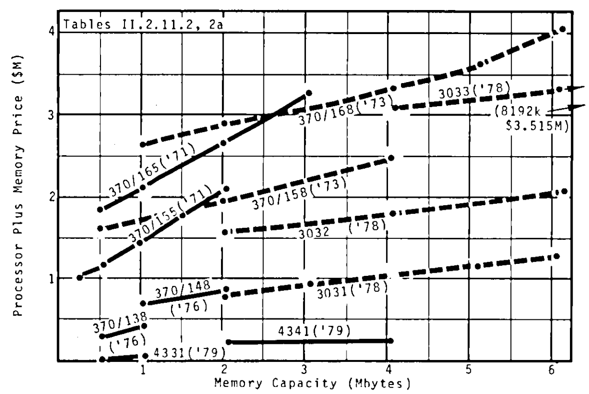



FIGURE 2.11.11a SYSTEM MEMORY CAPACITY AND PRICE III

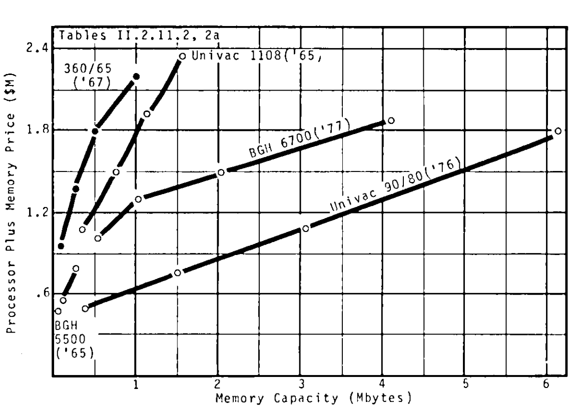



FIGURE 2.11.11b SYSTEM MEMORY CAPACITY AND PRICE IV

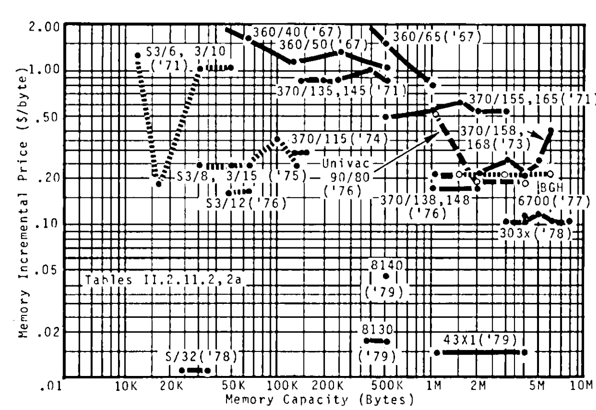



FIGURE 2.11.12a INTERNAL MEMORY PRICE/BYTE VS. CAPACITY

cache "misses" (See Footnote to table.) Apparently the kernels are more complex than representative real programs.

2. The Kolence averages give performance ratios for the IBM computers remarkably similar to those generally used in the industry—compare with the IDC ratios in Table II.2.11.6a.

**Knight's Performance Measure.** It is Knight's Commercial performance measure which forms the basis for Figures 2.11.7a and 2.11.8a (see definition and discussions on pp. 62, 358-359, of DPT&E, and in the notes to line 14 of Table II.2.11.1a of this Supplement). Knight's calculations led him to "confirm" Grosch's Law (p. 62b), or at least to conclude that performance and price are not linearly related. Thus if, for example, we perform a least-squares fit calculation of the form (System Speed) = Constant x (System Rental)$^k$, we find $k = 1.66$ for the 360/20, 30, 40, 50, 65, and $k = 1.74$ for the 370/115, 125, 135, 145, 155.

It may, however, be argued that Knight's measure is artificial, inasmuch as it arbitrarily assigns weights to such things as word length and memory size. If we were to use other measures for performance, what would we find? One possible measure is weighted arithmetic speed—the factor plotted in Figure 2.11.2a, computed assuming an instruction mix of 95% additions, 5% multiplications. A second often-used measure is a ratio of performance to that of some arbitrary reference. Manufacturers often use such ratios in describing the performance of new systems. Figure 2.11.8b shows that there is fairly good correlation between relative performance (collected by International Data Corp. from IBM announcements over the years) and weighted speed, for the IBM computers for which instruction speeds have been published. Figure 2.11.8c plots system rental vs. weighted arithmetic speed for a number of systems, and shows that speed increases with rent raised to some power between 1.38 and 2.09 for various IBM families. (Substituting the weighted speed vs. relative performance equation of Figure 2.11.8b into these same equations leads us to conclude that relative performance varies with the 1.1 to 1.5 power of rental, depending on the family.) From this evidence, it certainly appears that system pricing is departing farther and farther from Grosch's Law as time goes on. However, we must remember that the performance of the 303x's and the 4341 are based on approximations, since IBM has not yet published instruction timing data. When we have better data, and when more system family members are announced and shipped, the price-performance relationship may change.

**Memory Pricing.** Recent data on internal memory pricing appears in Figures 2.11.9a to 2.11.12a. (Dates shown are dates the prices were effective, not dates the systems were introduced.) Comments:

1. The increases in processor prices which accompanied decreases in incremental memory prices are nicely illustrated in Figure 2.11.11a: compare the 370/155 and /165 with the 370/158 and /168.

2. As remarkable as the reduction in per-byte cost is the increase in available capacity. Note the increase from one generation to the next. Taking the 650 maximum memory at 1, we see 650 : 1401 : 360/30 : 370/115 : 4331 = 1 : 1 : 4 : 8 : 50.

3. IBM's competitors generally match or better the big company's prices. In the mid-sixties, the Univac 1108 and Burroughs 5500 competed effectively with IBM's 360/65, as shown in Figure 2.11.11b. And the Univac 90-80 and Burroughs 6700 compete favorably with the IBM 370/158, as can be seen in both Figure 2.11.11b and 2.11.12a.

4. The staggering reductions in incremental price per byte are well illustrated in Figure 2.11.12a. Comparing it with Figure 2.11.12 on p. 65, we see we have had to shift the scale down by a full decimal order of magnitude to accomodate recently-announced machines. The 8130, 8140, 4331 and 4341 systems all make use of IBM's new 65 Kbit IC memory chip, which presumably helps account for the low cost per byte.

Trends in monthly rentals, and in maintenance and purchase prices appear in Figures 2.11.13a to 2.11.16a. The almost uniform upward trend in maintenance prices, driven by inflation and a high labor content, are notable.

**Small Business Computers.** We saw in Section 1.21a that the SBC is one of the fastest-growing segments of the computer industry. Table 2.11.2a provides a quick look at the characteristics of some of the leading products, from the user's point of view. They are low-priced, data-base oriented, typically encourage on-line data entry, and are offered with various kinds of applications programs. The hardware is generally not emphasized, for the small business user just wants his job done, economically and reliably, with no talk about bits and microseconds. But under the covers and out of sight, typically, is a minicomputer, often manufactured by DEC or Data General, and incorporated into a saleable package by a smaller company. (The more successful companies produce their own minicomputers—of the companies named in Table 2.11.2a, only Basic/4 used another company's computer.)

We have seen that SBC's are not so much a new and

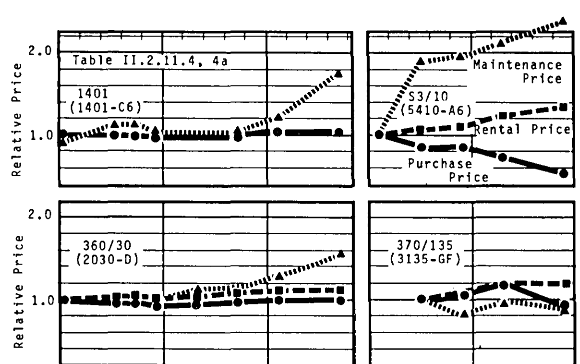



FIGURE 2.11.13a HISTORY OF IBM PRICING I
PROCESSOR PRICING RELATIVE TO A FIRST YEAR

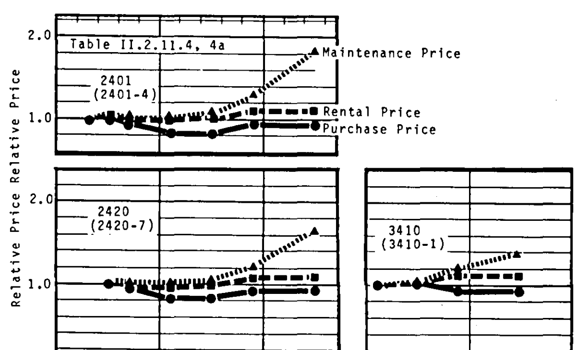



FIGURE 2.11.14a HISTORY OF IBM PRICING II
TAPE UNIT PRICING RELATIVE TO A FIRST YEAR

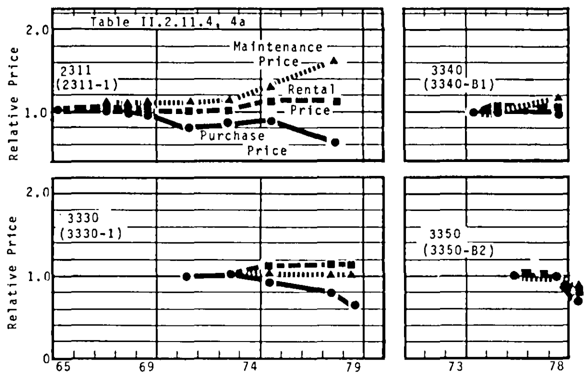



FIGURE 2.11.15a HISTORY OF IBM PRICING III
MOVING-HEAD FILE PRICING RELATIVE TO A FIRST YEAR

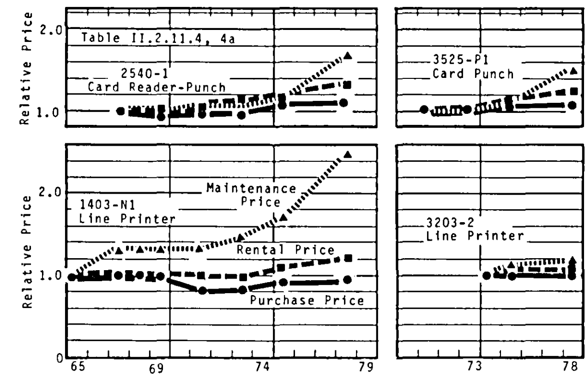



FIGURE 2.11.16a HISTORY OF IBM PRICING IV
UNIT RECORD EQUIPMENT PRICING RELATIVE TO A FIRST YEAR

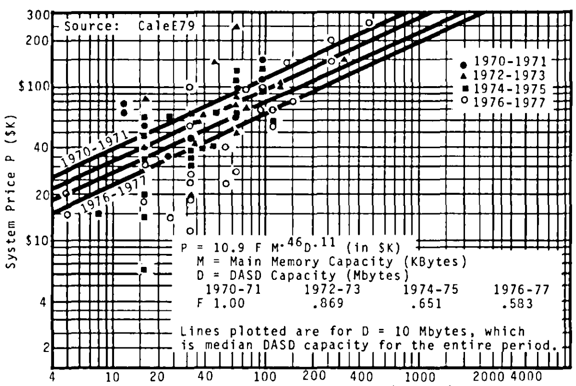



FIGURE 2.11.17a SMALL BUSINESS COMPUTERS
PRICE-MEMORY CORRELATIONS FOR DIFFERENT YEARS

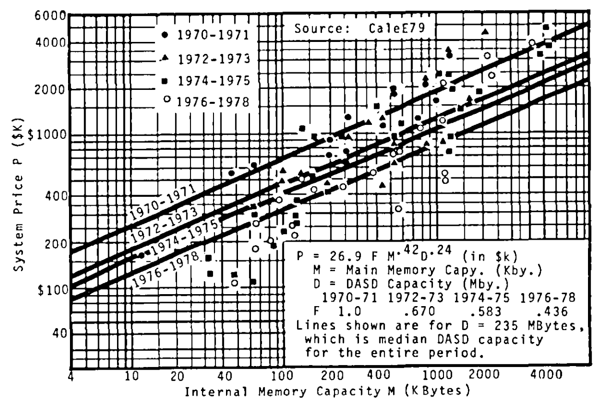



FIGURE 2.11.18a GENERAL-PURPOSE COMPUTERS
PRICE-MEMORY CORRELATIONS FOR DIFFERENT YEARS

## TABLE 2.11.2a SMALL BUSINESS COMPUTERS

| Computer | | Basic/4 400 | Burroughs B 700 | DEC 310 | DEC 357 | DEC 530 | IBM S/32 | IBM S/34 | NCR 8250 | Wang 2200T |
|---|---|---|---|---|---|---|---|---|---|---|
| Date 1st Installed | Mo./Yr. | 9/71 | 3/73 | 5/75 | 7/75 | 10/76 | 3/75 | 12/77 | 9/75 | 4/73 |
| Word Length | Bits | 8 | 64 | 12 | 16 | 16 | 8 | 8 | 16 | 8 |
| Raw Speed—Add | μsec. | 7.4 | 430 | 1000 | 1.07 | 1.07 | 150 | 68.5 | 2.4 | 800 |
| Decimal Digits Added | | 2 | 15 | 15 | 4 | 4 | 5 | 5 | 8 | 13 |
| Registers | | 3 | 4 | 8 | 9 | 7 | 4 | - | 0 | 0 |
| I/O Ports, Basic System | | 11 | 6 | 2 | 15 | 2 | - | - | 8 | 6 |
| Memory—Type | | MOS | MOS | Core | MOS | MOS | MOS | MOS | MOS | MOS |
| Cycle Time | μsec. | 0.6 | 0.5 | 1.4 | 0.7 | 0.7 | 0.6 | 0.6 | 0.8 | 1.6 |
| Minimum Size | Kbytes | 32 | 32 | 16 | 64 | 128 | 16 | 32 | 48 | 16 |
| Maximum Size | Kbytes | 64 | 80 | 64 | 248 | 256 | 32 | 128 | 128 | 32 |
| Peripherals—Standard | | | | | | | | | | |
| Moving-Head File (1) | Mbytes | C,10 | - | F,.67 | C,112 | P,1408 | F,.303 | F,.303 | P,80 | - |
| Mag. Tape Unit (2) | kbytes/sec. | - | - | - | - | - | - | - | C,.75 | - |
| Printer (3) | (3) | S,160 | S,60 | - | - | S,180 | S,80 | - | - | - |
| Peripherals—Optional | | | | | | | | | | |
| Moving-Head File (1) | Mbytes | - | F,.243 | C,12.8 | F,.512 | F,.512 | N,13.75 | N,27.1 | F,.25 | F,.786 |
| | Mbytes | | C,36.8 | | | C,112 | | | | C,20 |
| Mag. Tape Unit (2) | kbytes/sec. | R,10 | R,10 | - | R,10 | R,72 | - | - | R,20 | R,120 |
| | kbytes/sec. | | C,1 | | | | | | | C,.326 |
| Printer (3) | (3) | L,600 | L,400 | S,30 | S,30 | L,1200 | L,155 | S,120 | S,50 | S,200 |
| | (3) | | | L,300 | L,300 | | | L,300 | L,600 | L,600 |
| No. of Communication Lines | | 8 | 1 | 1 | 8 | 32 | 1 | 8 | 7 | 5 |
| Software Available (4) | | B | C,R | C | C | All | A,R | A,F,R | A,C | B |
| Price of Basic System | $k | 36.9 | 30.4 | 14.1 | 51.2 | 77.4 | 33.6 | 34.7 | 36.3 | 5.0 |
| Rental | $/mo. | 830 | 968 | - | - | - | 785 | 1062 | 1205 | 150 |

Source: Datapro SBC
(1) C = Cartridge; F = Floppy; P = Disk Pack; N = Non-Removable
(2) R = Reel-to-Reel; C = Cassette
(3) S = Serial (speed in bytes/sec.); L = Line Printer (speed in lines per minute)
(4) A = Assembly; B = Basic; C = COBOL; F = Fortran; R = RPG All = A,B,C,F,R

different product as they are a low-end extension of the GP product line. In a very interesting recent paper, Cale and his associates examined the characteristics of 82 GP and 85 SBC systems introduced between 1970 and 1977 (see CaleE79). Their results are summarized in Figures 2.11.17a to 2.11.19a. The authors collected data on "representative configurations" of the GP systems, and "typical or balanced" SBC configurations, noting prices, internal memory capacity, and DASD (direct access storage device—i.e. disk) capacity. The SBC systems are plotted in Figure 2.11.17a, and the GP's in 2.11.18a. The authors also fitted curves to the data, with the results shown in the figures. The curves were constrained to be parallel to one another, and to have the form shown, so that price could be computed from main and DASD memory capacity for each pair of years. Comments:

1. For this product sample, GP prices fell somewhat faster than SBC prices fell—11.2% per year average for the GP systems, only 7.5% per year for the SBC's.

2. Figure 2.11.19a shows the area of overlap between the 82 GP and the 85 SBC configurations. It shows, for example, that 24% of the SBC's contained less than 30 Kbytes of internal memory and less than 10 Mbytes of DASD memory, but no "representative" GP system configurations lay in that range. And that 4% of the GP's but 29% of the SBC configurations had between 30 and 100 kbytes of main memory and less than 10 Mbytes of DASD.

3. The authors concluded, incidentally, that they could find no useful or sensible measure of computer power or performance, and consequently that Grosch's Law is meaningless. One can sympathize with their frustration in trying to bring order to the chaotic situation in which a hundred companies, many small and inexperienced, are entering a new marketplace. One must also sympathize with the users and potential users of SBC's (and of GP's for that matter), who try to match their applications to equipment and find nothing but rules of salesmen's thumbs to help them. It is a subject we will return to in Section 2.21a.

## 2.12a PERIPHERAL EQUIPMENT

**Overview.** The cost and performance of computer memory products continued to improve, generally speaking, over the past five years; as shown in Figures 2.120.1a and 2.120.2a. Comments:

1. Improvements in recording density have lead to increased capacity and lower per-bit costs on moving-head files (MHF's). But head-per-track and magnetic tape unit technologies have been dormant.

2. The cost of IC memories fell spectacularly, as manufacturers were able to use larger and larger IC chips. In fact, IC memory costs dropped to the level where manufacturers have introduced IC-based products to compete with head-per-track files. For example, in June, 1979, Itel announced their FAST-3805, which—in one configuration—provides 12 Mbytes of storage with a 0.4 millisecond *maximum* acess time for $103,500, or 0.86 cents per byte. That price and capacity are very competitive with the head-per-track products available today, and the access time is an order of magnitude better. (see Fig. 2.12.8a below.) The disadvantage is that the IC memory is volatile—its contents are lost when power is removed.

3. The IBM 3850 mass storage system, based on a new magnetic tape cartridge, was first shipped in 1975 and established a new low in on-line cost per byte (see Table 2.12.1a). However, the system has not been widel accepted by customers; and IBM has introduced no other products based on 3850 technology.

With regard to Input-Output Technologies (see Figure 2.120.3 p. 67), there have been no price/ performance improvements comparable to those displayed by the MHF and IC memory. The continued evolution of the IC has, however, affected the performance of CRT and printing terminals. IC memories have made it possible to store large quantities of data in each terminal, ready for editing and display, and have increased print speeds by permitting right-

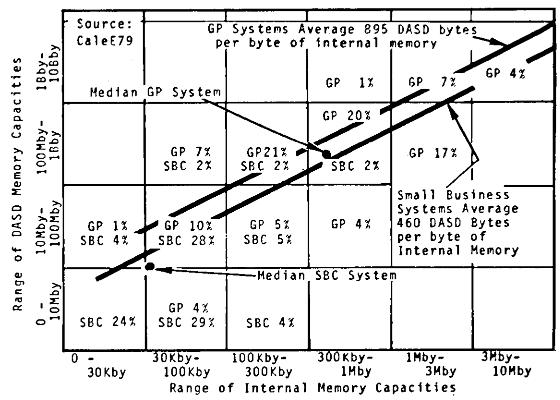



FIGURE 2.11.19a DISTRIBUTION OF MEMORY SIZES
PERCENT OF GP AND SBC SYSTEMS WITH MEMORY IN INDICATED RANGES

**TABLE 2.12.1a IBM 3851 CHARACTERISTICS**

| | |
|---|---|
| Date First Installed | /75 |
| Medium-Material | Mylar? |
| Width | 2.7 in. |
| Length in One Cartridge | 64.2 ft. |
| Recording Density—Area | 335 Kbits/in$^2$ |
| Capacity per cartridge | 50 Mbytes |
| No. of Cartridges | 4720 |
| Performance | |
| Access to Cartridge—Av. | 7 sec. |
| Access to Tape—Av. | 8 sec. |
| Total Access Time—Av. | 15 sec. |
| Max. Character Rate | 87k kby/sec. |
| Max. Capacity | 236.0 Bby |
| Prices | |
| Controller | 3830-3 |
| Price—Purchase | $144.0K |
| Rent | $4.24 K/mo. |
| Maintenance | $235/mo. |
| Drive | 3851-A4 |
| Price—Purchase | $1152.0K* |
| Rent | $30.08K/mo. |
| Maintenance | $3050/mo. |
| Price per 1000 bytes | .336 cents* |
| Maint. cost/$100k | $264.8/mo. |

*A linear regression analysis applied to 1975 prices for the 3851-A1 to A4 and B1-B4 establishes: one mass storage control $358.2K; two MSC $507.3K; Data recording device plus control cost $3.363K per Bbyte. In 1979 the incremental cost had risen to $3.50K per Bbyte.

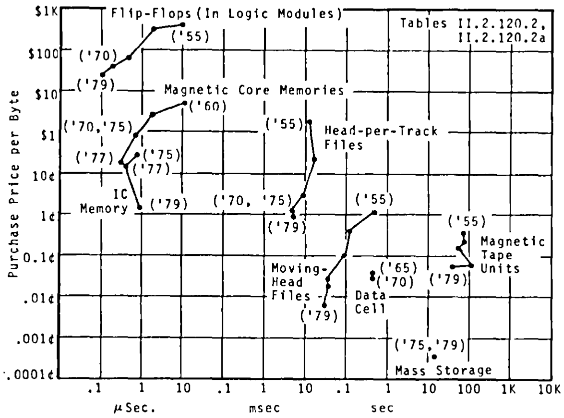


FIGURE 2.120.1a MEMORY TECHNOLOGIES I
PRICE PER BYTE AND ACCESS TIME

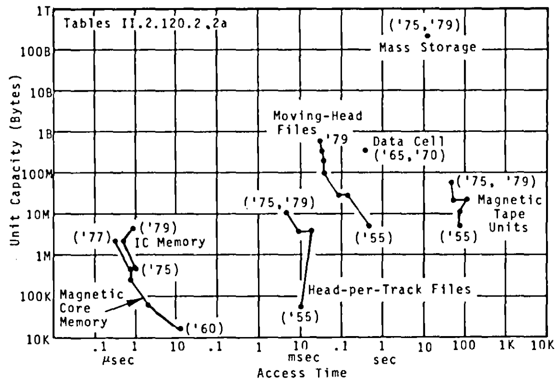


FIGURE 2.120.2a MEMORY TECHNOLOGIES II
MAXIMUM UNIT CAPACITY AND ACCESS TIME

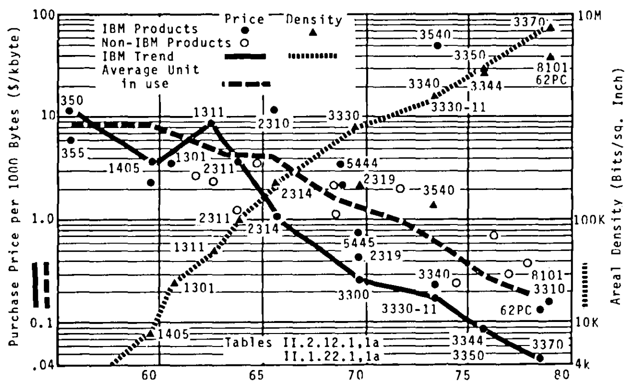


FIGURE 2.12.1a MOVING-HEAD FILES I
A CHRONOLOGY OF PRICE PER KILOBYTE AND STORAGE DENSITY

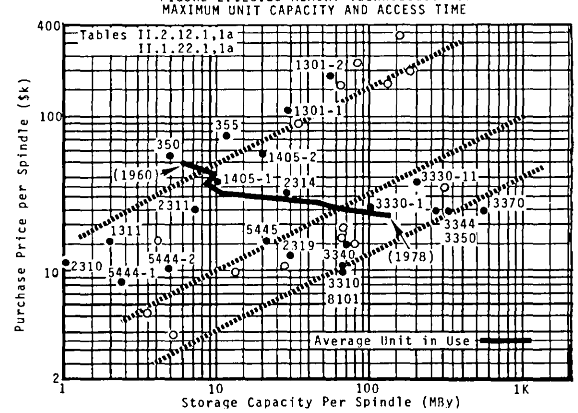


FIGURE 2.12.2a MOVING-HEAD FILES II
PRICE AND STORAGE CAPACITY

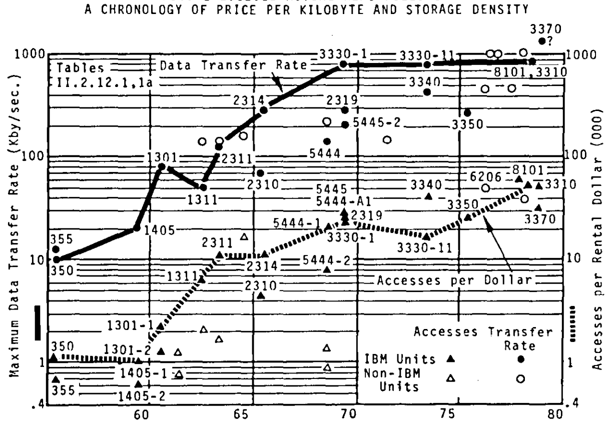


FIGURE 2.12.4a MOVING-HEAD FILES IV
TRANSFER RATE AND ACCESSES PER DOLLAR

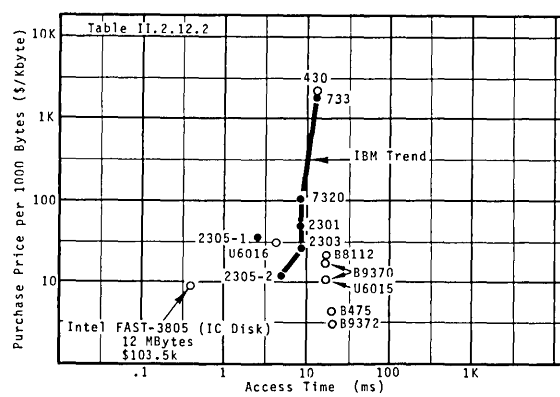


FIGURE 2.12.8a HEAD-PER-TRACK FILES
PRICE PER BYTE AND ACCESS TIME

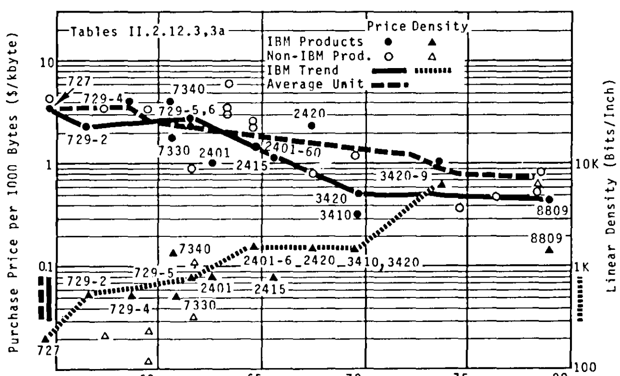


FIGURE 2.12.10a MAGNETIC TAPE UNITS I
CHRONOLOGY OF PRICE AND STORAGE DENSITY

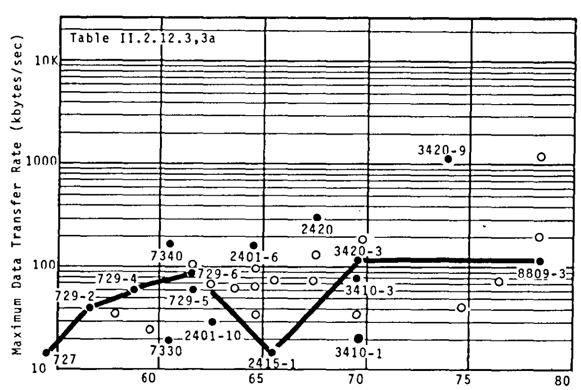


FIGURE 2.12.12a MAGNETIC TAPE UNITS III
CHRONOLOGY OF DATA TRANSFER RATES

to-left printing. And microprocessor-based, so-called "intelligent" terminals have many of the attributes of small computers.

**Memory Peripherals.** IBM introduced a number of new peripheral products to be delivered with its 43X1, 8100, and System/34 or System/38 equipment, and the most numerous and interesting products were moving-head files (see Figures 2.12.1a to 2.12.4a). The 3370 is the most spectacular of these, with a capacity of over 570 million bytes per spindle and an announced areal density of 7.5 million bits per square inch, over twice that of the 3344/3350, first shipped in 1976. The 3370 is also distinguished by having two independent actuators, each of which can access half of the disk. Thus, assuming that user requests for data alternate between heads, the effective seek time may result in an access time even less than the nominal 30ms given in the product specs. The 3310/8101/62PC, while not as spectacular, has led to a proliferation of new competitive eight-inch disk products as independent manufacturers scrambled to develop low-cost, megabyte-memory products for the mini and SBC markets.

In these and other figures in this section, the open circles and triangles show the characteristics of what seem to be the principal non-IBM devices (see the supporting tables in Part II for the identity of these units.) In the realm of moving-head file products, IBM continues to be the leader.

There were relatively few new magnetic-tape products introduced during the past five years—IBM introduced only one, the 8809, between 1974 and 1979. Although I have seen no detailed studies of system usage, it seems likely that most file processing these days is done on files stored on disks, and that tape units are employed mostly for low-cost off-line storage, and for "old" applications—jobs originated years ago when disks were relatively new, and remaining on tape because they are infrequently used.

If we look at Figures 2.12.2a and 2.12.13a, we are tempted to conclude that moving-head-files and magnetic tape units still exhibit Grosch-Law relationships when price is plotted against storage capacity or data rate.

**Unit Record Equipment.** There have been virtually no new punched-card products in the past five years. IBM introduced a magnetic card I/O device for the System/32, but encourages the direct entry of data from keyboard terminals for the S/34 and S/38. And in fact it appears that some combination of key-to-disk or diskette, and direct-entry of data from terminals is reducing the usage of punched cards, as we saw in Section 1.27a.

Though the punched card is fading in importance as an input means, printed output seems still to be growing in importance, and printer technology is as important as ever. Figures 2.12.15a and 2.12.16a show how some recent line printer products compare with older generations. The new IBM printers (3289 and 3262), whose print element is a belt, establish a new price level for printers of their capacity. The train-technology 3203-5, though a new product announced for shipment with the 43X1 processors, is priced like the old 1403-N1.

Character printers serve as the principal output device for many minis and SBC's, and DEC's LA180, first shipped in July of 1977, is shown in both figures—marked with an asterisk to note it is a character, not a line printer. When we look at a wide range of printer technologies—from the LA180 to the 3262, 3203-S, and 3800, all announced in the past five years—we again see evidence (Figure 2.12.16a) that peripheral performance increases faster than does price; but the evidence of those few products doesn't quite support the Grosch (i.e. the square-law), theory.

Nevertheless, at any given time, it appears to be a fact of life that we should be willing to base plans on, that we in general can get ten times the performance in any peripheral product area by paying something like three to five times the price.

**Peripheral Memory Data Rates.** We know that systems performance is dependent, among other things, on the rate at which data may be transferred between I/O devices, and particularly between peripheral memory devices and the processor. That data rate may be examined at various points in the path between peripheral and CPU, and we will look at two such points: at the device itself, and at the channel.

The device rate may be calculated as follows. In order to achieve high recording densities and therefore low costs per byte stored, equipment designers require that data be stored in blocks of contiguous bytes. The device rate is determined by dividing the block or record size by the time necessary to access and then read a record, so

$$D'_{dev} = B/(t_{ac} + (B + f)/d')$$

where

$D'_{dev}$ = Effective device data transfer rate (bytes/sec)

$B$ = Record size (in bytes)

$f$ = Number of format bytes required for each record

$t_{ac}$ = Time to begin reading the record, measured from the moment the previous record access was complete (in seconds).

$d'$ = Rate at which data is transferred once the record has been reached (bytes/sec.)

Table 2.12.2a supplies these factors for some widely-used peripheral memory devices, and some resulting data rates are plotted in Figures 2.12.17a, 2.12.18a, and 2.12.20a. Comments:

1. Even with maximum record sizes and zero seek time, the device data rates from rotating memories do not generally exceed two thirds their maximum value. With average seek times (solid lines of Figure 2.12.17a) the MHF device rates are less than 30% of their maximum value. To achieve two-thirds of its theoretical 120 kbyte/sec. rate, we must use a record size of 2500 bytes on the 3420-3 tape unit. (Figure 2.12.20a.)

2. If the user does not wish to waste space on a MHF or HPT file, his average block size must be (roughly) maximum block size divided by the number of blocks per track. For the 3330, for example, this means average block size will be 13,000 or 6500 or 3250 or etc. The use of other average block sizes gives rise to wasted space—to average 5000 bytes on the 3330, for example, a user would have to record two blocks per track and would waste roughly 3000 bytes per track.

3. The formula (and therefore the figures) omits some factors to keep things simple. It assumes the rotating-memory data is not accompanied by keys, and that there are no unusual conditions like detection of a defective track, or the execution of a write format instruction. For the tape unit it assumes there are no "seek end of file," "space record

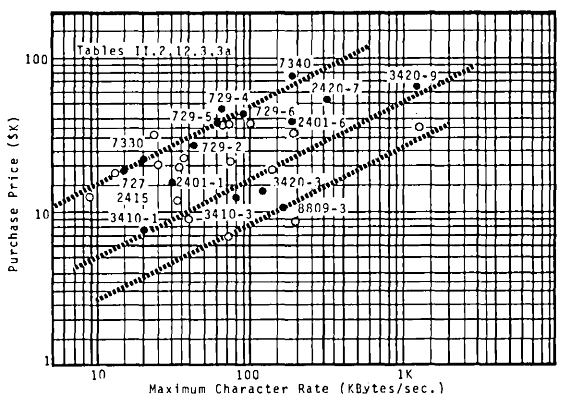



FIGURE 2.12.13a MAGNETIC TAPE UNITS IV
PRICE AND DATA TRANSFER RATES

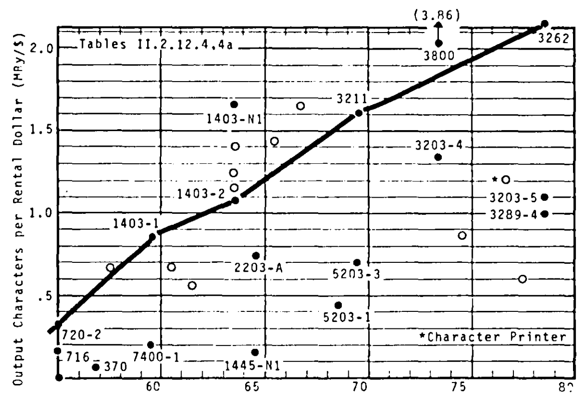



FIGURE 2.12.15a LINE PRINTERS I
CHRONOLOGY OF OUTPUT CHARACTERS PER DOLLAR

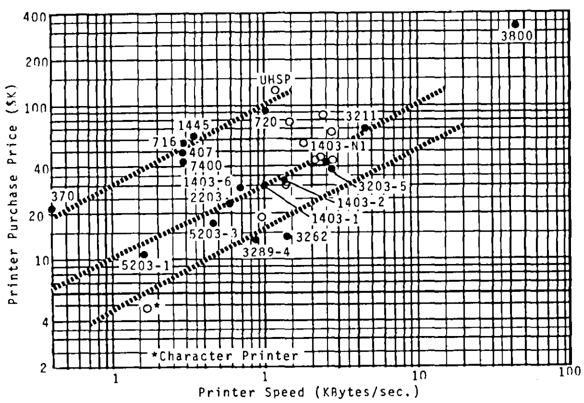



FIGURE 2.12.16a LINE PRINTERS II
PRINTER SPEED VS. PURCHASE PRICE

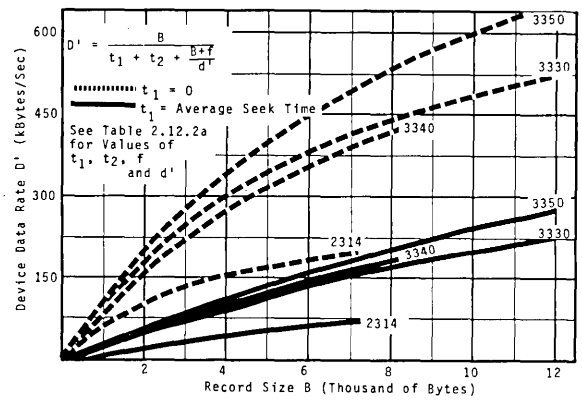



FIGURE 2.12.17a MOVING-HEAD FILES
DEVICE DATA TRANSFER RATE VS. RECORD SIZE

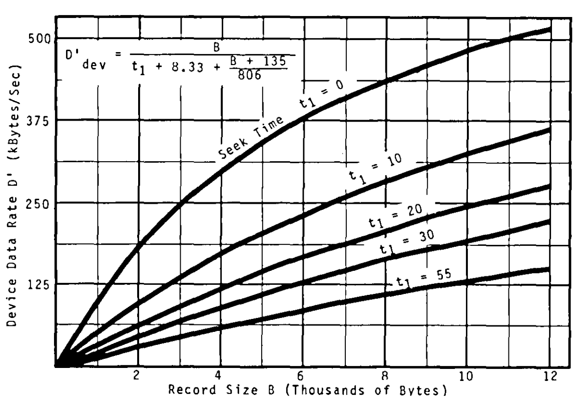



FIGURE 2.12.18a MOVING-HEAD FILES
DEVICE DATA TRANSFER RATE VS. RECORD SIZE FOR THE 3330

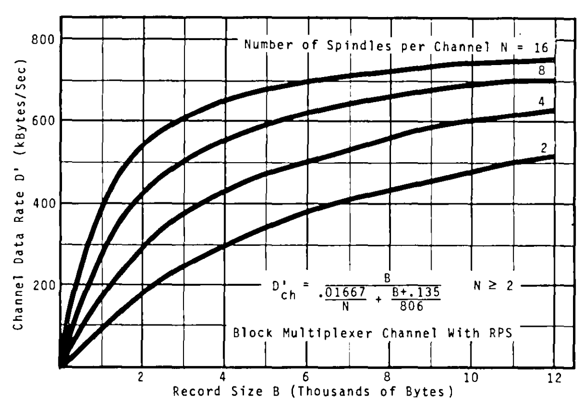



FIGURE 2.12.19a MOVING-HEAD FILES
CHANNEL DATA TRANSFER RATE FOR THE IBM 3330

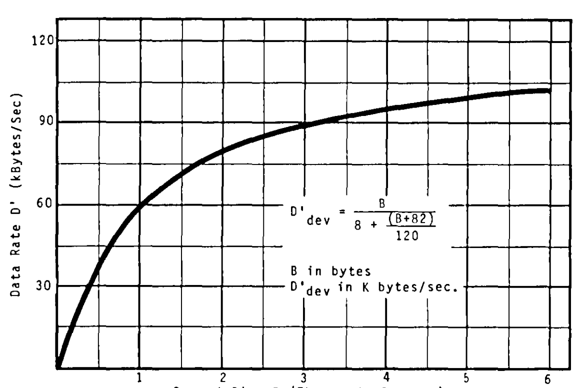



FIGURE 2.12.20a MAGNETIC TAPE UNITS
DATA TRANSFER RATE VS. RECORD SIZE ON THE 3420-3

forward," etc. commands, and that the tape moves continuously. The inclusion of such factors reduces the data rates.

4. Equipment supplier's software may further reduce the data rate by inserting control information in data fields. For example, the IBM programming systems add block length and record length fields to the data area on rotating-memory devices, thus reducing the effective data rate (and device storage capacity as well.)

If we look at data rates at the channel level, we must take into account the overlap between devices which the channel permits. Consider three possibilities:

1. No overlap possible. Then device and channel data rates are identical. Magnetic tape units typically do not permit overlap operations on a channel, and therefore have identical device and channel data rates.

2. Seek times overlap. On most of today's moving-head-file systems, though the device is of course tied up while heads move from track to track, the channel is not. Thus if there are two or more MHF's connected to a single channel, and if all of them are kept in operation by the operating system, (i.e. either seeking or reading or writing), the channel data rate is

$$D'_{ch} = B/(t_2 + (B + f)/d'), \text{ where}$$

$t_2$ = Time to reach data, once head is in position

$t_2$ is the rotational delay, and its average value, as shown in Table 2.12.2a, is half the revolution time of a rotating memory. Note that this mode of operation of a channel (typical of operation on an IBM selector channel or on a Block Multiplexer channel which does not use rotational postion sensing) gives a channel data rate equal to the device data rate with seek time $t_1 = 0$. Thus the dotted curves in Figure 2.12.17a may be interpreted as channel rates, when the channel is operated in the seek-time-overlap mode.

3. Seek time and rotational delay overlap. Some of today's rotating memory systems (including those described in Table 2.12.2a) have rotational position sensing (RPS) facilities which permit the operating system to request that a device look for a particular sector on the circumference of a track, *without* tying up the channel. If this facility is used with a channel containing two or more devices, then the average rotational delay can be less than $t_2$. The reduction comes about because, when the channel finishes handling data from one device, and two or more other devices have finished seeking (i.e. head movement complete) and are in the RPS mode, it next transfers data from or to the device whose data first appears under its read/write heads. It can be shown (KoleK76) that, assuming the channel is not held up for long seek times, the data rate is

$$D'_{ch} = \frac{B}{2t_2/N + (B + f)/d'}, \text{ where}$$

N = Number of devices on the channel ($N \geq 2$).

$2t_2$ = Device rotation time

Figure 2.12.19a shows how the channel data rate varies with record size for various numbers of devices on the IBM 3330, when operating in the RPS mode on a block multiplexer channel. Note that operation with N = 2 devices gives the same channel rate as a single device gives with seek time $t_1 = 0$ (which, we have seen, is the rate for two or more devices operating in the seek-time-overlap mode on a Selector channel). The addition of devices in the RPS mode is very effective, especially at small record sizes: going from 2 to 16 3330's on a channel *triples* the effective data rate at a 2000-byte record size.

In summary, then, channel data rate may equal device rate, may equal device rate with zero seek time, or may equal device rate with zero seek time and with rotational delay time reduced by the factor 1 / (number of devices), depending on the mode of operation.

## 2.14a DATA COMMUNICATIONS

**Telephonic Data Communications.** The apparent trend in the cost of transmitting a million bits a distance of 300 miles continued downward with the introduction of AT&T's 1.5 Megabyte per second Dataphone Digital Service (DDS) in about 1977 (See Figure 2.14.1a.). However, the cost of the more commonly-used low-frequency (dashed-line) service has not changed appreciably since the mid-sixties. And the price of the telephone company's 300-mile DDS service has actually increased, as a result of an FCC ruling that AT&T's original rates were predatory and uncompetitive. Figures 2.14.1b and 2.14.1c show comparable data for 30- and 3000-mile lines. The trends are generally similar, but prompt two comments:

1. Long-distance charges have fallen faster than have short-range charges. The ratio of the cost per million bits of a

**TABLE 2.12.2a PERIPHERAL MEMORY TIMING FACTORS**

| Device | | $t_{ac}$ (ms) Av. | $t_1$ Max. | Min. | $t_2$ | f (bytes) | d' (kbytes/sec) | Track Capacity (bytes) |
|---|---|---|---|---|---|---|---|---|
| MTU | IBM 3420-3 | -- | -- | -- | 8 | 82 | 120 | |
| MHF | IBM 2314 | 60 | 130 | 25 | 12.5 | 101+.043B | 312 | 7191 |
| | IBM 3330 | 30 | 55 | 10 | 8.3 | 135 | 806 | 12895 |
| | IBM 3340 | 25 | 50 | 10 | 10.1 | 167 | 885 | 8201 |
| | IBM 3350 | 25 | 50 | 10 | 8.3 | | 1198 | |
| HPT Files | IBM 2305-1 | 0 | 0 | 0 | 2.5 | 430 | 3000 | 13504 |
| | IBM 2305-2 | 0 | 0 | 0 | 5.0 | 198 | 1500 | 13645 |

Notes:
1. $t_{ac} = t_1 + t_2$
2. $t_1$ = Time to move head to proper track (seek time).
3. $t_2$ = Time to reach data, once head is in position
4. Track capacity is the number of data bytes in the biggest possible record.
Source: IBM Manual GC20-1649-9 for MHF and HPT. KoleK76 for MTU.

75 wpm circuit in 1955 to that of a 9600 bps circuit in 1979 is about 25, 75 and 100 to one for the 30-, 300- and 3000-mile circuits, respectively.

2. Though DDS charges increased between 1975 and 1978 for short distances, they *decreased* significantly for long ones.

The break-even points at which a private line costs the same as a dialed connection have changed slightly in the past four or five years. Comparing Figures 2.14.2 (p. 77) and 2.14.2a we find the prices of direct dial calls have increased by two cents per minute; the cost of the cheapest voice grade private line has hardly changed; the price of the most expensive private line, connecting smaller cities, has dropped substantially, and the price of a DDS 4800 bps line has increased. As a result, the break-even point for DDS service has increased slightly, and that for a voice grade line has dropped sharply—from almost 2000 minutes per month to just over 1000 for a one-minute day call, for example. Note that the figure shows costs for a 300-mile line. On longer lines break-even point usage times have dropped substantially, as can be seen by comparing Figures 2.14.3a and 2.14.3 (p. 77): in 1975, the break-even time for a 3000-mile line in a major city was about 110 hours (6700 minutes); by 1979 it had fallen to 72 hours (4300 minutes).

With long-distance costs falling faster than short-haul costs (and with some short-haul costs actually rising in the past few years), we find, comparing 1975 system costs on Figures 2.14.4 and 2.14.5 with 1979 costs on corresponding Figures 2.14.4a and 2.14.5a, that the spread between 30- and 3000-mile costs has narrowed. To transmit 2 billion bits per month on a 300-mile line in 1975 cost $186. It cost $2000, or 10.7 times as much to transmit those same bits on a 3000-mile line. In 1979 the corresponding figures were $287 and $1760—only 6.1 times as much for the long line. AT&T (with the encouragement of the FCC) is making it relatively easier for us to operate at arm's length from one another.

DPT&E included a section describing the services provided by Datran, a specialized common carrier. Unhappily, Datran was unable to find the financing which would permit it to remain in business, and went bankrupt in 1976. Among the remaining competitors, the companies which offer data communications services with prices tied to the volume of traffic transmitted are relatively new and interesting. Telenet, the earliest of these, was recently acquired by GTE

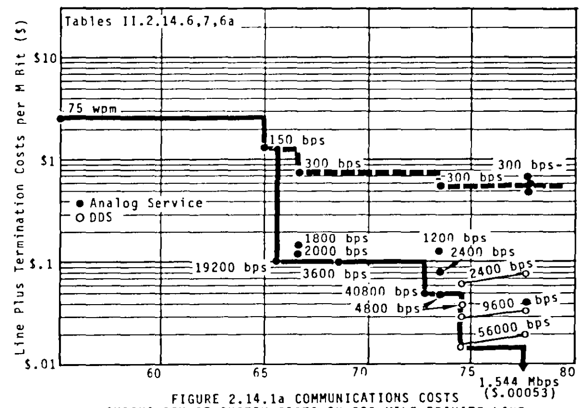



FIGURE 2.14.1a COMMUNICATIONS COSTS
CHRONOLOGY OF SYSTEM COSTS ON 300-MILE PRIVATE LINE

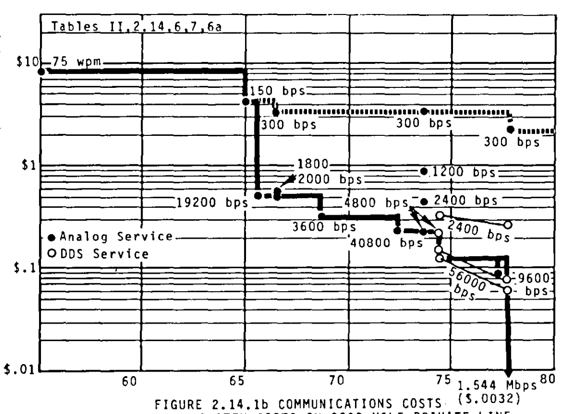



FIGURE 2.14.1b COMMUNICATIONS COSTS
CHRONOLOGY OF SYSTEM COSTS ON 3000-MILE PRIVATE LINE

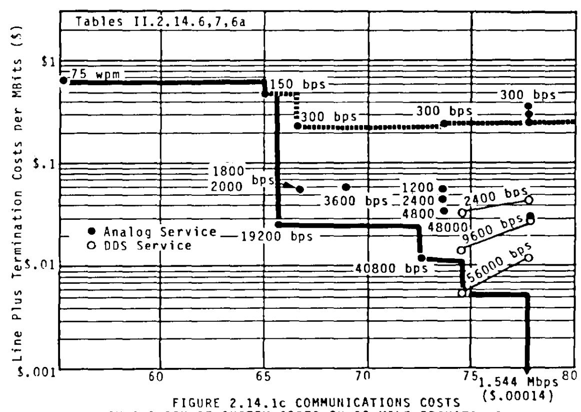



FIGURE 2.14.1c COMMUNICATIONS COSTS
CHRONOLOGY OF SYSTEM COSTS ON 30-MILE PRIVATE LINE

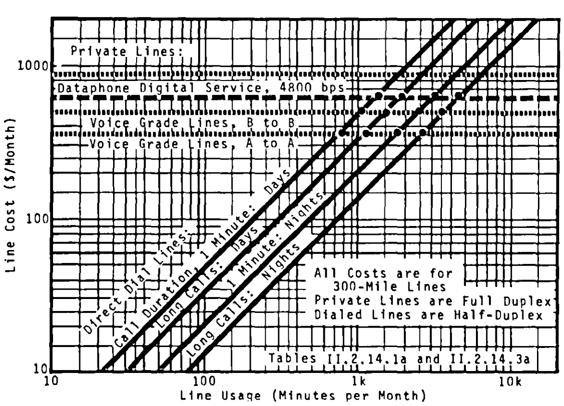



FIGURE 2.14.2a COMMUNICATIONS COSTS II
BREAKEVEN POINTS FOR DIALED AND PRIVATE LINES

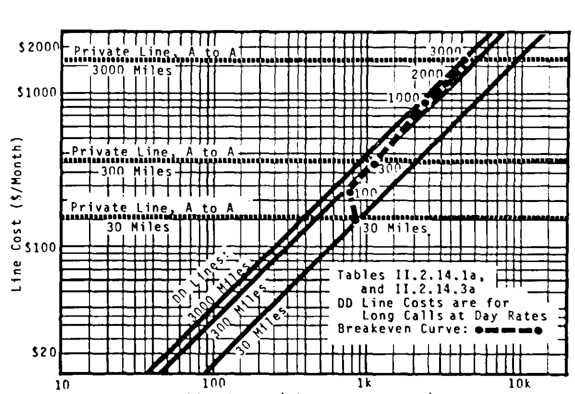



FIGURE 2.14.3a COMMUNICATIONS COSTS III
BREAKEVEN POINTS FOR DIFFERENT LINE LENGTHS

and is thus no longer a specialized common carrier. Tymnet, Inc., a subsidiary of the computer services company Tymshare, remains independent and is probably the fifth largest communication carrier—after AT&T, GT&E, Western Union, and United Telecommunications (*Datamation,* July, 1979, p. 136).

Tymnet provides two kinds of communication service, using the TYMNET network originally designed for its parent Tymshare, Inc., to employ in its computing service business. The first communication service makes it possible for a user to connect a number of remote sites to his central computer. Instead of connecting his communications interface equipment to the telephone company's lines, he connects it to a Tymnet processor. The processor acts as an intelligent multiplexer/demultiplexer, transmitting characters both ways between the user system and the TYMNET network.

The second Tymnet service is a message switching service ("OnTyme"), which enables a user to transmit a message from one point in the network to another—or from one point to several others. A user at a terminal can dial into the local Tymnet outlet, log in, transmit an address (or addresses), and his message. The system assigns a number to each message, notes time and date, maintains records for traffic analysis purposes, and forwards the message to its destination. If the destination does not answer, or is busy, the system stores the message and forwards it on later.

The network itself consists of a set of high-speed lines connecting nodes at which special computers perform multiplexing, routing, checking, and logging functions. The traffic from or to a particular user's terminal is collected at the nodes and is transmitted in variable-length multiplexed packets, which typically contain characters from several users' "virtual" circuits. Asynchronous user terminal traffic may operate at data rates from 110 to 1200 bits per second.

Charges for both services are summarized in Table II.2.14.2b, in Part II. For the processor-oriented service there is a monthly charge for the Tymnet processor, a connect charge for the period of time the user is connected to the net, and a "per-character" charge for the actual number of characters transmitted. Alternately, a customer may order a "dedicated host port", which gives him one full-time access to the system from any location in the country for a fixed monthly charge—with no incremental connect or character charges. For the message switching service there is a monthly service charge (independent of the number of terminals which send and receive messages), a connect charge, a message charge (independent of the length of the message), and a "per-character" charge. For both services there is a minimum connect time of one to six minutes.

The Tymnet system was initially designed to handle traffic from keyboard-oriented devices, typically operating at the rate of up to 120 characters per second. But the communication cost per million bits transferred is obviously dependent on the *actual* rate at which characters are transmitted, not just on the capacity of the channel. The costs plotted in Figure 2.14.1a to 2.14.5a are computed assuming each system operates at its full rated capacity—150 or 4800 or 1,544,000 bits per second or whatever is the channel capacity. If the user doesn't employ the full channel bandwidth, then clearly it will take him longer to transmit a million bits than it would if he operated at top speed. And consequently his cost per million bits will increase. The current Tymnet average system data rate per terminal is 28,000 characters per hour, or 7.78 characters per second. (Such a traffic rate would be generated, for example, by a terminal whose user entered 20 characters every 20 seconds, waited 2 seconds for a reply from the computer, and then received a 200-character reply at 30 characters per second.)

AT&T system costs per month for a 300 bps (30 character/sec maximum) line are plotted in Figure 2.14.6a with these things in mind. The solid lines show how system costs increase with traffic for four different character rates. The horizontal line represents the cost of a 30-mile private line. Note the breakeven point varies with the character rate. The dashed and dotted lines show the corresponding curves for 300- and 3000-mile lines, though for clarity I only show part of the 30 ch./sec curves.

A comparable set of curves for the Tymnet system appears in Figure 2.14.6b. Tymnet has different rates for three different classes of cities, and the curves show the difference between the cheapest (high-density) and most expensive classes. The intermediate set of cities lies in between the curves shown. The graph also shows the difference in cost between the slowest and fastest transmission speeds.

In Figure 2.14.6c we compare the costs of the Tymnet and AT&T systems, both assumed operating at 7.78 characters per second. The solid line represents the AT&T costs for a 300-mile line. The dotted lines are relevant costs for the Tymnet system of Figure 2.14.6b, and show the cost difference for 7.78 cps in the two classes of cities. The two dashed lines show the high-density-city costs for two other Tymnet systems. Comments:

1. Tymnet costs are independent of distance, while AT&T charges vary with distance as shown in Figure 2.14.6a. Remember that Figure 2.14.6c shows the 300-mile AT&T cost only.

2. The effect of Tymnet's combination of a low connect cost and a "per-character" cost is clear: at the low data rates typical of terminal-to-computer operations, Tymnet's incremental cost for transmitting characters is much lower than AT&T's—the slopes of the dotted and dashed curves are much lower than that of the solid curve. Tymnet achieves this result by making efficient use of telephone company bandwidth, and passing the saving on to the user. The telephone company holds a channel open for the user for the duration of his call (whether or not the user is transmitting or receiving), and charges for that full-time capability.

3. The duration of each call must be 10 minutes or longer for the curves to be applicable. Shorter calls incur a higher DD rate for the AT&T service, and run the risk of encountering the Tymnet minimum-time charge.

4. The results are very sensitive to the number of users who share the large fixed costs of the Tymnet processor. My assumption is the very conservative one that an access channel is always available to each user. If each of 24 users is expected to use the system an average of only two hours per eight-hour day, we might use a cheaper (8-user) Tymnet processor and cut the apportioned processor cost per user by almost $50 per month. The disadvantage would be that at times more than eight users would want to use the system and some would have to wait.

5. The dedicated host port cost (the horizontal Tymnet line in Figures 2.14.6b and 2.14.6c) can also be reduced by sharing the port among users. Once again I conservatively assign one port to each user.

6. Despite the consertive assumptions, the graph clearly shows the cost advantages a user can obtain if his communications load is character-oriented and if his

terminals are widely distributed geographically. Table 2.14.2a shows how bits transmitted per month vary with various operating schedules and data rates. Note that, at about half-time usage, the traffic is likely to be higher than the break-even point (depending on the data rate), and the user will do best with a dedicated port: And that at low usage rates (5 hours per day or less on a terminal) the Tymnet processor costs can be shared among more terminals than those used in the calculations behind Figure 2.14.6c, with the result that fixed costs are lower, the left-hand portion of the Tymnet curves drops, and Tymnet looks even more desireable from an economic point of view.

7. Tymnet (and Telenet) service also provide other important advantages not available to a user who employs AT&T's DD or private line facilities to connect his terminals to a computer. The primary advantages are reliability (ensured by error detection, data retransmission, and network rerouting), and monthly accounting data on system usage.

Finally, we may compare Tymnet's message switching service with the alternative of using AT&T's direct dial or private line services. Figure 2.14.6d provides the basis for such a comparison. Comments:

1. The incremental costs for message switching on Tymnet are higher than those for computer-to-terminal connections, in part because both sender and receiver of the message must pay character and connect-time costs, and in

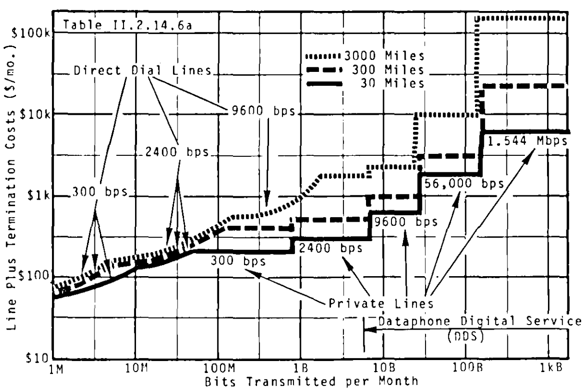



FIGURE 2.14.4a COMMUNICATIONS COSTS IV
MONTHLY SYSTEM COSTS VS. TRANSMISSION VOLUME

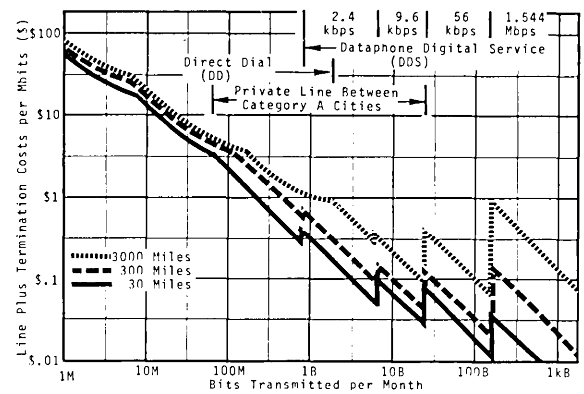



FIGURE 2.14.5a COMMUNICATIONS COSTS V
SYSTEM COST PER MILLION BITS VS. TRANSMISSION VOLUME

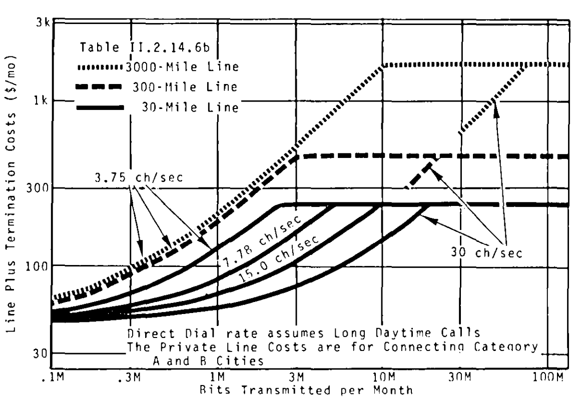



FIGURE 2.14.6a COMMUNICATIONS COSTS VI. AT&T SYSTEM
COSTS FOR A 300bps LINE OPERATED AT VARIOUS SPEEDS

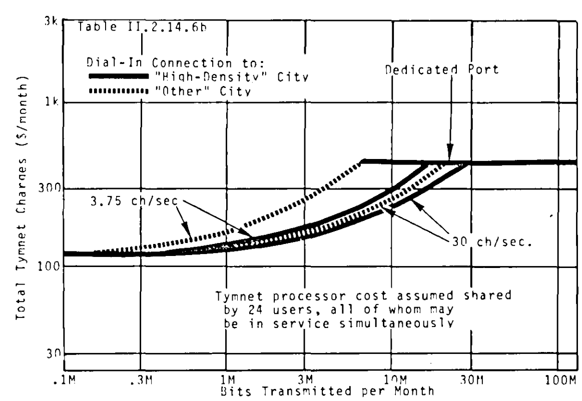



FIGURE 2.14.6b COMMUNICATIONS COSTS VII. TYMNET SYSTEM
CONNECTING TERMINALS TO A CENTRAL PROCESSOR

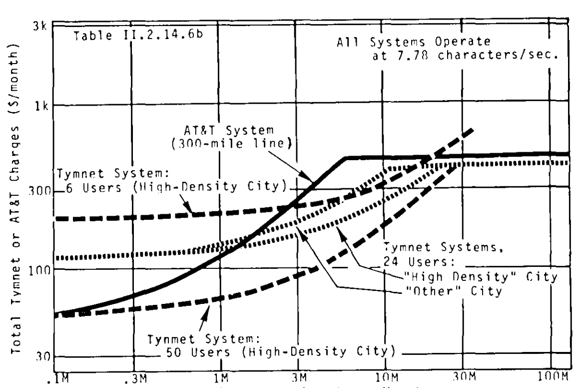



FIGURE 2.14.6c COMMUNICATIONS COSTS VIII. COMPARING TYMNET
AND AT&T COSTS FOR A COMPUTER-TO-TERMINALS SYSTEM

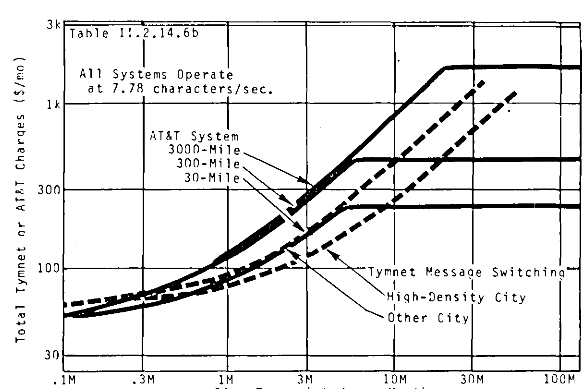



FIGURE 2.14.6d COMMUNICATIONS COSTS IX. COMPARING TYMNET
AND AT&T COSTS FOR MESSAGE SWITCHING

part because those basic costs are higher. Note the Tymnet incremental charge for an "other" city is almost the same as AT&T incremental costs for a 30-mile line.

2. The graph does not include the Tymnet charge of $.05 per message—we assume that messages are so long that that cost is negligible. A large number of short messages will change the economics, both because of the message charge and also because of the minimum-connect-time charge.

3. We assume the $100/month service charge is divided between ten user terminals. If fewer terminals participate in message switching the fixed costs will increase.

4. The Tymnet message switching service looks attractive economically, compared with the use of AT&T DD services, for message traffic in the range 4 million to 100 million characters per month, depending on the cities and distances involved. A number of miscellaneous advantages add frosting to the cake—the system: numbers and dates messages; provides monthly summaries of messages sent; can send a message to multiple destinations; holds messages until they are requested by the destination; allows user inquiry of message status; and permits on-line message preparation and editing.

Data communications services provided by companies like Tymnet, besides being useful in themselves, remind us of what is feasible when the entrepeneur is allowed to use new technology to invent new products. It also helps the conventional common carriers, whose natural tendency is to provide black telephones forever (presumably because we have always had black telephones), find ways to serve us better.

**Postal and Facsimile Communications.** Data may be transmitted from one place to another by mail as well as by wire. And any document which can be mailed can also be sent on facsimile equipment over telephone lines. Analog facsimile equipment is the oldest technology, and requires a relatively long transmission time per document. Digital equipment speeds up the transmission process by encoding data in a way such that blank spaces on the paper require little communication time. Table 2.14.3a compares the cost of analog and digital facsimile transmissions. The fixed costs are for two machines (one to transmit, one to receive), and the variable costs include supplies and communication line costs. Resulting costs are plotted in Figure 2.14.8b, where they are compared with 1979 mailing costs (first-class postage went up to 15 cents per ounce in 1978). Facsimile costs include the effect of using a private line when that becomes economical.

Expensive as it is, the postal service is still cheap compared with facsimile. In fact, comparing this figure with Figure 2.14.5a (and converting bits to bytes using the factor 8), we see that if the facsimile equipment itself were free, the most expensive postal costs would be cheaper than wire communication costs for volumes less than 50 to 400 million bytes per month, depending on the transmission distance. The postal system (and other messenger services) is a bargain if you're not in a hurry.

## 2.15a PROGRAM PRODUCTS

There is still not much data available on the use of various languages for applications programs. Some recent studies suggest that COBOL continues to grow in popularity, and that the assembler is no longer losing ground to the procedure-oriented languages. Figure 2.15.1a shows what seem to be the trends. Note that Basic, Algol, APL, and other academically interesting languages are not widely used, and that the use of RPG and PL-1 has apparently levelled off. The average number of languages used per site is apparently about 2.8, though it was about 3 in the late Sixties (See Tables II.2.15.1 and II.2.15.1b).

Three fairly recent studies give us some data on the actual use of various languages. Table 2.15.1a compares eight different programs written in various languages and run on a Univac 1108. The top part of the table summarizes the principal characteristics of the programs, five of which were "scientific" and three "business" types. The bottom part gives CPU execution times, relative to the slowest language for each problem. Note that FORTRAN did surprisingly well compared to COBOL on business-type problems—and note also the large difference in running times for the three different COBOLS and the two different FORTRANS. However, different programs were written by different people, and it is not clear how that may have affected the results. Table 2.15.2a shows that the use of a generalized data management system like Informatics' Mark IV can outperform COBOL by improving programmer productivity—though the users who reported this result did not say which system used more computer time.

Finally, we can see in Figure 2.15.2a the results of an experiment which compared the performance of BASIC on ten different time-sharing systems. The experimenters ran the same program three times on each system. The program computed the determinant of a matrix, and the three runs handled matrices of sizes 5x5, 6x6, and 7x7. The left-hand plot in the figure shows how "process units" required by each system vary with the size of the matrix, relative to the requirements for the smallest matrix. The line labelled "Dartmouth, GE, SBC," for example, shows that those three time-sharing systems each charged three times as much for a 6x6 matrix as they charged for a 5x5, and eighteen times as much for a 7x7 as for a 5x5. ("Process units" are generally defined differently for different systems, but are used as the basis for the charge made to the user.) The right-hand plot in the figure shows the actual dollar charges made by each service. Comments:

1. Clearly there are no programmer or program differences which affect these results. The differences are the result of differences between compiler implementations, or system efficiencies, or billing algorithms.

2. There are remarkable differences between systems. Leaving aside the very cheap UCS system (which runs on a CDC 6500), there was a 4:1 difference between relative process unit charges—ITS only charged nine times as many units for a 7x7 as for a 5x5, while Tymeshare and Hewlett-Packard charged over 36 times as many as for a 5x5. And there was an almost 10:1 difference in dollar cost between the most and least expensive service for handling a 7x7 matrix (again leaving out the UCS system).

In short, we have every reason to believe that there are large differences in efficiency or cost-effectiveness between different implementations of a common language; and we can be equally sure that some programming tools are better than others, as applied to specific problems. It is surprising, therefore, that so little work is done in measuring the effectiveness of software. And it seems extraordinary to the author that so much money is paid for programming packages, based only on qualitative claims for performance.

**TABLE 2.14.2a MEGABITS TRANSMITTED PER MO.**

| Operations Schedule Hrs./Day | Days/Wk. | Terminal Operating Speed (Characters/second) 3.75 | 7.78 | 15.00 | 30.00 |
|---|---|---|---|---|---|
| 1 | 1 | .6 | 1.2 | 2.3 | 4.7 |
| 1 | 5 | 2.9 | 6.1 | 11.7 | 23.4 |
| 4 | 5 | 11.7 | 24.3 | 46.8 | 93.6 |
| 8 | 5 | 23.4 | 48.5 | 93.6 | 187.2 |
| 8 | 7 | 32.8 | 68.0 | 131.0 | 262.1 |
| 12 | 7 | 49.1 | 101.9 | 196.6 | 393.1 |
| 16 | 7 | 65.5 | 135.9 | 262.1 | 524.2 |
| 24 | 7 | 98.3 | 203.9 | 393.1 | 786.2 |

**TABLE 2.14.3a FACSIMILE SYSTEM COSTS**

| Manufacturer: Model Number: | | 3M 9600 | 3M 9600 | Xerox TC400 |
|---|---|---|---|---|
| Transmission Rate | bps | 2400 | 9600 | - |
| Time per Page | sec | 80 | 20 | 240 |
| Fixed Cost | | | | |
| Equipment Rental | $/mo | 590 | 590 | 110 |
| Variable Costs | | | | |
| Paper | cts./page | 4.6 | 4.6 | 8.7 |
| Toner | cts./page | 0.4 | 0.4 | 0 |
| Message Unit* | cts./page | 4.0 | 1.0 | 0 |
| Telephone Line**–30 Miles | cts./page | 24.0 | 6.0 | 72.0 |
| 300 Miles | cts./page | 45.3 | 11.3 | 136.0 |
| 3000 Miles | cts./page | 50.7 | 12.7 | 152.0 |
| Total–30 Miles | $/Mby | 110 | 40.0 | 269 |
| –300 Miles | $/Mby | 181 | 57.7 | 482 |
| –3000 Miles | $/Mby | 199 | 62.3 | 536 |

*$0.03 per minute charge. **Assumes a day call of long duration—i.e. several documents sent for each connection. Documents are assumed to be 8 1/2 x 11 inches containing 3000 bytes.

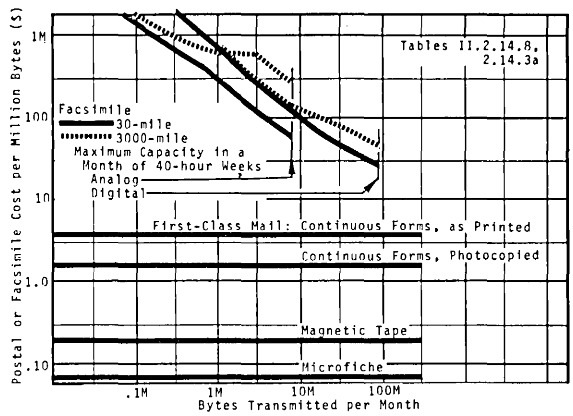



FIGURE 2.14.8b COMMUNICATIONS COSTS FACSIMILE VS. MAILING COSTS, 1979

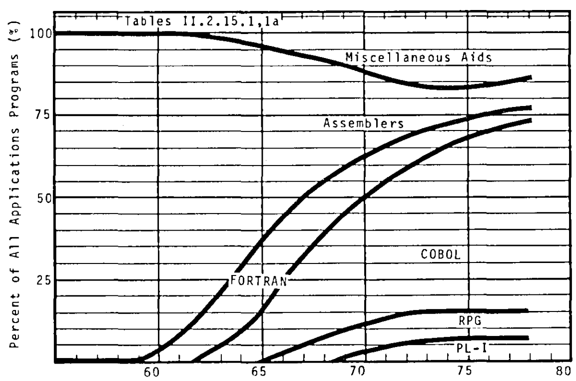



FIGURE 2.15.1a PROPORTION OF APPLICATION PROGRAMS WRITTEN USING DIFFERENT PROGRAMMER AIDS

**TABLE 2.15.1a COMPARISON OF EXECUTION TIMES OF DIFFERENT COMPILED PROGRAMS**

| | Scientific Algorithms: Hyperbolic and Exponent. Functions | Random Number Generator | Newton's Method—Non-Linear Eqns. Single Precision | Double Precision | Simple Precednce. Grammar Analyzer | Business Algorithms: "Tower of Hanoi" Logic Problem | Graph of Grades | Freshman Advising Report |
|---|---|---|---|---|---|---|---|---|
| **Problem Characteristics** | | | | | | | | |
| Iterations | X | X | X | X | | | | |
| Functions | | X | X | X | | | | |
| Subroutines | | | | | X | | | |
| Math. | | | | | | | | |
| Single Precision | X | X | X | | | | | |
| Double Precision | | | | X | | | | |
| Matrix Multipl. | | | | | X | | | |
| Input/Output | | | | | | | X | X |
| Report Formating | | | | | | X | X | X |
| Logic Processing | | | | | | X | X | |
| Sorting | | | | | | | | X |
| **Relative Execution Times** | | | | | | | | |
| ALGOL | 0.25 | 0.91 | 0.23 | 0.47 | 0.93 | 1.00 | | |
| NUALG | 0.23 | 0.76 | 0.25 | 0.44 | 0.28 | 0.66 | | |
| FORTRAN V | *0.15 | 0.18 | 0.20 | 0.33 | *0.20 | 0.83 | 1.00 | *0.99 |
| Reentrant FORTRAN | 0.16 | 0.25 | *0.16 | *0.22 | 0.36 | 0.74 | | |
| COBOL | 1.00 | 0.78 | 1.00 | 0.99 | 0.50 | 0.51 | | |
| ANSI COBOL | 1.00 | 1.00 | 1.00 | 1.00 | 0.48 | 0.52 | *0.90 | 1.00 |
| ASCII COBOL | 0.33 | 0.93 | | 0.47 | 1.00 | 0.59 | | |
| Basic | 0.28 | | | | | 0.95 | | |
| Assembler | | *0.08 | | | | | | |
| APL | | | | | | *0.40 | | |

Source: BlayJ78. *Identifies best execution time for the algorithm.

### 2.16a MEDIA

There has been little change in media technology in the past few years, except for the evolution of the floppy disk. Disk pack and magnetic tape prices have fallen slightly, but densities today are the same as those of 1974. Inflation has driven the price of paper up, and with it the cost of cards and printing paper. But the diskette is a new technology, is very widely used, and is subject to strong competitive forces. Demand, inventiveness, and competition have made it possible to increase recording density while reducing media price–and additional improvements beyond those shown in Figure 2.16.1a are already in production.

## 2.2a System Performance and Usage

### 2.21a PROCESSING REQUIREMENTS (Workloads)

It should be a matter of some embarrassment to all of us in the computer community that, after thirty years of designing, producing and distributing computers, we still have no generally-accepted way of measuring data processing work. There have been some attempts at establishing such a measure (See Refs. HellL72, JohnR72, KoleK76), but none seem to help us find answers to questions like these (the term "wirk" means "information work"):

1. Is wirk done in transferring data, unchanged, from one point to another? Is the amount of wirk done a function of the distance between the points?

2. Is wirk done in converting data from one form to another–from analog to digital, or from electrical to mechanical, for example?

3. Is wirk done in manipulating information? For example: in adding two four-bit numbers to get a five-bit result, do we do less wirk than is done in adding two eight-bit numbers to get a nine-bit result? If we multiply two four-bit numbers, is the same amount of wirk done as when we add the same numbers? If we add 2 + 3 do we do the same amount of wirk as we do in adding 4 + 5? Does it take more wirk to compute the reciprocal, the sine, or the log of a number to five decimal positions?

We need, not only to be able to answer these questions, but also to be able to compute the amount of wirk done in each instance.

To appreciate the need for a way to compute wirk (and powir, the rate at which wirk is done) we need only compare a computer buyer with an individual who wants to buy, say a motor. The latter determines what torque his load requires, and how many revolutions per second it must turn. He can then compute the horsepower required from a suitable motor. And the computer buyer? He has no corresponding way of measuring his data processing wirkload; and if he did, he would not be able to find, from any computer manufacturer, a measure of the powir which can be supplied by available equipment. The owner of a small business, acquiring his first computer, has no way of describing quantitatively how big his job is, and finds it difficult to judge the relative capacity offered by competing computer vendors. If we could measure his wirkload and the competitors' computer powir, we would reduce the margin of error and the number of lawsuits brought by unhappy customers.

Wirk/powir measures would help in other ways, as well. The bicyclist may use his knowledge of work to plan a trip: he knows that, because of energy losses due to friction, a route which is uphill all the way will be easier on him than another route between the same two points which is part uphill and part down. A programmer would like to have a corresponding wirk measure to help him write efficient programs. Given a problem statement, he would like to be able to compute the minimum amount of wirk necessary to solve the problem. He could then compare the result with the wirk performed by each of several proposed programs, and thus choose the best algorithms for his job.

Finally, consider how measures of wirk and powir would help the computer designer. The modern engineer who plans a new engine could hardly function without an understanding of thermodynamics, and the concepts of force, torque, power and work. Today's computer engineer is on a par with the Victorian engineers who designed the early steam engines: they could generally design a machine which would perform, but the performance was inefficient in ways they could not understand. Our designs probably suffer from the same kinds of problems. A theory which tells us how much wirk is accomplished in employing an algorithm should also tell us how much wirk is employed in implementing that algorithm in each of several instruction codes.

I don't have a solution to this problem–I can offer no definitions for wirk and powir. But I suggest we ought to be aware of what we lack, and encourage computer scientists to develop a theory we can use in practice.

**Procedure Execution.** Figures 2.21.6a, 2.21.9a and Table 2.21.10a provide scraps of information on procedure execution workloads (see Table 2.21.4, p. 92-93 of DPT&E). James L. Elshoff has analyzed a number of commercial PL-I programs in use at General Motors Corp., and Figure 2.21.6a shows a distribution of program size. The *largest* program in the sample contained 3735 source statements. Comparing this distribution with that given in Figure 2.21.6 (p. 95), where the median program contains over 36,000 object instructions, raises questions which can only be answered with more data: what *is* an application program–is one installation's "program" another's "module"? Given a standard definition for the term, how does program size vary from installation to installation? From application to application?

Programmers use arithmetic unit registers for temporary storage of repeatedly-used data. Table 2.21.10a and Figure 2.21.9a show how such registers were used during the execution of 41 widely different programs. Note that, on the average, 3.9 registers are in use at any time, and that a register is used 4.2 times in its 11.9-instruction life. Note that 90% of the time eight registers would have been sufficient for the programs. One is tempted to conclude either that engineers are providing too many registers, or that

**TABLE 2.15.2a COMPARISON OF PROGRAMMING EFFORT—COBOL VS. INFORMATICS MARK IV**

| | Units of Work | |
|---|---|---|
| | COBOL | MARK IV |
| Systems Design | 20 | 14 |
| Coding | 40 | 25 |
| Testing | 20 | 10 |
| File Conversion | 10 | 10 |
| Documentation | 5 | 2 |
| System Test | 5 | 4 |
| Total | 100 | 65 |

Source: FlynJ77

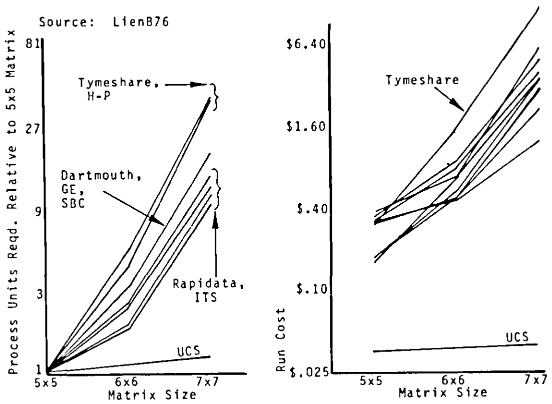



FIGURE 2.15.2a COMPARING THE COSTS OF USING BASIC ON TEN DIFFERENT TIME-SHARING SYSTEMS

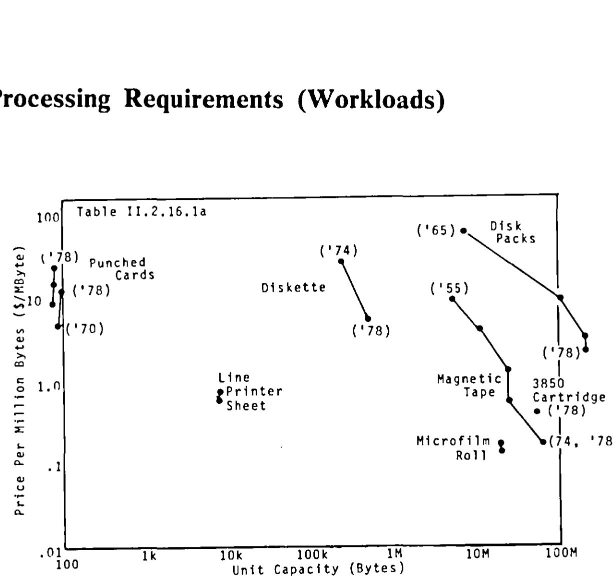



FIGURE 2.16.1a MEDIA TECHNOLOGY PRICE PER MILLION BYTES VS. CAPACITY

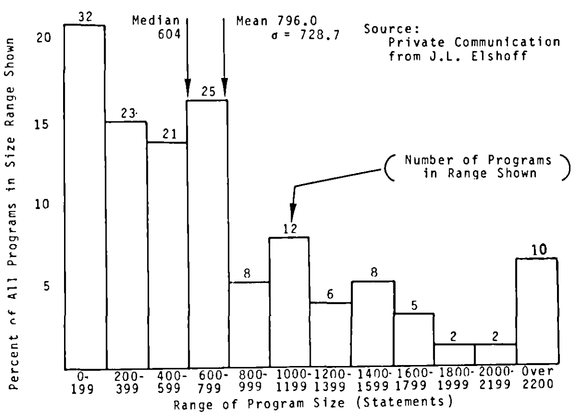



FIGURE 2.21.6a DISTRIBUTION OF PROGRAM SIZE 154 PL-I PROGRAMS AT GENERAL MOTORS

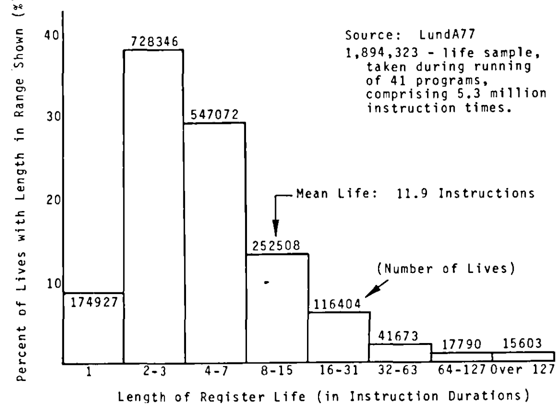



FIGURE 2.21.9a DISTRIBUTION OF REGISTER LIVES

## TABLE 2.21.10a REGISTER USAGE BY 41 DEC SYSTEM 10 PROGRAMS

| | Language | | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | Assy. | ALGOL | BASIC | BLISS | FORTRAN1 | FORTRAN2 | |
| Number of Programs | 3 | 6 | 5 | 13 | 7 | 7 | |
| Average Register Life | 18.7 | 12.7 | 11.6 | 11.8 | 9.3 | 11.6 | 11.9 |
| in Instructions | (15-24) | (6-17) | (11-12) | (8-18) | (4-15) | (6-20) | |
| Register Usages | 4.6 | 4.1 | 3.6 | 4.8 | 3.8 | 3.8 | 4.2 |
| per Life | (4-6) | (4-5) | (4-7) | (3-6) | (3-5) | (3-5) | |
| Average Number | 4.9 | 4.9 | 3.6 | 3.9 | 3.2 | 3.8 | 3.9 |
| of Live Registers | | (3-7) | | (3-5) | (2-6) | (3-6) | |
| Register References | 1.20 | 1.61 | 1.10 | 1.59 | 1.33 | 1.28 | 1.40 |
| per Instruction | (1.1-1.4) | (1.6-1.7) | (1.0-1.2) | (1.2-1.7) | (1.1-1.6) | (1.1-1.5) | |
| Memory References | .38 | .49 | .51 | .48 | .59 | .57 | .51 |
| per Instruction* | (.32-.42) | (.30-.65) | (.45-.59) | (.31-.60) | (.44-.69) | (.35-.64) | |
| Fractions of Register Life: | | | | | | | |
| No Arithmetic | .797 | .496 | .691 | .498 | .512 | .456 | .538 |
| Fixed Pt. Arith. | .203 | .411 | .098 | .314 | .309 | .351 | .299 |
| Fltg. Pt. Arith | .001 | .094 | .211 | .188 | .178 | .193 | .162 |
| Number of Registers Sufficient: | | | | | | | |
| 100% of time | 13.0 | 13.7 | 8.8 | 8.2 | 10.7 | 12.1 | 10.4 |
| 98% of time | 9.0 | 9.7 | 6.8 | 6.5 | 7.6 | 7.7 | 7.6 |
| 90% of time | 7.3 | 8.0 | 5.8 | 5.7 | 5.4 | 5.6 | 6.1 |

Source: LundA77. See Notes in Part II. Parenthetical entries show range, other figures are means.
*Memory references exclude instruction fetches.

programmers are not making enough use of the registers they have.

**Amdahl's Rule.** In discussing procedure-execution workloads, and in particular the ratio s of computer operations to I/O bytes, I overlooked a famous rule of thumb. Gene Amdahl, architect of the IBM System/360 and founder of the Amdahl Corporation has propounded, but apparently never published, a statement which has informally become known as Amdahl's Rule: two bytes of memory and one bit per second of I/O are required for each instruction per second, in order to have a balanced system. (In a letter to the author in May, 1979, Dr. Amdahl wrote, "these figures have held within a reasonable fluctuation for most scientific and commercial installations which deal with a fairly highly varied workload, and in today's virtual memory systems are not troubled with heavy paging rates.")

The rule implies the very low ratio $s = 8$ computer operations per I/O character (assuming 8-bit characters). The data cited in DPT&E (see index under "computer operations per I/O character") gives values of s which range from 26 to several thousand. However, these values were determined by dividing total instructions executed by the number of data bytes the user supplied as input and received as output. The transfers of programs, of internal data bases which may have been referenced, and of bytes moved in the name of system efficiency were not included. If Amdahl's Rule is accurate, there are evidently hundreds of these auxiliary bytes transferred for every user I/O byte.

## 2.23a COMPUTER SYSTEM PERFORMANCE

Potential system performance is completely determined by the speed of the CPU, the number of I/O channels connected to it, and the speed of the I/O channels. Actual performance is determined by these factors, together with characteristics of the operating system and of the workload. These factors are summarized in Table 2.23.0a. They were (except for operating system efficiency $\epsilon$ and the breakdown of D into $D_1$ and $D_2$) used to establish the throughput model of Figure 2.23.5 on p. 105 of DPT&E.

Operating system efficiency continues to be a factor not well described or understood. We often find data which divides CPU utilization (i.e. fraction of the time the CPU is busy) into a user portion and a "supervisor" or overhead portion. Table 2.23.5a displays some recent data of this kind. But presumably some portion of the "supervisor" time is spent in I/O routines called by users, and should thus legitimately be assigned to users. On the other hand, to the extent that the operating system transfers I/O data or program segments more than once between peripheral and internal memory for its own purposes (e.g. to maintain several programs each in a portion of internal memory, or to provide fast response to on-line terminal users), those transfers should properly be charged to the supervisor, not to the user. Presumably every system operator has the option of running only one user program at a time, thus increasing efficiency $\epsilon$ and making more internal memory available for the user programs–both advantages arising because the operating system's multiprogramming functions would not be needed. But we have no measures, that I know of, from which we can determine how $\epsilon$ would change when a multiprogrammer became a monoprogrammer.

We also do not have good data on the breakdown of total I/O data D between its internal and external components $D_1$ and $D_2$. For the Army and Air Force management information systems described in Tables II.2.21.1-2 in DPT&E, the median data base contained 13M bytes and the median input and output volumes (presumably totalling $D_1$) were 6 and 12.5M bytes, respectively, per month. But we don't know how representative that sample is of today's practice. (In fact, we are not even sure how to interpret it, because we don't know how many times each program was run per month, and I/O data values were given in characters per month.)

In any event, system managers find themselves in a dilemma when they establish data base storage formats: to maximize I/O data rates (and storage efficiency in bytes per disk or tape), they should record data in large blocks; but if the blocks are large, the result may be that $D_2$ is much larger than it need be. If we are updating a file, for example, and know that an average of one record in ten will be changed, we can input only the records to be changed, if we store one record per block. But if we store two or four or eight records per block to increase the data rate, then we may unnecessarily read in one, or three, or seven records we *don't* want to update for every record we do want to update. (The hardware may generally make it possible to avoid storing these unnecessary records in internal memory; but it does not yet make it possible for us to avoid taking up channel time, which is a major determinant of throughput.)

Given data of the kind shown in Table 2.23.0a, we can use a model of one kind or another to predict throughput and response or delay time. In the next paragraphs we will discuss an expanded version of the model descriped on pages 104 to 111 of DPT&E.

**System throughput and turnaround time.** Some recent work on queuing theory, beautifully summarized by Denning and Buzen in a recent paper (DennP78), makes it possible for us easily to compute the effect of multiprogramming on throughput, and to estimate turnaround time (or system delay) as well. (See Figure II.2.23.3a for details of the mathematics used).

The model to be discussed is shown in Figure 2.23.5a. In its simplest form, shown at the top of the figure, it consists of a CPU and an I/O channel, each having an associated queue. Each job segment is assumed to take an average time $S_1$ to be served by the CPU, and an average time $S_2$ to be served by the channel. As soon as the CPU finishes a job segment, the job enters the channel queue, and there waits its turn to be served. And as soon as it has been served by the channel, it enters the CPU queue. We assume that each job visits the CPU $V_1$ times and the channel $V_2$ times before being completed. Furthermore, we assume there are a fixed number of job segments J in the system–that as soon as a job has completed the appropriate number of visits, it disappears and is replaced by a new job. Thus the sum of the number of jobs in the CPU and channel queues is always J.

Adopting the features of the throughput model of DPT&E (Figure 2.23.5, p. 105), we remember the system is characterized by a CPU speed of C' operations per second and a channel speed of D' characters per second. And the workload is characterized by a number of characters kD to be handled by the I/O system, a number D to be processed, and a processing load s operations per character. From these figures, the average CPU and channel service times can be calculated as shown in the figure, assuming each job visits the CPU and channel once.

A slightly more general model is shown at the bottom of

## TABLE 2.23.0a FACTORS AFFECTING SYSTEM PERFORMANCE

| Factor | Symbol | Primary Determinants | Ref. in DPT&E and Supplement |
|---|---|---|---|
| **Equipment Factors** | | | |
| Processor Speed | C' | Electronics in Processor and Memory | p. 60-61 |
| | | Instruction Mix | p. 92-97 |
| I/O Speed | D' | Electromechanics of Devices | p. 64-75 |
| | | Data Format Used | Fig. 2.12.5a, 2.12.14a, 2.12.17a |
| Number of I/O Channels | I | | |
| **Operating System Factors** | | | |
| Multiprogramming Level | J | Internal Memory Capacity | |
| Efficiency (fraction of CPU Time spent on user job processing) | $\epsilon$ | | Tables 2.23.5a, 2.23.5, II.2.21.5 |
| **User Job Factors** | | | |
| Amount of data to be transferred between CPU and I/O equipment* | D | Job Size | Fig. 2.21.1-3, Tables 2.21.3, 2.23.4b |
| Data external to the system* | $D_1$ | | Tables II.2.21.1-2:6-11 |
| Data from and to Internal Data Base* | $D_2$ | | Tables II.2.21.1-2:12-20 |
| Program Length | D(k-1) | Job Complexity | Fig. 2.21.6 |
| Total I/O characters | kD | | |
| Processor operations per I/O character | s | Job Complexity | Fig. 2.21.7, Table 2.21.3 |

*Data external to the system comes from and/or goes to terminals, punched card equipment, and printers. Data from and to internal data bases is maintained on peripheral memory equipment. $D = D_1 + D_2$.

## TABLE 2.23.5a CPU AND I/O ACTIVITY OF VARIOUS SYSTEMS

| | Utilization Total | CPU User | CPU OH | Channels CH1 | Channels CH2 | | Utilization Total | CPU User | CPU OH | Channels CH1 | Channels CH2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **IBM 370/155-2** | | | | | | 370/168—Av. 72 Users | .360 | .145 | .215 | | |
| 3.7 Batch Jobs | .696 | | | .576 | .400 | 370/168—Av. 117 Users | .963 | .560 | .403 | | |
| Batch and Time-sharing | .893 | | | .478 | .211 | **Typical MVS Environment** | | | | | |
| Batch and Time-sharing | .914 | | | .510 | .071 | Under-utilized | .70 | | | .10 | .10 |
| **Time-sharing Systems** | | | | | | Over-utilized | .98 | | | .30 | .60 |
| 370/135—Av. 4 Users | .171 | .053 | .118 | | | **370/125 with DOS/VS** | .92 | .48 | .44 | | |
| 370/145—Av. 8 Users | .840 | .425 | .415 | | | **370/158 Under MVS** | | | | | |
| 370/145—Av. 15 Users | .966 | .408 | .558 | | | 15 time-sharing users | .430 | .176 | .254 | | |
| 370/155—Av. 20 Users | .222 | .067 | .155 | | | 30 time-sharing users | .641 | .236 | .405 | | |
| 370/155—Av. 23 Users | .369 | .107 | .262 | | | 5 batch jobs, 30 users | .995 | .560 | .435 | | |
| 370/158—Av. 37 Users | .592 | .315 | .277 | | | **CDC6600 under UT-20** | | | | | |
| 370/158—Av. 46 Users | .703 | .378 | .325 | | | Batch-Interactive Load | .818 | .307 | .511 | | |
| 370/158—Av. 24 Users | .688 | .522 | .166 | | | Pure Batch Load | .933 | .759 | .174 | .28av | .28av |

OH = Overhead.

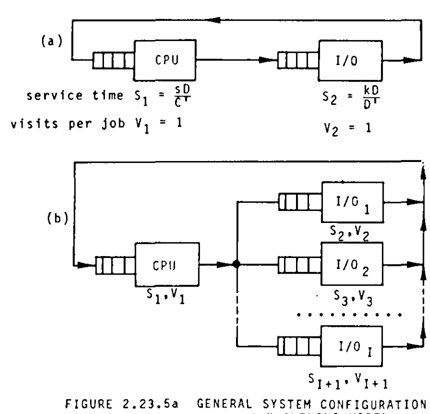



FIGURE 2.23.5a GENERAL SYSTEM CONFIGURATION FOR A "SINGLE-SERVER" QUEUING MODEL

Figure 2.23.5a. Here there are I I/O channels each having a service time $S_i$ and a visit ratio $V_i$. Suppose:

W = System throughput, in jobs/second

$U_i$ = Fraction of the time facility i is busy

R = Response or turnaround time for one job

then the analysis of Figure II.2.23.3a shows that, with suitable simplifying assumptions

$$W = U_i/(S_iV_i)$$

$$R = J/W$$

and gives us a way of computing W and R, from system and workload parameters. The results for a system with one I/O channel are shown in Figures 2.23.6a and 2.23.6b. Comments:

1. We may compare this result to one of those shown in Figure 2.23.15 of DPT&E. The top dotted curve there, and the top dotted curve of Figure 2.23.6a, both employ the exponential distribution for CPU time, and both have J = 10. The results are quite comparable. The difference comes about because of slight differences in the models—the Gaver model has one queue for *all* I/O channels, instead of one queue per channel—and because the Gaver model provides an exponential distribution of the ratio of processor to I/O time, while our model requires an exponential distribution of I/O channel time itself.

2. Response time (Figure 2.23.6b), which is the turnaround time the computer operator sees as he inserts jobs into the system, is easy to understand. When compute time is small (s small compared with $s_c$), most of the delay is in the channels, and the delay is simply I/O time kD/D' multiplied by the number of jobs. Similarly, when compute time is large, the delay is *compute time* multiplied by the number of jobs. But we know that compute time is sD/C' = $(s/s_c)$(kD/D'). Thus, as shown in the figure, response time is proportional to J and to $s/s_c$ when the system is compute-bound.

3. We may use the results of the model, shown in Table II.2.23.3a in Part II, to compute performance in more complicated systems. For example, suppose we have an Amdahl 470/V5 CPU operating with sixteen IBM 3330 MHF's, and want to estimate the effect of varying numbers of channels and various multiprogramming levels on performance, at different job complexities. As we add channels, we potentially increase throughput because the I/O rate is increased; but the I/O rate *per channel* actually goes down as we reduce the number of spindles per channel, because it takes many spindles to keep the channel busy (see Figure 2.12.19a). The assumptions made in the analysis are shown at the bottom of Table 2.23.6a. The results are shown in the body of that table, and are plotted in Figures 2.23.6c and 2.23.6d. Note that the one-channel system is I/O bound for both s = 40 and 80, but that, even with 20 levels of microprogramming on eight channels, we cannot make CPU utilization 100% at s = 40. Note also (Figure 2.23.6d) the eight-channel system is not much better than the four-channel system—the reduction in channel data rate which comes from cutting from four to two 3330's per channel results in an I/O data rate increase of only 32% (from 1480 to 1960 kbytes/sec) when we double the number of channels.

**Time-sharing System Performance.** We can apply the model to the operation of a time-sharing system connected to J active users, with the result shown in Figure 2.23.6e. At any time, some of the terminals will be in the "think" or "input" mode, with average total time Z, and the rest will be "in process" at the computer system, with average delay or response time R. Considering the user-computer system as a whole, it should be evident that its total throughput is J/(R+Z)—each of J users gets a "job" done every (R+Z) seconds. However, we know that R and Z are complex functions of J. Without knowing *exactly* what those functions are, we can nevertheless deduce the nature of the relationship by means of the analysis shown in the figure. Suppose the computer system contains a number of facilities each with service times and visit ratios given. If there is only one terminal connected, we know the computer response time is simply the sum of the average facility times. If there are a

**Table 2.23.6a THROUGHPUT**

| I | Spindles per Channel | D'/I (Kbps) | D' (Kbps) | $s_c$ =kC'/D' (op/by) | $W_{max}$ =D'/kD (Jobs/sec) | $s/s_c$ | J=1 | J=2 | J=5 | J=10 | J=20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Throughput (Jobs/sec) | | | | |
| | | | s=40 Operations per I/O Character | | | | | | | | |
| 1 | 16 | 600 | 600 | 96.8 | 0.030 | 0.413 | .0214 | .0267 | .0297 | .03 | .030 |
| 2 | 8 | 500 | 1000 | 58.1 | 0.050 | 0.688 | .0186 | .0277 | .0388 | .0443 | .0473 |
| 4 | 4 | 370 | 1480 | 39.3 | 0.074 | 1.019 | .0147 | .0246 | .0410 | .0525 | .0612 |
| 8 | 2 | 245 | 1960 | 29.6 | 0.098 | 1.349 | .0105 | .0188 | .0361 | .0515 | .0643 |
| | | | s=80 Operations per I/O Character | | | | | | | | |
| 1 | 16 | 600 | 600 | 96.8 | 0.030 | 0.826 | .0165 | .0219 | .0270 | .0289 | .0295 |
| 2 | 8 | 500 | 1000 | 58.1 | 0.050 | 1.377 | .0148 | .0221 | .0309 | .0348 | .0363 |
| 4 | 4 | 370 | 1480 | 39.3 | 0.074 | 2.036 | .0123 | .0201 | .0313 | .0358 | .0365 |
| 8 | 2 | 245 | 1960 | 29.6 | 0.098 | 2.702 | .0092 | .0162 | .0288 | .0355 | .0365 |

Assumptions:
1. Amdahl 470/V5 CPU has an add time of 162.5 nanosec. and a multiply time of 357.5 nanosec. Assuming 95% additions and 5% multiplications, we find C'=5.81 million operations per second.
2. Data is stored on IBM 3330's in 3 kbyte blocks. Channel data rate is from Fig. 2.12.19a, and depends on number of spindles per channel.
3. Average job complexity s is 40 or 80 operations per I/O character. Ratio of total characters read into the system (including program, data base, and repetitive I/O for operating system convenience) is k=10. 4. Throughput is found from Table II.2.23.3a, by interpolating the required $s/s_c$ value under the proper value of I, and multiplying the resulting utilization figure by $W_{max}$.

large number of users, then the throughput will be limited by some bottleneck facility within the computer system. Throughput will be $U_b/(S_bV_b)$, and $U_b$ will approach one as J gets larger and larger. The resulting shape of the throughput and response time curves is shown at the bottom of the figure. The critical number of users J* is called the *saturation point* of the system.

To give an example of the use of this analysis, let us look at the time-sharing systems briefly described in Table 2.23.5a. Let's suppose the IBM 370/145 system described there, whose CPU shows a 0.966 utilization with 15 users, is operating at the saturation point. Let's further assume the CPU is the bottleneck, and that the other facilities all added together have a total $\Sigma VS$ equal to $V_bS_b$. Then

$$J^* = (2V_bS_b + Z)/(V_bS_b)$$

and we can solve for $\quad V_bS_b = Z/(J^* - 2)$

Given a typical user time Z of 20 seconds (Figure 2.22.2, p. 99), we find

$$V_bS_b = 20/(15\text{-}2) = 1.54 \text{ sec}$$

and the maximum possible throughput is $1/(V_bS_b) = 0.65$ jobs per second. We can estimate the *minimum* response time with 25 users as

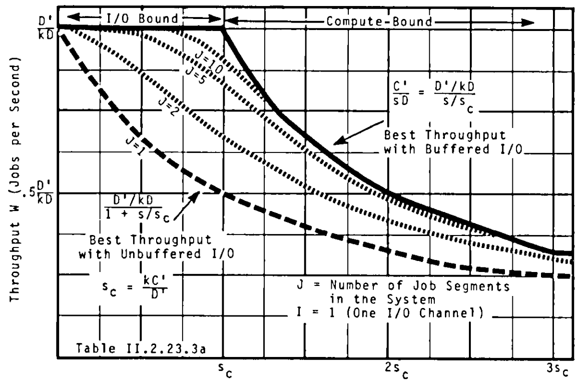



FIGURE 2.23.6a SYSTEM THROUGHPUT VS. WORKLOAD

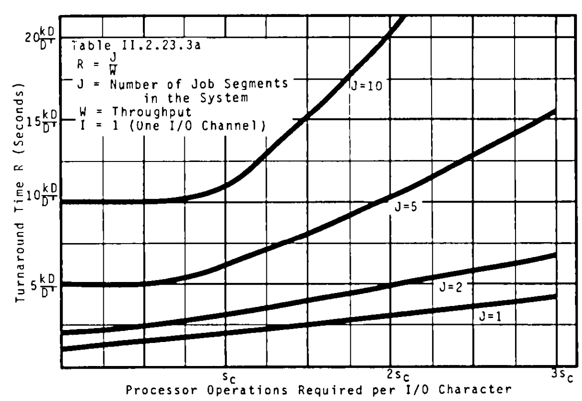



FIGURE 2.23.6b JOB TURNAROUND TIME VS. WORKLOAD

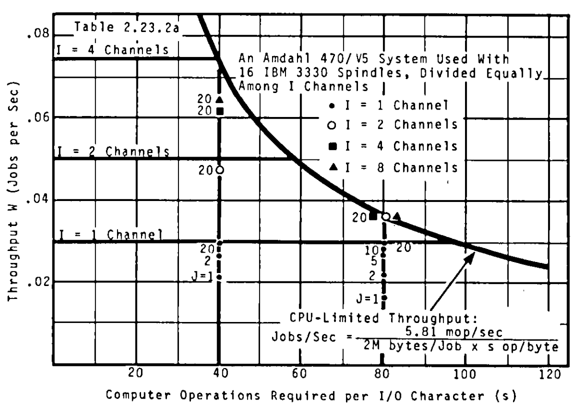



FIGURE 2.23.6c A THROUGHPUT EXAMPLE I
THROUGHPUT VS. JOB COMPLEXITY

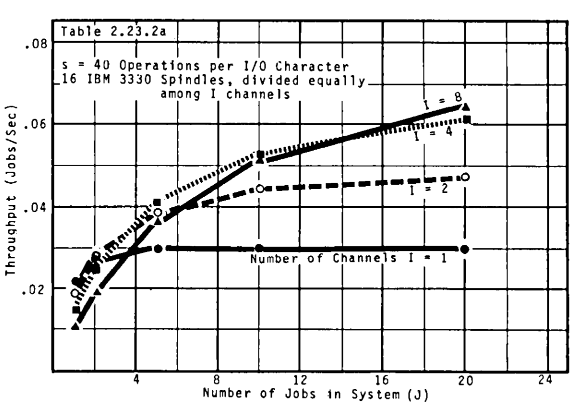



FIGURE 2.23.6d A THROUGHPUT EXAMPLE II
THROUGHPUT VS. MULTIPROGRAMMING LEVEL

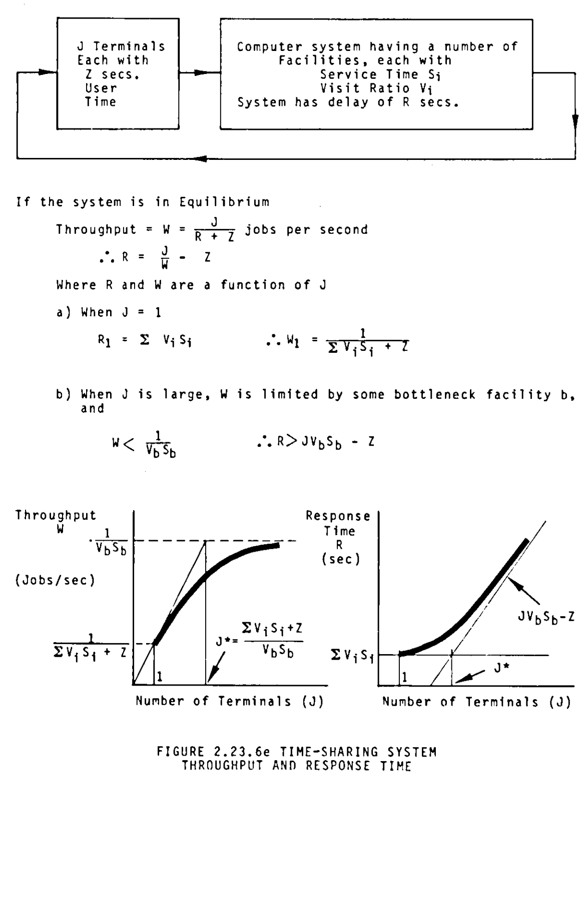



FIGURE 2.23.6e TIME-SHARING SYSTEM
THROUGHPUT AND RESPONSE TIME

$$R_{min} = 25(1.54) - 20 = 18.5 \text{ seconds}$$

Furthermore, if we assume (Figure 2.22.2 again) the user sends and receives 100 I/O characters per interaction, and that the 370/145 has a C' of 329,000 op/sec, we can compute a value of interaction complexity

$$s = (C't)/D = 329{,}000 \times 1.54/100 = 5060 \text{ op/byte}$$

which would seem to be a fairly heavy load.

**Maximum Throughput at a Given Cost.** Trivedi and Kinicki used the queuing model in an ingenious analysis of throughput at a fixed cost (TrivK78). They envisioned a system having various facilities whose throughput can be computed as a function of the multiprogramming level and of facility performance. Furthermore, they assumed the cost of each facility can be expressed as a function of its performance or (in the case of internal memory) its capacity. Total system cost they assumed to be the sum of facility costs plus internal memory cost, where the size of internal memory is proportional to the multiprogramming level. If we look at throughput as a function of multiprogramming level for a fixed cost, we see there will be an optimum level. We know that, for a given system, an increase in J increases throughput. But if cost is to remain fixed, and every increment in J causes an increment in internal memory cost, we have less and less money to spend on CPU and I/O system performance with larger and larger J. And the reduced CPU-I/O performance subtracts from the throughput increase we get by increasing the multiprogramming level.

The authors took a particular example to show how the computation would be carried out, and the results are shown starting with Figure 2.23.6f. The sample system looked like Figure 2.23.5a (b), and consisted of a CPU, two MHF's, and a HPT file. The CPU requires 400,000 operations per job, and for each job 40,000 bytes must be transferred between HPT file and memory, and 24,000 and 12,000 bytes between the first and second MHF's and memory, respectively. (Note the assumption that $s = 400/(40+24+12) = 5.26$ operations per byte.) Figure 2.23.6f shows how throughput varies with J for a memory requirement of 100 kbytes per job and four different system costs, given the performance-cost curves shown in Figure 2.23.6g. As we might expect, the optimum value of J increases with system size. Figure 2.23.6h shows how throughput, in jobs per second, varies with system price for two different requirements of internal memory per job.

Figure 2.23.6i shows the same results plotted on the throughput-s plane. We observe here that all the optimum systems operate in the compute-bound mode. Why is that? Why not spend more on the CPU and less on the I/O equipment (and perhaps less on internal memory) and move the CPU line to the right and the I/O-limiting line down? The answer is that, with the cost parameters chosen (Figure 2.23.6g) the CPU and memory already represent around 80% of system cost. Thus we don't gain much performance by adding CPU cost. The example would have been more realistic had the authors used higher MHF and HPT file costs, to account for the fact that in most systems the design requirement is for a string of files on a channel, not for a single device.

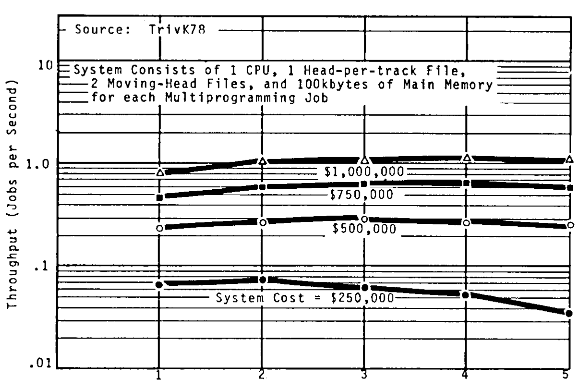



FIGURE 2.23.6f MAXIMIZING THROUGHPUT AT A GIVEN COST I
THROUGHPUT VS. NUMBER OF MULTIPROGRAMMING JOBS

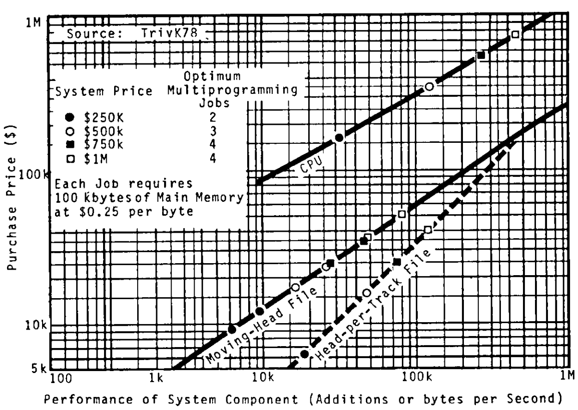



FIGURE 2.23.6g MAXIMIZING THROUGHPUT AT A GIVEN COST II
ASSUMED PRICE/PERFORMANCE RELATIONSHIPS

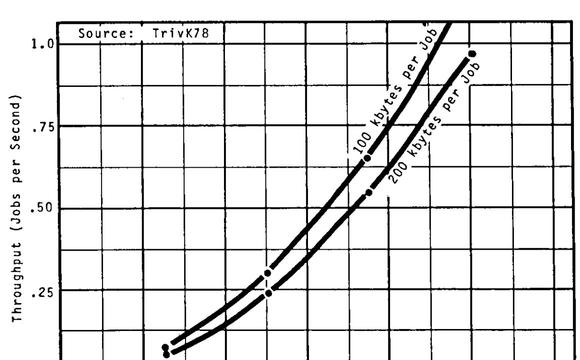



FIGURE 2.23.6h MAXIMIZING THROUGHPUT AT A GIVEN COST III
MAXIMUM THROUGHPUT VS. PRICE

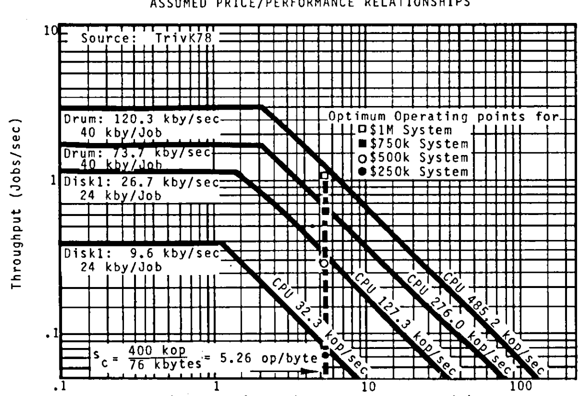



FIGURE 2.23.6i MAXIMIZING THROUGHPUT AT A GIVEN COST IV
OPTIMUM OPERATING POINTS ARE COMPUTE-BOUND

## 3.0a Applications—Introduction

We defined *data* (p. 120) as "a representation of facts, concepts, or instructions in a formalized manner suitable for communication, storage, or processing, by human or by automatic means." Let us now further divide data into two categories: recorded data and transient data. *Recorded data* is that which is recorded on media by organizations which expect to make use of it later, in the course of business. The media may be human- or machine-readable. *Transient data* is data which is of momentary interest, and is not saved by the organization because the likelihood of its later use is low.

The definitions are admittedly loose. How long must data be saved before it is classified as "recorded data"? What exactly does "of momentary interest" mean? If a secretary leaves a message on my desk informing me that my wife called and wants me to call her, is that recorded data since it appears on a piece of paper? Suppose the message is from a customer who wants to place an order before a stated deadline—would the answer be the same? The answers are to some extent arbitrary, but I would classify the first message as transient data (it will be acted upon and then discarded) and the second as recorded data (the slip of paper might be filed, as evidence of the customer's action, and brought forth if there is later controversy about that action). But for the most part, the definitions can be applied without much difficulty. Business records of the kinds listed in Table 3.0.6 (p. 126) are clearly all examples of recorded data. So are statistical records maintained by the government, student records and course descriptions maintained by a university, book inventories and member records maintained by a library, and tax records maintained by an individual. On the other hand, most telephone and face-to-face conversations, along with most telegraph and teletype messages, consist of transient data. (Had Mr. Nixon's conversations in the Oval Office remained transient, he might have completed his second term.) Most physical measurements used as the basis for control consist of transient data. For example, a thermostat which compares room temperature to temperature setting, or an industrial instrument which opens and closes a valve in response to a flow measure, deal with transient data. It is, of course, possible for transient and recorded data to coexist in a system: a process control computer will discard the vast majority of measurements it uses, but may record some on a sampling or averaging basis for a permanent record; a reservation system may handle much more transient data (inquiries about availability) than it handles recorded data (reservations and cancellations.)

It seems certain that the biggest area of growth for computing over the next twenty years will be in the processing of transient data. That is surely the microcomputer market, for example. But for the moment let us concentrate our attention on recorded data, which has been the basis for the initial growth of the data processing industry. How can we quantify the data processing which is done by an organization? I suggest we need three measures, as follows: Suppose:

D = Average number of bytes of recorded data stored in the organization's files in a given year, normalized by dividing it by annual revenue, or by number of employees.

f = Fraction of those bytes which are processed during the year. Processing may consist simply of referring to them, or may involve arithmetic and logical manipulations. The fraction f may be greater than one—obviously is, for some portions of the data, though probably not for the total data D in most organizations.

s = Number of elementary operations which must be performed, by a human or machine, to process one byte of data. For a computer, an elementary operation is an instruction. For a human, it is an equivalent action—copying a number on a worksheet, or finding the folder "P" in a file drawer, for example.

Given these measures, we can compute the total amount of processing which must be done per dollar of revenue or per employee. For a given organization in a given year:

$$\text{Total processing workload} = f\ s\ D$$

The factors D, f, and s presumably all change with time. Table 3.0.7a gives my estimates of their value in six different years, along with the data from which the estimates were derived. A detailed description of the derivation of the figures appears in Part II, in the notes to the table. And the results are plotted in Figures 3.0.2a and 3.0.3a. I don't pretend these estimates faithfully record what actually happened between 1950 and 1974. If one makes slightly different assumptions, the results change significantly (and in a recent paper —*Computer Design*, August, 1979, p. 42—I presented an earlier estimate noticeably different in its details from the present one). However, any reasonable set of assumptions seems to lead to an S-shaped curve of the general form shown in Figure 3.0.3a. In the fifties and earlier, virtually all processing was performed by humans. As the computer came into use, the total amount of processing per year per million dollars of revenue increased sharply, and since sometime in the sixties, the majority of processing has been handled by computers. *I conjecture that, over the past ten years, the rate of growth of processing has slowed, and that it will decrease further during the coming decade.*

Since the mid-Sixties, the fsD curve of Figure 3.0.3a has been dominated by computer operations (compare lines 6 and 14 of Table 3.0.7a). So my conjecture simply says that total computer operations per year will grow relatively more slowly than will total revenues (or total employees). The conjecture is easily challenged. For one thing, there was an apparent acceleration in growth of installed GP computer operations between 1974 and 1978. I argue that that acceleration is a statistical fluctuation, not a trend. For another thing, the analysis fails to account for computer operations of the two fastest-growing portions of the DP field: SBC's and word processors. I argue that the speed and storage capacity of such systems are so low, compared with GP systems, that their inclusion would not materially affect the results shown even if a million SBC's and word processors were in use.

There are, it seems to me, logical reasons why the fsD curve should flatten out. A given organization at any time possesses a finite number of bytes of recorded data, in manual files and on computer media. Table 3.0.6 provided an overview of those files. Once the organization is large enough to have its own computer, it more-or-less quickly mechanizes the more obvious and direct applications. And then it provides valuable but not essential auxiliary reports, analyzing the files in various ways to help management identify problems or improve efficiency. But there must come a point where every useful permutation of data has been programmed. Then what? We can all agree on the value of a program which multiplies hours worked by hourly rate and prints a paycheck. We can appreciate the usefulness of a program which sorts accounts receivable by age and by dollar amount, and prints out a report for action by sales and financial executives. But whan we've done those useful things, do we write programs to merge the vendor file with the assets file, or to multiply employee addresses by part numbers, just to keep the computer busy? The answer is obvious, and equally obvious, it seems to me, is the necessary levelling off of the fsD curve.

There are several important conclusions to be drawn from this analysis:

1. The fsD curve may continue its upward slope if management decides that the systems which handle the organization's recorded data should do more and more transient data processing. Certainly there will be pressure to do just that—to let salesmen have access to a manufacturing control system, so they can determine the status of an order; or to give employees on-line access to job descriptions; or to let managers retrieve and examine last year's budgets. Some proposed new transient applications may be easy to justify, others may be difficult. Management must sharpen up justification criteria, or else face the effects of Parkinson's Law for DP: applications will increase to fill up the available, and ever-increasing, computer capacity.

2. There are a few application areas which seem to have an insatiable appetite for computer power. In many scientific calculations, we can learn more and more by dividing the universe under study into finer and finer grids. In many engineering and business areas, we can make better and

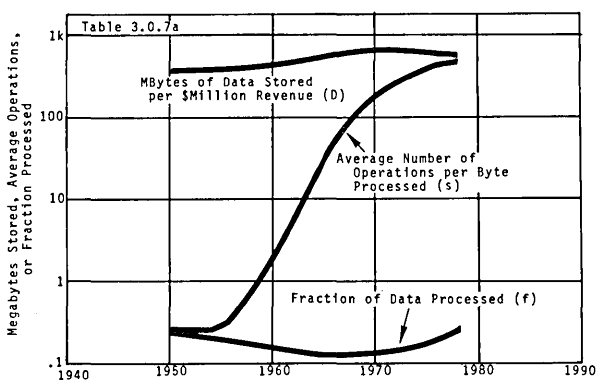



FIGURE 3.0.2a AN ESTIMATE OF BUSINESS RECORD ACTIVITY I
DATA STORED, OPERATIONS PER BYTE, AND FRACTION PROCESSED

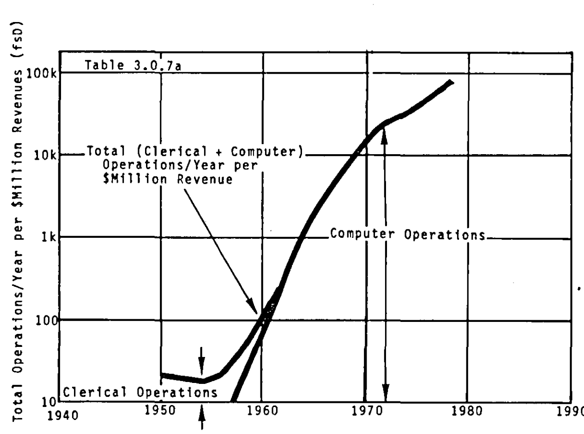



FIGURE 3.0.3a AN ESTIMATE OF BUSINESS RECORD ACTIVITY II
TOTAL OPERATIONS PER YEAR PER $MILLION REVENUE VS. TIME

**TABLE 3.0.7a AN ESTIMATE OF BUSINESS RECORD ACTIVITY**

| | | 1950 | 1955 | 1960 | 1965 | 1970 | 1974 | 1978 |
|---|---|---|---|---|---|---|---|---|
| 1. | Revenues from Corporations, Partnerships, and Proprietorships | $655B | $880B | $1095B | $1469B | $2082B | $3557B | $5250B |
| 2. | Total Employment (Non-govt.) | 52.9M | 55.2M | 56.7M | 61.0M | 66.0M | 71.7M | 77M |
| 3. | Revenue per Employee | $12.4k | $15.9k | $19.3k | $24.1k | $31.5k | $49.6k | $68k |
| | **Clerical Processing** | | | | | | | |
| 4. | Total Number of Clerks | 7.63M | 8.37M | 9.70M | 11.14M | 13.71M | 15.04M | 17M |
| 5. | Clerks per $1 Million Revenues | 11.6 | 9.51 | 8.91 | 7.58 | 6.59 | 4.23 | 3.2 |
| 6. | Clerical Operations/yr. per $1M | 20.9M | 17.1M | 16.0M | 13.6M | 11.9M | 7.6M | 5.8M |
| 7. | File Cabinets per Clerk | 2.6 | 3.2 | 4.0 | 5.0 | 6.2 | 7.8 | 8.4 |
| 8. | File Cabinet Bytes per $1M | 362M | 365M | 428M | 455M | 490M | 396M | 323M |
| 9. | Clerical Operations per Character | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| 10. | Fraction of Data Processed | .231 | .187 | .150 | .120 | .097 | .077 | .072 |
| 11. | Bytes Processed by Clerks per $1M | 83.6M | 68.3M | 64.2M | 54.6M | 47.5M | 30.5M | 23.3M |
| | **Computer Processing** | | | | | | | |
| 12. | Total U.S. GP Operations/Sec. | 0 | .12M | 7.5M | 213M | 2194M | 6925M | 26064M |
| 13. | Computer Operating Hrs./Month | - | 300 | 300 | 325 | 350 | 375 | 380 |
| 14. | Computer Operations/Yr. per $1M | 0 | 1.77M | 88.8M | 2.04B | 15.9B | 31.5B | 81.5B |
| 15. | Computer Data Storage—Total Bytes | 0 | 10B | 3240B | 106kB | 369kB | 773kB | 1512kB |
| 16. | Per $1M Revenue | 0 | .011M | 2.96M | 72M | 177M | 217M | 288M |
| 17. | Computer Operations per Character | - | 100 | 200 | 300 | 400 | 500 | 600 |
| 18. | Fraction of Data Processed | - | 1.61 | 0.15 | .094 | .225 | .290 | .471 |
| 19. | Bytes Processed by Computer per $1M | 0 | .018M | .44M | 6.8M | 39.8M | 62.9M | 135.6M |
| | **Summary** | | | | | | | |
| 20. | Total Operations/yr. per $1M (fsD) | 20.9M | 18.9M | 105M | 2054M | 15912M | 31508M | 81506M |
| 21. | Total Data Storage per $1M (D) | 362M | 365M | 431M | 527M | 667M | 613M | 611M |
| 22. | Total Bytes Processed per $1M (fD) | 83.6M | 68.5M | 64.6M | 61.4M | 87.2M | 93.5M | 159M |
| 23. | Fraction of Data Processed (f) | .231 | .188 | .150 | .117 | .131 | .152 | .260 |
| 24. | Average Operations per Character (s) | 0.25 | 0.28 | 1.62 | 33.5 | 183 | 337 | 513 |

Source: See Notes in Part II

better designs or plans by exploring–i.e. by simulating–more and more alternative designs or courses of action. But these are really examples of transient data processing: the vast amount of data existing in intermediate steps in the course of designing or planning is of no interest, and is not recorded. The transient data processing justification criteria mentioned in the previous paragraph should thus apply here, too, at least in the engineering and business areas.

3. There is a tendency for management to permit the data processing budget to increase each year, for any of several reasons: it has increased every year for the past 20 years; there are new applications which must be added; we need a computer to replace the ten-year-old one we have, whose capacity has been stretched to the limit; the budget is set at a fixed percentage of corporate revenue, and the company is growing. There is even a theory that justifies such growth (NolaR73), though it envisions an S-shaped levelling-off of *expenses* with time, comparable to the S-shaped levelling off of required *capacity* that I hypothesize. But if my conjecture is right, we must conclude that, as an organization's data processing operation matures, it will reach the point where increased capacity is no longer necessary, and (because the hardware to perform those calculations is cheaper every year, and no new applications programs need be written) the dp budget necessary per revenue dollar may then actually *decrease.*

4. Companies which supply computer equipment and services will in the future find themselves competing in a limited and shrinking market, if my hypothesis is correct. When processing of recorded data has reached maturity in most organizations, and users have put a lid on the growth of transient DP, the only significant increase in DP capacity required will come about because of increases in total revenue–that is, increases in the U.S. economy itself. But with continuing improvements in technology, the total required U.S. DP capacity can each year be supplied by cheaper and cheaper equipment. Supplier revenues can at that point be expected to decline from year to year. In fact, the supplier situation may at that point be fairly unstable, for electronic equipment does not wear out, and once the users perceive that they have enough capacity, they are likely to buy their hardware rather than rent it, and will then not be so interested in new systems with improved price/performance.

5. Anyone can test my conjecture by determining the growth rate and status of data processing in his own organization. First, choose a measure to estimate computer operations per year performed now and at two- to five-year intervals in the past. Normalize the result, dividing by total revenue or total number of employees in those years. The result is the computer portion of fsD. Now estimate the number of clerical hours per year spent preparing, managing, filing, manipulating, and retrieving data in those same years. Multiply by estimated clerical operations per hour, and normalize that result to get the manual portion of fsD. Now plot the two fsD terms, and their sum, as a function of time. Finally, estimate the additional fsD capacity to be added over the next five years to handle planned new applications, and incorporate that data in the plot. Is the curve concave up or down? If up, my hypothesis is proven wrong, or at least inappropriate for the organization under study. If down, it may be interesting to extrapolate and try to determine when advances in computing technology will actually permit a reduction in the organization's annual DP budget.

6. What is needed, I suggest, is a systematic study of the parameters f, s and D in several organizations, or preferably in several industries. (It seems possible that in a given industry, companies will have certain common DP requirements quite different from those in another industry.) A preliminary investigation of the recent history of the product fsD (as discussed in the previous paragraph) might be a starting point for such a study in a given organization. But to understand better what has been happening, it will be necessary to look at the files and computations which use the lion's share of the DP facilities in the organization. Pareto's Law says that 80% of the activity resides in 20% of the applications, so the study task should be manageable. For these key applications, it should be possible to estimate the size of the data base (D), the fraction of that data base which is processed each year (f), and the number of computer operations per byte processed (s). The latter parameter may be estimated by estimating the amount of computer time per year devoted to the application, multiplying by an estimated processor operations per second (this gives fsD), and then dividing by the already estimated fD. A look at these three parameters, *and their rate of change over a 5- to 10-year period* for the major applications, is likely to suggest a host of questions, depending on the results: why is s for this application so much greater than for this one? Why is this f increasing so rapidly? Why is this f decreasing? If the results of such studies can be made generally available, they will help us judge whether the conjecture regarding an early leveling-off of demand for computing power is fact or fantasy.

## 3.1a Computer Applications—History and Status

### 3.11a COMPUTER USE IN ORGANIZATIONS

The GP computer, generally leasing for $1500 per month and more, is employed by the larger organizations throughout the economy. As we have seen, (Figures 1.21.1a, and 1.21.5a), the number of GP systems in use in the U.S. has been fairly constant since 1973, though the average value of each system has risen sharply. Figure 3.11.1a shows how these systems have been and are distributed across industries and in government. (The solid lines show distribution by number; the dotted lines, on the right, distribution by value. The numbers show the actual percentage distributions in selected years. At the top right corner, for example, we see

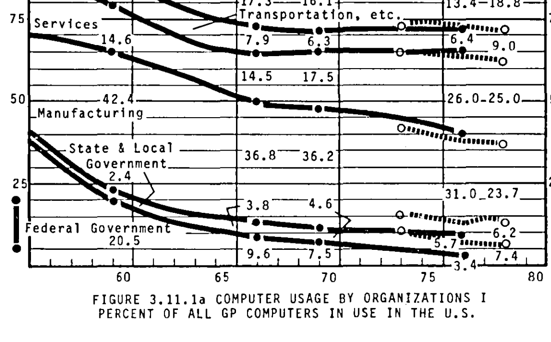



FIGURE 3.11.1a COMPUTER USAGE BY ORGANIZATIONS I
PERCENT OF ALL GP COMPUTERS IN USE IN THE U.S.

that in 1976 wholesale and retail trade companies used 13.1% of the GP systems, and in 1978 those companies used GP systems worth 7.8% of the value of all U.S. GP computers.) Comments:

1. The trade and manufacturing industries use GP computers of less-than-average size (percent by value less than percent by number); the service industry employs average-sized systems; the other groups shown use bigger-than-average size GP systems.

2. In the past ten years the government, manufacturing, and financial sectors have all lost their late-sixties proportion of GP systems in use. The service and trade industries have increased their share. Since the total number of GP systems in use has been constant over the past five years, a loss in proportion corresponds to a loss in actual numbers of systems in use. The implication is that the government, manufacturing, and financial organizations have cut back on their use of GP systems.

The ratio of number of GP systems in use to number of organizations (in this case proprietorships, partnerships, and corporations) is shown in Figure 3.11.5a. Note that the saturation ratio–the ratio of computers per organization at which GP systems are no longer added–is different for different industries. The ratios presumably are determined by the complexity of applications in each industry and by the size distribution of organizations in that industry.

To understand the nature of the market for computer products and services, we should know something about the size of the organizations which are actual or potential customers. Figures 3.11.6 through 3.11.8 (p. 129 of DPT&E) provided some data on the size distribution of plants in various industries and in the economy as a whole, along with information on the number of computers in use in those plants in 1967 and 1971. Figures 3.11.6b through 3.11.6e give some additional information on organization size.

The U.S. government records statistics on business organizations in two different ways. The first, shown in Figure 3.11.6b, counts "reporting units" or (since 1973) "establishments." An establishment is a "single physical location where business is conducted or where services or industrial operations are performed." The data is published by the Department of Commerce, and comes from tax returns filed by Proprietorships, Partnerships, and Corporations (PP&C's), supplemented by other data on the larger organizations, which typically operate two or more establishments. Government and railroad employees are not included, nor are self-employed persons. "Reporting Units", counted in 1973 and earlier, were similarly defined except that, if an organization operated more than one establishment in a given county, only the first was counted.

The Internal Revenue Service in the Treasury Department publishes the other set of statistics, on PP&C's (see Figures 3.11.6c to 3.11.6e). Where the Commerce Department publishes establishment size distributions based on the number of employees at each establishment, the IRS publishes PP&C size distributions based on reported receipts.

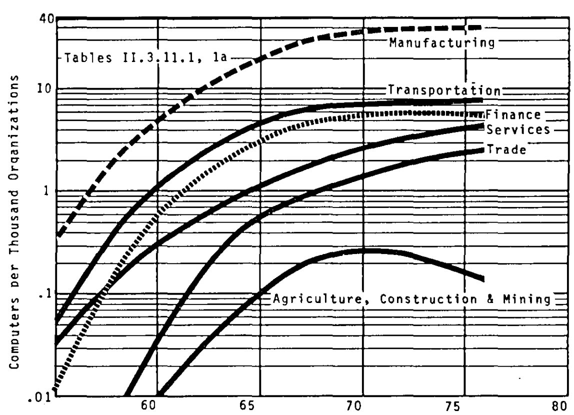



FIGURE 3.11.5a COMPUTER CONCENTRATION
GP COMPUTERS IN USE PER THOUSAND ORGANIZATIONS

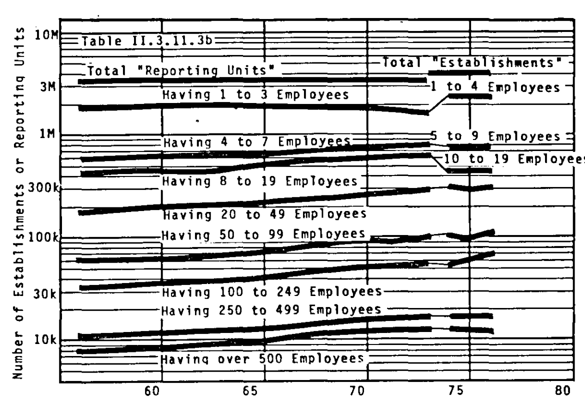



FIGURE 3.11.6b POTENTIAL CUSTOMERS OF DP EQUIPMENT & SERVICES I
NON-GOVERNMENT LOCATIONS WHERE BUSINESS IS CONDUCTED

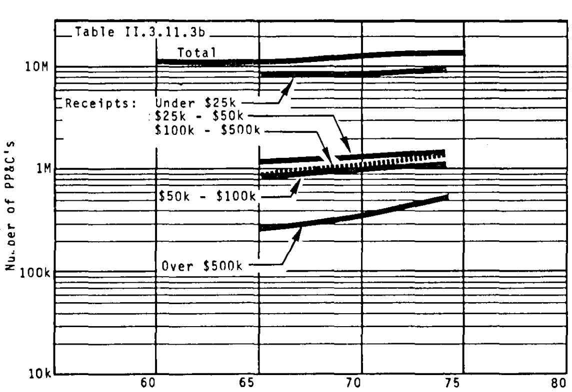



FIGURE 3.11.6c POTENTIAL CUSTOMERS FOR DP EQUIPMENT & SERVICES II
PROPRIETORSHIPS, PARTNERSHIPS, AND CORPORATIONS--RECEIPTS

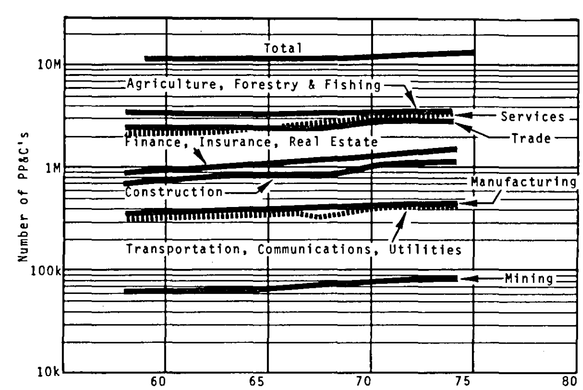



FIGURE 3.11.6d POTENTIAL CUSTOMERS OF DP EQUIPMENT & SERVICES III
PROPRIETORSHIPS, PARTNERSHIPS, AND CORPORATIONS--BY INDUSTRY

Comments:

1. Inasmuch as a proprietorship, partnership, or corporation may operate more than one establishment, we naturally expect the number of establishments to exceed the number of PP&C's and are thus surprised to discover there are over 10 million PP&C's and less than 4 million establishments. I have seen no formal reconciliation of this anomaly, despite the fact that the two sets of data apparently come from a common source—tax returns. Partly, the difference is explained by the fact that the PP&C data includes railroad employees and self-employed persons, who are excluded from the establishment figures. But undoubtedly most of the difference can be attributed to the millions of PP&C's whose receipts are less than $25,000 per year, and which have no full-time employees and thus no establishments—physical locations where business is conducted.

2. The total number of organizations or establishments grows fairly slowly from year to year—reporting units grew at an average rate of only 0.7% per year from 1959 to 1973, and PP&C's at an average rate of 1.4% per year from 1959 to 1975. From Table 3.0.7a we see that PP&C revenues increased from $1095B to $3557B in current prices, or from about $1063B to $2090B in 1968 prices, between 1960 and 1974—an average increase of 4.9% per year in real prices; and non-government employment increased from 56.7 million to 71.7 million in that same period—an average of 1.7% per year. Thus in recent years the average real revenue per PP&C, and the average number of employees per establishment have both increased. From Figure 3.11.6b we see there were fewer of the smallest reporting units (having 1 to 3 employees) in 1973 than there were in 1959. Meanwhile the number of reporting units with 20 or more employees grew faster than 3% per year, with the 250 to 499 employee size class growing fastest of all.

3. The number of PP&C's in each major industry grouping except agriculture, forestry, and fisheries increased over the period 1959-1975. Financial and Service organizations increased the fastest (in percentage per year) followed by construction firms, as shown in Figure 3.11.6d.

4. As might be expected, our bigger business institutions are corporations, our smaller ones are proprietorships, and partnerships fall in between, but on the small side. The actual distribution in 1974-1975 is given in Figure 3.11.6e (the proprietorship and partnership data plotted as "$10 to $50 million" is actually "all over $10 million." More detailed breakdowns of the distribution of large proprietorships and partnerships are not available.)

Finally, Table 3.11.1b shows how the GP systems were distributed goegraphically across the United States at year-end 1977. Comments:

1. As we might expect, GP systems are concentrated in and around the biggest cities.

2. The 58,100 systems were located in 45,750 sites, for an average of 1.27 systems per site. Note the top 100 metropolitan areas all average around 1.3 systems per site; the others average less than 1.2.

3. There is a striking difference between the averages, from one metropolitan area to another, of the dollar value of

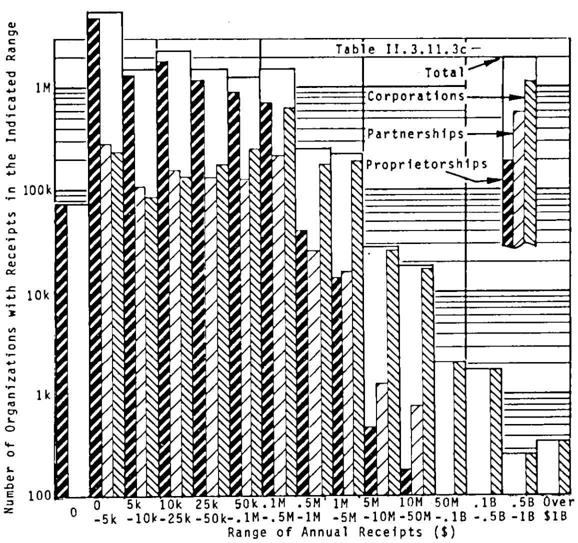



FIGURE 3.11.6e POTENTIAL CUSTOMERS FOR DP EQUIPMENT & SERVICES IV
PROPRIETORSHIPS, PARTNERSHIPS, & CORPORATIONS--SIZE DISTRIBUTION 1974-1975

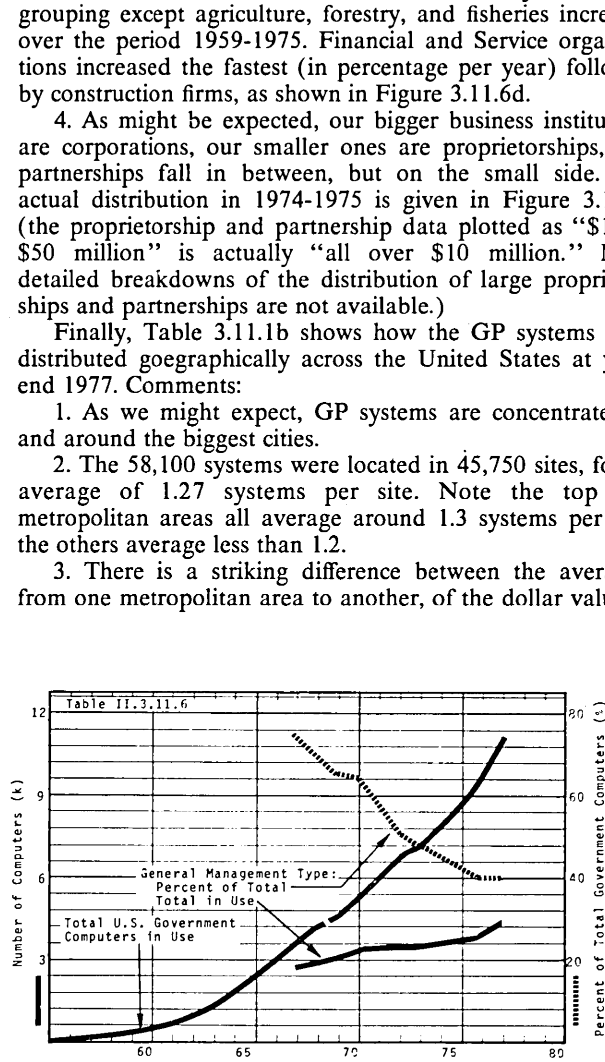



FIGURE 3.11.20a U.S. GOVERNMENT COMPUTERS I
TOTAL COMPUTERS IN USE, AND PERCENT "GENERAL MANAGEMENT"

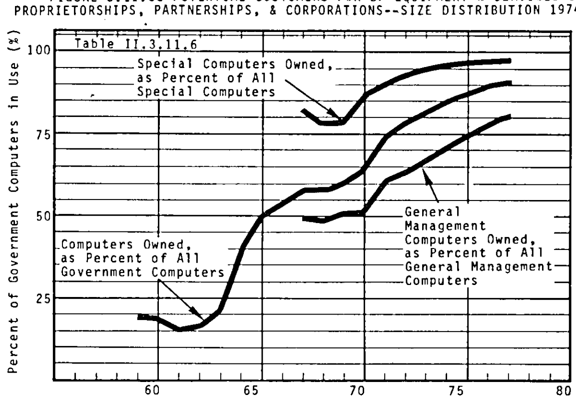



FIGURE 3.11.21a U.S. GOVERNMENT COMPUTERS III
PERCENT OF COMPUTERS IN USE OWNED BY THE GOVERNMENT

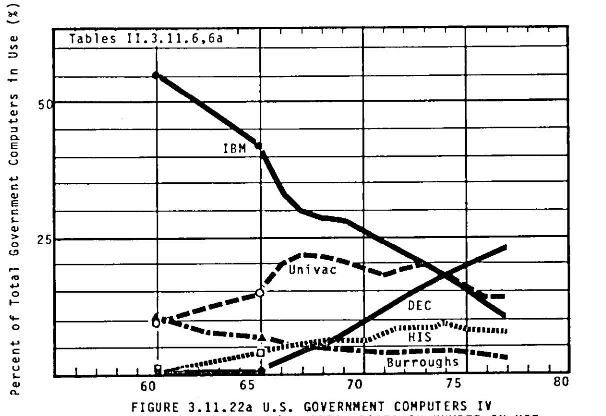



FIGURE 3.11.22a U.S. GOVERNMENT COMPUTERS IV
PRINCIPAL MANUFACTURERS' SHARES, BASED ON NUMBER IN USE

systems per site. The Melbourne, Florida area has the largest average, followed by San Jose, California and Washington, D.C. The Washington average is easy to understand, for U.S. government systems are concentrated there. Presumably the NASA operations at Cape Kennedy account for the large average in the Melbourne area. Stanford University, Moffat Field, and Silicon Valley are all in the San Jose area, and presumably contribute to the high average there.

**U.S. Government Installations.** Figures 3.11.20a through 3.11.22a show how the U.S. Government computer market has evolved. Note the continuing trend toward purchasing as opposed to leasing (Figure 3.11.21a), and the emergence of DEC as the most successful supplier (as measured by *number* in use–see Figure 3.11.22a).

## 3.2 Data Processing Costs

### 3.24a DATA MANIPULATION COSTS

The cost of 100,000 additions has continued to fall, though IBM's pricing shenanigans–specifically, the processor price increases which accompanied memory price reductions–helped slow the pace. The open dots and dotted line in Figure 3.24.3b trace the history of the cost of 100,000 additions performed by a processor with no memory. Until 1970 the improvement from generation to generation was spectacular. But the 370/115 cost more than the 360/30, introduced 9 years earlier, and the System 3/4 cost more than the 3/10, despite six years of progress in technology. With the introduction of the 4331, the downward trend has continued.

In a series of advertisements in the late 1970's, IBM reported that the cost of 100,000 multiplications had fallen from $1.26 in 1952 to 0.7 cents in 1978. The solid dots and solid line in Figure 3.24.3b display IBM's data. In deriving these figures, IBM used actual monthly rental prices of a systems configuration including the named processor. The reported results were calculated by multiplying the monthly rent by the fraction of 176 hours it takes each such system to perform 100,000 multiplications. However, IBM has refused to disclose the rental prices, or the system configurations, or the multiplication times used in the calculations, so it is not possible to verify their results.

### 3.25a SYSTEM OPERATING COSTS

**User's Total Cost.** Operating costs for the average GP user are shown in Figure 3.25.12a. Comments:

1. For the most part, the trends in Figures 3.25.10 to 3.25.16 (p. 151) have continued. Total cost continues to grow faster even than CPU costs (Figure 3.25.14a). "Operations"

**TABLE 3.11.1b GEOGRAPHICAL DISTRIBUTION OF GP COMPUTERS, 12/31/77**

| | SMSA | Number of Sites | Number of Systems | Systems per Site | $M | Installed Value % of Total | Installed Value $M per Site | $M per System |
|---|---|---|---|---|---|---|---|---|
| 1. | New York, NY, NJ | 2792 | | | 3145 | 7.5 | 1.13 | |
| 2. | Chicago, IL | 2435 | | | 2462 | 5.9 | 1.01 | |
| 3. | Los Angeles, CA | 1663 | | | 1796 | 4.3 | 1.08 | |
| 4. | Washington DC, MD, VA | 715 | | | 1428 | 3.4 | 2.00 | |
| 5. | Philadephia, PA, NJ | 1156 | | | 1242 | 3.0 | 1.07 | |
| 6. | San Francisco, CA | 895 | | | 1076 | 2.6 | 1.20 | |
| 7. | Detroit, MI | 912 | | | 1023 | 2.4 | 1.12 | |
| 8. | Dallas-Ft. Worth, TX | 825 | | | 1011 | 2.4 | 1.23 | |
| 9. | Boston-Lowell, MA | 845 | | | 1000 | 2.4 | 1.18 | |
| 10. | Houston, TX | 683 | | | 987 | 2.3 | 1.45 | |
| | Subtotal–Top Ten | 12,921 | 17139 | 1.33 | 15,170 | 36.0 | 1.17 | .885 |
| 12. | Minneapolis-St. Paul, MN,WI | 814 | | | 725 | 1.7 | .89 | |
| 13. | San Jose, CA | 283 | | | 699 | 1.7 | 2.47 | |
| 25. | Anaheim, CA | 332 | | | 370 | 0.9 | 1.11 | |
| | Subtotal, 11-25 | 7031 | 9325 | 1.33 | 8173 | 19.4 | 1.16 | .876 |
| 33. | Providence, RI, MA | 526 | | | 267 | 0.6 | .507 | |
| 47. | Sacramento, CA | 131 | | | 194 | 0.5 | 1.48 | |
| 50. | Des Moines, IA | 163 | | | 181 | 0.4 | 1.11 | |
| | Subtotal, 26-50 | 6249 | 8269 | 1.32 | 6043 | 14.4 | .967 | .731 |
| 54. | New Haven, CT | 275 | | | 163 | 0.4 | .593 | |
| 70. | Melbourne, FL | 43 | | | 118 | 0.3 | 2.74 | |
| 75. | Toledo, OH | 153 | | | 108 | 0.3 | .706 | |
| | Subtotal, 51-75 | 3604 | 4720 | 1.31 | 3493 | 8.3 | .969 | .740 |
| 86. | San Bernardino, CA | 153 | | | 84 | 0.2 | .549 | |
| 88. | Colorado Springs, CO | 47 | | | 80 | 0.2 | 1.70 | |
| 100. | Topeka, KS, OK | 68 | | | 59 | 0.1 | 1.15 | |
| | Subtotal, 76-100 | 2632 | 3262 | 1.23 | 2115 | 5.0 | .804 | .648 |
| | Total, 1-100 | 32,437 | 42,715 | 1.32 | 34,994 | 83.1 | 1.079 | .819 |
| | Total, US | 45,750 | 58,100 | 1.27 | 42,100 | 100.0 | .920 | .725 |
| | Total, Other SMSA | 13,313 | 15,385 | 1.16 | 7,106 | 16.9 | .534 | .462 |

Source: IDC, published by *Computerworld* in a poster-map in December, 1978. SMSA stands for Standard Metropolitan Statistical Areas, a US government-defined geographical entity. The chart showed data on the 100 top SMSA's. I have included only the top ten, plus 12 others each of which represent an extreme value of average installed value or installed value in its group.

costs—including the cost of central site hardware—have continued to drop as a fraction of the total, and were overtaken by programming costs in 1977-1978 (Figure 3.25.13a). Note, however, that this latter result is a natural consequence of an assumption made in estimating user personnel counts in Table II.1.4.2a. In the absence of a census of computer personnel, I assumed tha the number of systems analysis and programmers has ranged from 11.2 to 10.7 per million dollars of equipment in use over the past few years. This assumption implies of course that the average user has added systems analysis and programmers as average system size increased. A similar ratio was used in estimating the computer operator population. Labor costs were also affected, of course, by increases in salaries and overhead.

2. Data entry costs have seemingly leveled off, as shown in Figure 3.25.13a. However, remember that this analysis only includes the cost of computer center data entry staff. As previously noted, computer terminal operators apparently are handling much data entry these days, and their costs are not included here.

3. Card costs per punch have fallen (Figure 3.25.17a) despite a rise in card prices. Even so, note that the per-unit cost of the expendables (paper) greatly exceeds that for tapes and disks.

**Costs and System Size.** Despite the importance of SBC's, I have not seen any new data on operating costs of small systems. The only related source of information is the survey of user budgets published annually in *Datamation* (McLaR74-2). The 1974 data is shown in Figure 3.25.21 (p. 153). The more recent surveys show the same trend, though with a less pronounced difference between small and large systems. (In fact, the total costs shown in the 1975 survey were nearly constant, independent of system size—see Table II.3.25.7a).

**Summary.** Internal company cost information is, of course, private and confidential, and that presumably explains why there is little good data available on computer operating costs. However, in my own limited experience, I have discovered that few operating people have good visibility on costs, and it is my impression that many companies do not take the trouble to collect, analyze, and act on data regarding the costs of computing.

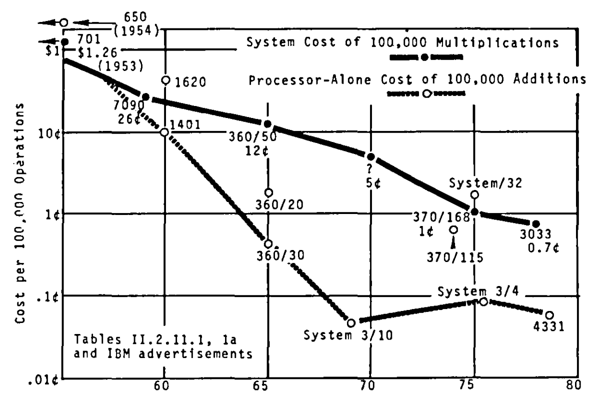



FIGURE 3.24.3b TRENDS IN ARITHMETIC PERFORMANCE/COST
COST OF 100,000 ADDITIONS OR MULTIPLICATIONS

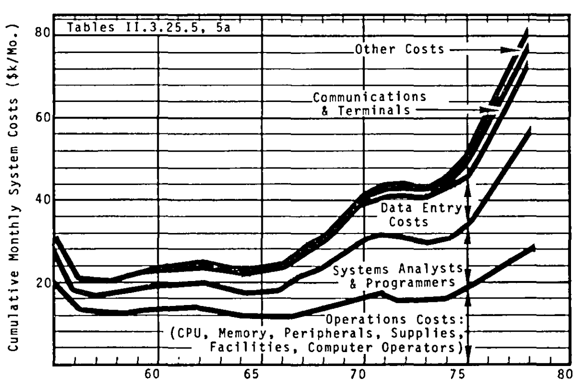



FIGURE 3.25.12a USER OPERATING COSTS I
TOTAL CUMULATIVE COSTS SHOWN BY FUNCTIONAL CATEGORY

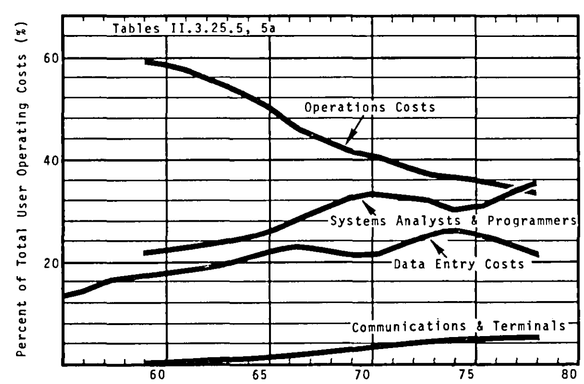



FIGURE 3.25.13a USER OPERATING COSTS II
PROPORTION OF TOTAL COSTS BY FUNCTIONAL CATEGORY

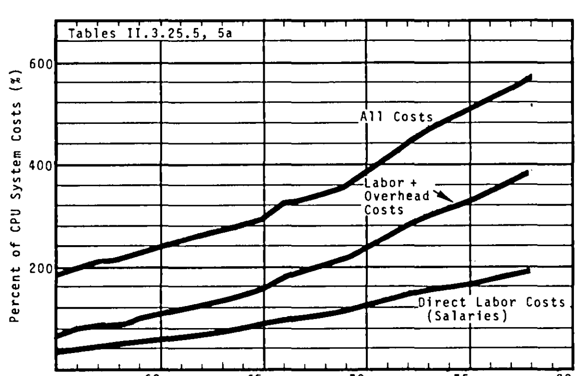



FIGURE 3.25.14a USER OPERATING COSTS III
COSTS AS PERCENTAGES OF CPU SYSTEM COSTS

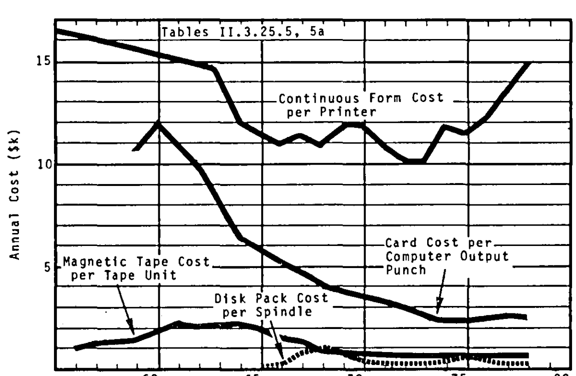



FIGURE 3.25.17a USER SUPPLIES COST
ANNUAL SUPPLIES COST PER UNIT IN USE

## 3.27a SOME CONCLUSIONS

**Market Elasticity.** In section 3.0a we distinguished recorded data, which is stored on media by organizations which expect to use it later, from transient data, which is of momentary interest and is not saved because the liklihood of its later use is low. I argued that most of what we call business data processing applications deal primarily with recorded data, and that these are the basis for the growth of the GP and SBC markets. (See Table 3.21.1, page 137, for a list of the most prominent applications. Of those shown, only "production control" and "engineering/scientific calculations" handle mostly transient data.) The minicomputer market, on the other hand, is largely based on transient data applications: engineering/scientific calculations, process control, test equipment, communications handling, etc.

In Section 1.21a, we observed that the number of GP systems in use has remained fairly constant at around 58,000 over the past five years. The data in Section 3.11a, on the number of Proprietorships, Partnerships, and Corporations in the U.S., can help us rationalize the 58,000, and at the same time help us predict the limits of the SBC market.

According to the data in Table 3.11.1 (page 131), the hundred biggest firms in the U.S. in 1969 had about $14,000 worth of computer equipment for every million dollars of revenue. We therefore might agree that a company with annual sales of $5 million can afford a $70,000 system which might rent for $1,750 per month. Now $1,750 per month is just about the lower price bound for what we call GP computers, so any company with over $5 million in sales can afford at least one GP system. Table II.3.11.3c indicates there were 50,500 such PP&C's in the U.S. in 1974-75—remarkably close to the 58,000 GP computers. Furthermore, if we look at the distribution of PP&C size compared with GP computer size, we are struck by the similarity. Figure 3.27.7a superimposes the two sets of data on the price/performance plane (compare with Figure 3.27.7, p. 163). Along the left side are listed the number of PP&C's able to afford various hardware budgets. At the low end are the 1.54 million with $100k to $500k annual revenues ($35 to $175 per month for computers); at the high end the 600 firms with sales over $500 million (over $175,000 per month for computers).

The diagonal line on the right approximates the limit of the computer price/performance curve in 1979 (compare with Figure 2.11.8a), and alongside it are plotted the approximate number of GP and SBC systems in use in each of a number of price ranges at year-end 1978. The price ranges given are those of Table II.1.31.2c. At the high end, there were about 800 GP's renting for $100k per month or more; at the low end, there were about 21,800 GP's renting for between $1,563 and $3,125 per month. The SBC distribution at year-end 1978 is also shown—the two overlap in the under-$3,125 price range. Comments:

1. The chart, together with the argument of Section 3.0a about the potential limits to an organization's computations, suggest that the GP market will become more fiercely competitive in the next few years, as the manufacturers fight over a fixed number of customers whose application requirements may be growing more slowly than are the technologies which improve system price/performance. IBM's aggressive pricing for the 43x1 systems suggests that the fight has begun.

2. The SBC market has just begun to be tapped. There are 224,000 PP&C's in the $1 to $5 million revenue range, presumably able to afford hardware worth $350 to $1750 per month ($14,000 to $70,000 purchase price). Apparently, only about 60,000 of them had systems at year-end 1978. There are another 244,000 in the $7,000 to $14,000 price range, and this market is virtually untapped. With 72,800 SBC's in use at year-end 1978 and a shipment rate of about 30,000 per year and growing, the market for the over-$14,000 SBC's should saturate in the mid-1980's, and that for the $7k-$14k systems soon after.

3. Though the total *number* of SBC systems required by the market is much larger than the number of GP's required, the *value* required is much less. The PP&C's with revenue over $5 million earned a total of $2,410 billion in 1974-1975 (Table II.3.11.3c), while the firms with revenues of $500k to $5 million only earned $634 billion. Thus the potential SBC market is at most only a quarter the size of the GP market, in dollar terms.

There is, however, still another DP market not included in the analysis of Figure 3.27.7a. The ratio $14k of computing equipment per million dollars sales was based on the 1969 use of computers by big firms for business data processing. These firms, and other smaller ones, still process much recorded data by hand, to the extent that people write and type and file letters, reports, and other documents. The data volume is very small compared to that handled by computers (see Table 3.0.7a) but the money spent—the salaries of the professional, technical, and clerical people—is very large. This is the "Office Automation" market, where first typewriters, then dictating machines, then copiers, and more recently word processors have been sold to improve efficiency.

The continuing reduction in the costs of digital technology will permit digital techniques to be applied more and more broadly to offices over the next decade. A recent IBM study, whose results are summarized in Table 3.27.2a and 3.27.3a, gives some idea of how white-collar people spend their time and where and how the non-computer recorded data is originated and distributed. Note that "word processors" only touch on a portion of this workload. The functions of office systems will expand to include communications (of both recorded and transient data) and to cover more of the functions shown in Table 3.27.2a. The market for such systems is obviously very large, and is related to the number of "clusters" of white-collar workers.

The market for digital equipment for processing transient data is the most difficult one to quantify. It includes much of the already-existing minicomputer market, as we have already discussed. It includes "pocket calculators" of ever-increasing sophistication, used by clerks and engineers and scientists and stockbrokers and many others. It includes "personal computers", whose functions are mostly entertainment and education. And it includes microprocessors used increasingly in appliances and automobiles and other artifacts. It is a diverse field, in which stored-program computers will be employed by the hundreds of millions. But it is difficult to measure.

### TABLE 3.27.2a ANALYSIS OF TIME SPENT BY OFFICE PERSONNEL — RESULTS OF A SURVEY OF PERCENT TIME DISTRIBUTION

| | Principals | | | | Secre-taries | Clerks |
|---|---|---|---|---|---|---|
| | Level 1 | Level 2 | Level 3 | All | | |
| Typing | | | | | 37.0 | 7.8 |
| Meetings | 24.5 | 14.5 | 8.2 | 14.2 | 4.3 | 1.9 |
| Writing | 9.8 | 17.2 | 17.8 | 15.6 | 3.5 | 7.3 |
| Telephone | 13.8 | 12.3 | 11.3 | 12.3 | 10.5 | 9.2 |
| Travel | 13.1 | 6.6 | 2.2 | 6.4 | | |
| Checking Documents | | | | | | 10.4 |
| Calculating | 2.3 | 5.8 | 9.6 | 6.6 | | 10.3 |
| Searching | 3.0 | 6.4 | 6.4 | 5.6 | | 10.2 |
| Using Equipment | 0.1 | 1.3 | 9.9 | 4.4 | 1.3 | 6.3 |
| Reading | 8.7 | 7.4 | 6.3 | 7.3 | 1.7 | 2.9 |
| Filling out Forms | | | | | | 8.3 |
| Mail Handling | 6.1 | 5.0 | 2.7 | 4.4 | 8.1 | |
| Copying/Duplicating* | 0.1 | 0.6 | 1.4 | 0.9 | 6.2 | 3.9 |
| Filing | 1.1 | 2.0 | 2.5 | 2.0 | 4.6 | 5.9 |
| Giving Dictation | 5.9 | 2.6 | 0.4 | 2.5 | | |
| Planning/Scheduling | 4.7 | 5.5 | 2.9 | 4.3 | | 1.2 |
| Taking Shorthand | | | | | 5.5 | |
| Collating/Sorting | | | | | 2.6 | 5.2 |
| Retrieving Files | 1.8 | 3.7 | 4.3 | 3.6 | 2.8 | |
| Proofreading | 1.8 | 2.5 | 2.4 | 2.3 | 3.9 | |
| Other | 3.1 | 6.7 | 11.4 | 7.7 | 8.2 | 9.2 |
| Total | 99.9 | 100.1 | 99.7 | 100.1 | 100.2 | 100.0 |
| Number in Survey | 76 | 123 | 130 | 329 | 123 | 115 |

Source: Engel, GH, et al, "An Office Communications System," *IBM Systems Journal, 18,* 3, 1979, p. 402-431. Level 1 Principals are upper management; Level 2 are other managers; Level 3 are non-managers.

* Average six copies made per original.

### TABLE 3.27.3a DOCUMENT FLOW IN OFFICES

| Source or Destination | Incoming Documents | Outgoing Documents |
|---|---|---|
| Inside Company | 75% | 81% |
| Department Files | - | 24% |
| Department Personnel | 3% | 19% |
| Other HQ Dept. | 14% | 24% |
| Other Company | 58% | 14% |
| Outside Company | 25% | 19% |

Source: See Table 3.27.2a

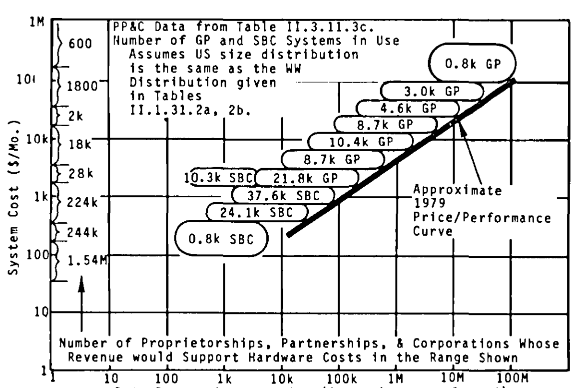



FIGURE 3.27.7a AN ESTIMATE OF THE DP MARKET IN THE U.S. POTENTIAL AND ACTUAL USERS IN VARIOUS PRICE RANGES

# 4.0 Costs

## 4.1 Manufacturing Costs

### 4.11a LOGIC COSTS

The years 1974-1978 have been marked by continuing improvements in integrated circuits, and by new developments in power supply technology. In integrated circuit design, our ability to manufacture very dense circuits has continued, generally speaking, to exceed our ability to find uses for that density. We will discuss the notable exceptions: the microcomputer and read-only memories in this section; the IC memory in Section 4.13. The exceptions are extremely important as we shall see. But in processor- or controller-like applications (excluding main memory), it appears that the LSI chips still represent only about 10% of the integrated circuits in a typical system, with the remaining 90% split roughly equally between SSI and MSI circuits.

Developments in power supply technology have resulted in the increasing use of the so-called "switching" power supply, whose most significant feature is a reduction in weight and volume over the older linear-regulated supply.

**Elements of Electronic Technology**

**Components.** The fundamental logic elements, which are the basis for all digital design, are flip-flops and gates. In the early days of computer technology, several components were required to construct a single flip-flop or gate. Since the introduction of the IC each component *contains* at least one flip-flop or gate, and our point of view regarding system design and construction has had to change. Designers employ registers and counters, decoders and multiplexers, arithmetic/logic units and processors as their units of design, and no longer have much reason to count or even to contemplate the basic logic elements which once were so expensive.

And yet, though the LSI components are the glamorous ones which attract all the attention, the great majority of components in typical systems are the older and prosaic SSI and MSI elements. Furthermore, those SSI/MSI units contain a very substantial fraction of the total number of gates and flip-flops in the system. We will therefore begin by examining these somewhat elementary logic building-blocks.

Figure 4.11.5a describes a representative sample of circuits. Each point represents a particular component, indicating the number of flip-flops and/or gates it contains. The SSI units, grouped in the lower left corner, contains 0, 1, or 2 flip-flops and up to 6 gates. The MSI elements contain up to 8 flip-flops and 63 gates. (In "gates" I include OR, AND, NOR, NAND, EXCLUSIVE OR, buffers, inverters, and Schmitt triggers. In "flip-flops" I also include latches. The specific circuits in the sample are listed in PhisM79.)

Various combinations of circuits, assembled in a system, may have an average gate and flip-flop count anywhere within the boundaries defined by the outside lines in the graph. For example, a 4-bit adder (0 flip-flop, 30 gates) and two 4-bit shift registers (each with 4 flip-flops and 21 gates) would have an average count of $8/3 = 2.67$ flip-flops and $72/3 = 24.0$ gates, and this "average" component lies in the graph on the straight line between the points (30,0) and (21,4). We have seen some evidence (Table 4.11.7, p. 177) that the number of gates per flip-flop in a system averages somewhere between 15 and 20. The dashed line in Figure 4.11.5a describes average components having 17 gates for every flip-flop. And we can conclude that if a system containing MSI and SSI elements only is to average 17 gates per flip-flop, more than half of the components must be purely gating elements, containing no flip-flops.

Trends in average SSI and MSI prices are shown in Figure 4.11.5b. The solid lines trace the history since 1970 of standard circuits, the dashed lines the recent prices of the newer low-power Schottky components (74LS). Note that SSI prices have bottomed out at about $.20 each, that the 74LS prices are rapidly approaching those of the standard circuits, and that MSI prices seem still to be falling.

But integrated circuit pricing is a complex subject. Prices are somehow, of course, a function of manufacturing costs as discussed in Section 4.12. And manufacturing costs generally decline with time and with volume production. For simple circuits, IC chip size can be small, and the lower bound on manufacturing cost is the cost of packaging and testing (see Figure 4.12.16). The manufacturer must also recover his development and marketing costs, and must return a profit to his stockholders.

Prices are also a function of distribution costs. Distributors, located in the major cities, buy IC's (and other electronic parts) from the manufacturers, stock them, and resell them to customers as required. The distributor's costs of procuring and managing the inventory of parts, of providing information and advice on their characteristics and use, and of delivering them as required, must be paid by the customer.

But prices are also dependent on conditions in the marketplace—on the state of the economy, on competition and competitive products, on the quantity of parts available from manufucturers and the quantity required by users (i.e. on supply and demand), and on the fact that old parts are continually being made obsolete by newer ones. Each manufacturer publishes price lists of the IC's it offers for sale. In practice, the actual prices may differ from those published by factors of two or more, depending on the quantity bought, and on the circumstances of the sale. (By "circumstances of the sale" I refer to the fact that, for example, a particular buyer may be focussing his attention on the price of a particular component as part of a large purchase, and the seller may offer an extra discount on the price of that component to close the sale.)

Price is thus a most difficult subject. Some of the difficulty can be seen in Figures 4.11.5c and 4.11.5d, which plot 1978 prices of MSI and SSI circuits as a function of their complexity, measured by number of gates and flip-flops. Comments:

1. Prices of SSI circuits are more or less constant, moderately independent of complexity. The "best fit" formula shown in Figure 4.11.5c for a sample of 42 74XX SSI IC's suggests a base price in 1978 of 17.7 cents, to which is added 1.1 cents for each gate (up to 6) or 3.6 cents for each flip-flop (up to two). The corresponding formula for a sample of 22 lower-power Schottky SSI circuits (model numbers 74LSXX) is shown in the lower left corner of Figure 4.11.5d.

2. MSI circuit prices are more strongly a function of complexity. The incremental cost of the 74XX MSI circuits shown in Figure 4.11.5c is 3.1 cents per gate and 6.3 cents per flip-flop. The corresponding prices for the 74LSXX MSI circuits are 5.4 cents per gate and 10.7 cents per flip-flop.

3. On the average, the low-power Schottky circuits are about 70% more costly than the standard 74XX IC's.

Power consumption is another important consideration in design and Figures 4.11.5e and f, show how IC power varies with complexity for standard SSI and MSI circuits, and for low-power Schottky MSI circuits. The SSI Schottkys each consume very close to one fifth the power of the corresponding standard 74XX IC. The MSI Schottky's require an average of 30% of standard MSI power. Of course power, unlike price, is susceptible of analysis. A detailed look at the circuit design of each IC would explain the differences we see in these figures in power dissipation per gate. No comparable investigation is likely to be quite as successful in explaining price per gate.

Finally, Figure 4.11.5g gives estimates of price trends for memory and microprocessor IC's. The rapid price reductions (readily understood when we understand the IC manufactur-

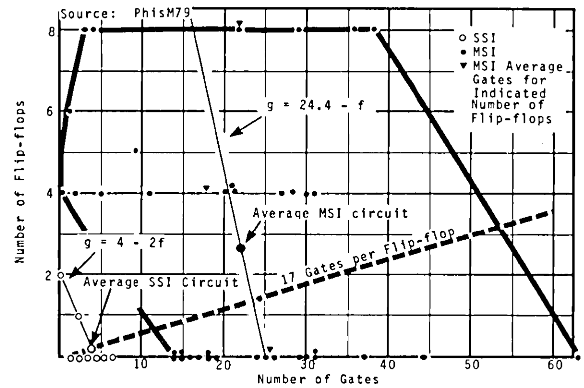



FIGURE 4.11.5a LOGIC ELEMENTS IN SSI AND MSI IC'S NUMBER OF FLIP-FLOPS AND GATES PER IC

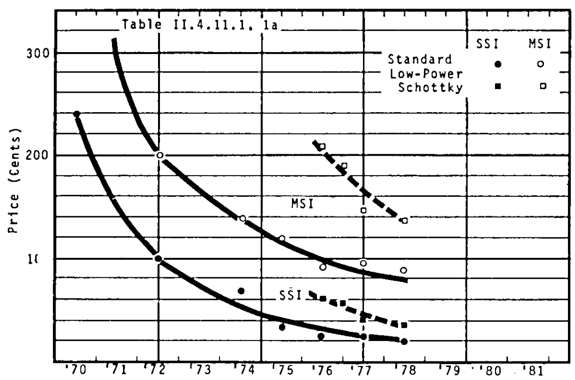



FIGURE 4.11.5b SSI AND MSI PRICE TRENDS

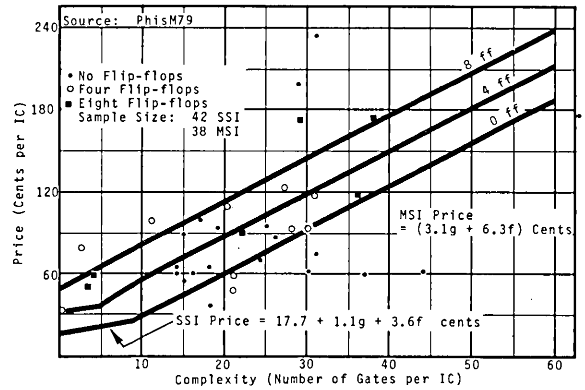



FIGURE 4.11.5c STANDARD IC PRICES VS. COMPLEXITY (1978)

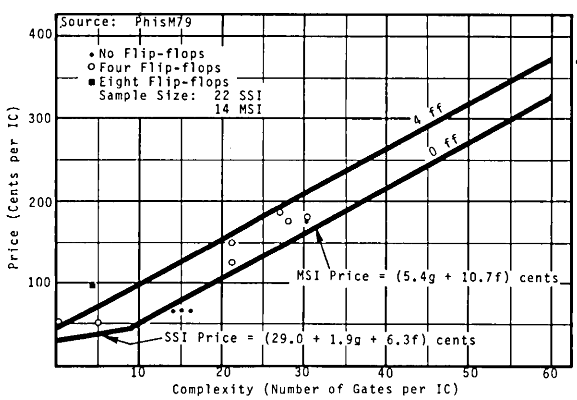



FIGURE 4.11.5d LOW-POWER SCHOTTKY PRICE VS. COMPLEXITY (1978)

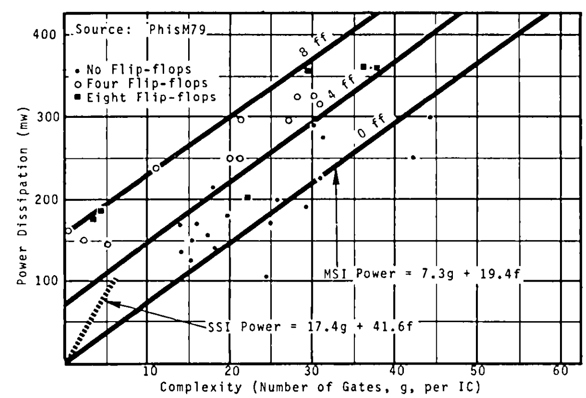



FIGURE 4.11.5e STANDARD MSI/SSI IC'S POWER VS. COMPLEXITY

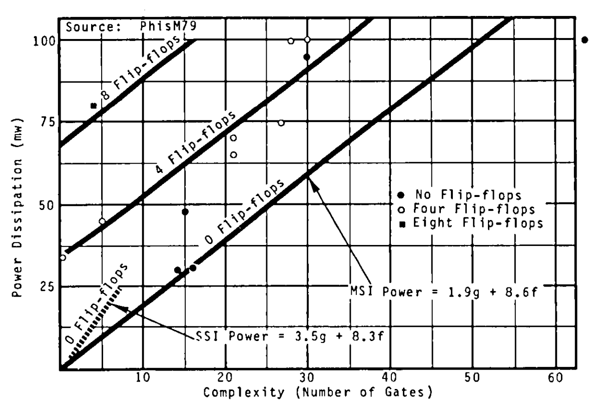



FIGURE 4.11.5f LOW-POWER SCHOTTKY POWER VS. COMPLEXITY

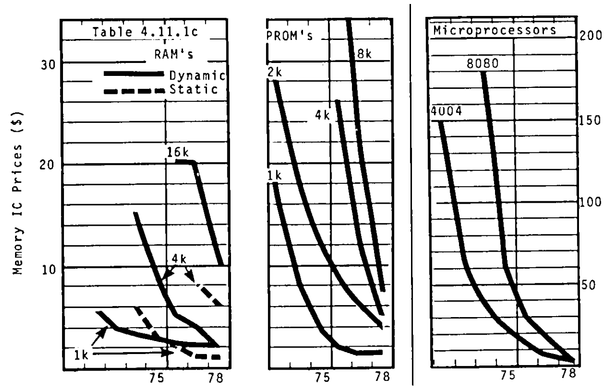



FIGURE 4.11.5g IC PRICE TRENDS MEMORY AND MICROPROCESSOR IC'S

ing process–see Section 4.12a) have made possible the development of programmable calculators, personal computers, word processors, and small business computers–which, as we have seen in Section 1.21a, represent the fastest-growing segments of the dp marketplace.

**Interconnects.** The printed circuit board (PCB) is still the primary, first-level interconnect element, upon which components are mounted. Steady progress has been made in improving PCB manufacturing technology, and the cost of multi-layered boards continues to fall. The interconnect capability per square inch of board surface is also improving, as manufacturers increase etched line density, increase the number of holes drilled per square inch, and reduce the dimensions of the "pads" which must exist around holes.

Printed circuit boards are manufactured in batches. Each batch consists of a group (perhaps 50 to 250) of panels which pass through a variety of drilling, plating, photo-resist or silk screening, etching, and inspection operations together. Each panel in the batch may represent one large board, or may be laid out as two or more identical smaller boards. At the end of the batch process, the panels are cut to final board size, and the individual PCB's then pass through a final series of steps which include cleaning, inspection, and (perhaps) electrical test.

Suppose a batch consists of m panels, and each panel contains n boards. We can establish an estimate of the cost of a board as follows. The total cost of a batch is the sum of material and labor costs. Assume the cost of the laminate and of the photo-resist chemicals are proportional to panel area, and that the cost of other materials (mostly chemicals) is included in the factory overhead. Assume also that there are two components of labor time spent: a large one covering the time spent on the batch of panels, and proportional to the number of panels in the batch; and a smaller one covering the final work done on individual boards, and proportional to the total number of cards.

Then the total cost of the m×n PCB's produced in a batch is

$$\text{Total Cost} = C_A A_p m + R(T_b m + T_c mn)$$

Where

$C_A$ = material cost per unit area

$A_p$ = panel area in square inches

R = factory labor rate, including overhead

$T_b$ = average time spent per panel in the batch process

$T_c$ = average time spent per individual card, after the batch process is complete, and the cards are cut apart

With a perfect process, this expenditure produces m×n perfect boards. In practice, it produces fewer because of imperfections in materials, processes, and people. If the yield Y (less than one) represents the fraction of good boards in the batch, then the final cost per good board is

$$\text{Cost per Board} = \frac{C_A A_p}{Yn} + R\left(\frac{T_b}{Yn} + \frac{T_c}{Y}\right)$$

Now the area of a card or board is $A = A_p/n$, and we can use this formula to eliminate n and express cost per board as a function of board area

$$\text{Cost per board} = (1/Y)[C_A A + R(T_b(A/A_p) + T_c)],$$

remembering this is really nothing more than

$$\text{Cost per board} = (1/Y)[\text{Material costs} + R(\text{Labor Time})]$$

The yield, Y, is of course a critically important factor. It varies with board area, being high for small boards and lower for larger ones. Suppose we take

$$Y = Y_o \frac{(1 + .001A + .0001A^2\Delta)}{(1 + .001A + .0001A^2)}$$

where $Y_o$ is the yield for very small boards, and $\Delta Y_o$ is the yield for large boards.

The quantities $Y_o$, $\Delta$, $C_A$, $T_b$, and $T_c$ are fixed for a given board complexity but will vary as complexity changes. Complexity is measured by the number of layers in a board, by the density of the lines etched (line width and spacing), and by the average number of holes drilled per square inch of board area. We will take the values from Table 4.11.1a as reasonable estimates for the given parameters, for the complexities indicated, and in the year 1978. Thus for example, the cost of a two-layer board with 15-mil lines would be given by evaluating

$$Y = \frac{1 + .001A + .000084\ A^2}{1 + .001A + .0001\ A^2}$$

$$\text{Material cost} = .028\ A\ \text{(dollars)}$$

$$\text{Labor Time} = 115\ (A/A_p) + .6\ \text{(minutes)}$$

In applying the formula, we must remember that only an integral number of boards can come from a panel. If we want to know the cost of 4 x 5 inch boards, for example, and panels are 18 x 24 inches, we will discover that at best we can lay out 19 boards on a panel (a rectangular array of 16 boards, with three more aligned along one edge). Thus n = 19, and $A = A_p/19 = 18 \times 24/19 = 22.74$ square inches. With 1978 wages at $5.10 per hour and overhead at 185%, labor cost will be $.242 per minute, and we can find Y = .992, Material cost = $.636, Labor Time = 6.653 minutes, and

$$\text{Total Cost per Board} = [\$.636 + \$.242(6.653)]/.992 = \$2.26.$$

PCB costs calculated using this formula are shown in Figure 4.11.6a. The figure shows cost versus area for the two degrees of complexity indicated in Table 4.11.1a, and for 2-, 4-, and 8-layer boards. Trends in PCB costs are shown in Figure 4.11.6b. Note that the original Figure 4.11.6 showed a 10 x 10 inch board, while here I refer to an 8.5 x 11.25 inch board–the area is still 100 square inches, but four boards this size will fit on an 18 x 24 inch panel.

Inflation has had its impact on connector costs, which increased sharply between 1974 and 1978, as shown in Figure 4.11.7a.

Backwiring costs, shown in Figure 4.11.8a, have not changed much in recent years despite the rapid increase in labor rates, because of the widespread use of AWW machines which require relatively little manual intervention per pin wired. A new AWW machine was announced in 1972, and its impact is shown in the figure.

**Power supply system.** The use of LSI circuits, and the increasing use of low-power SSI and MSI components, have resulted in a continuing reduction in average power per gate and flip-flop in the system. Meanwhile, inflation has increased power supply costs and at the same time a new type of supply, called the switching power supply, has become economical for use in computing systems.

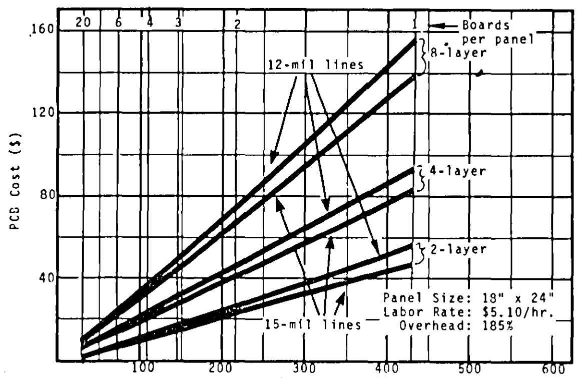



FIGURE 4.11.6a PRINTED-CIRCUIT BOARD COSTS (1978)

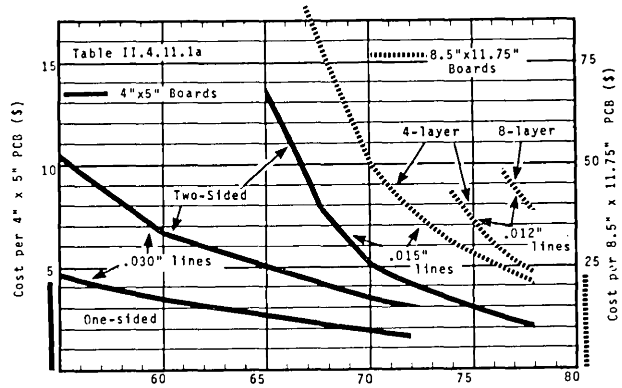



FIGURE 4.11.6b PRINTED CIRCUIT BOARD COST TRENDS

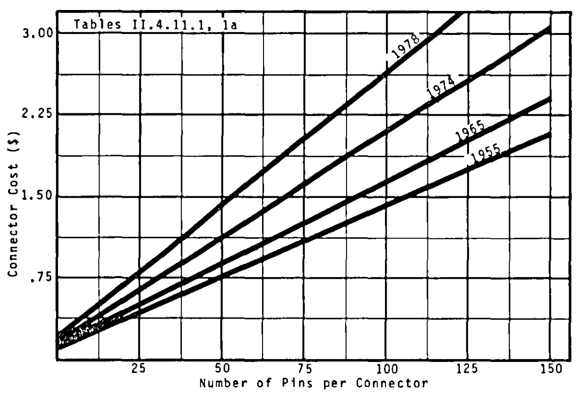



FIGURE 4.11.7a CONNECTOR COSTS

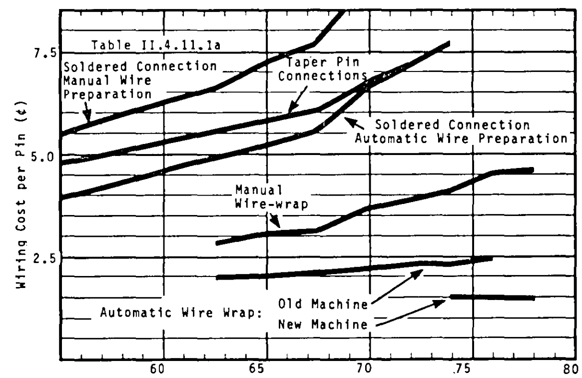



FIGURE 4.11.8a BACKWIRING TECHNOLOGY COST HISTORY

## TABLE 4.11.1a PRINTED CIRCUIT BOARD MANUFACTURING COST PARAMETERS (1978)

| Complexity | No. of Layers | $Y_o$ | $\Delta$ | $C_A$ \$/ In.$^2$ | $T_b$ Minutes | $T_c$ Minutes |
|---|---|---|---|---|---|---|
| 15-mil line width & | 2 | 1. | .84 | .028 | 115 | .6 |
| spacing, 20 holes | 4 | .92 | .83 | .056 | 155 | 7.5 |
| drilled per in.$^2$ | 8 | .84 | .81 | .112 | 185 | 12.0 |
| 12-mil line width & 10-mil | 2 | .95 | .83 | .028 | 135 | .6 |
| spacing, 22 holes | 4 | .87 | .82 | .056 | 170 | 7.5 |
| drilled per in.$^2$ | 8 | .79 | .80 | .112 | 200 | 12.0 |

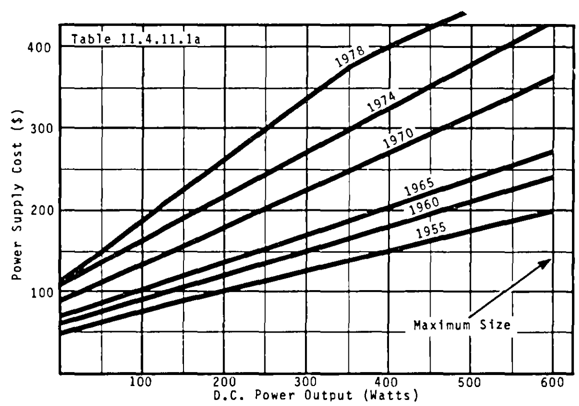



FIGURE 4.11.9a POWER SUPPLY COSTS

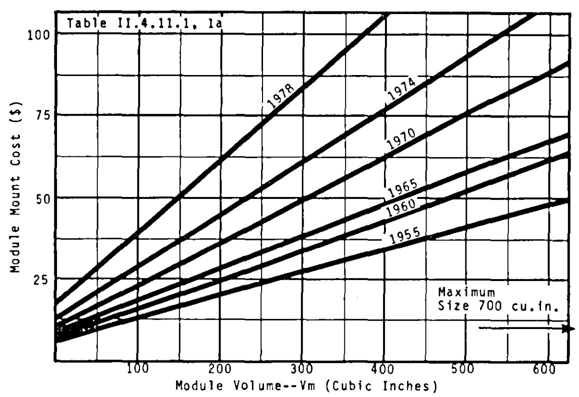



FIGURE 4.11.10a PACKAGING COSTS--MODULE MOUNTS

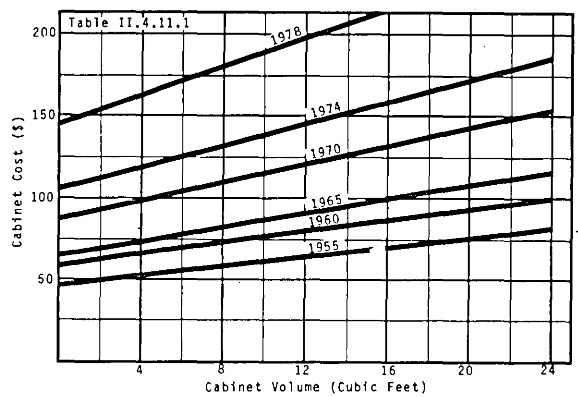



FIGURE 4.11.11a PACKAGING COSTS -- CABINETS

Until recently, the linear regulated power supply was the technology most widely used with computers. In such a supply, the line voltage is stepped down with a transformer, and the resulting waveform is rectified, filtered, and regulated by means of a power transistor, usually in series with the load. In the past few years, the evolution of semiconductor technology has made it practical to rectify the line voltage directly, convert the resulting direct current to a high frequency (e.g. 20kHz), and then transform and rectify that high-frequency waveform. These *switching* supplies weigh less than, occupy less volume than, and are more efficient than the older linear regulated supplies, and can be cheaper if the power supply is big enough. (See HirsW78).

Figure 4.11.9a provides an estimate of 1978 power supply prices, superimposed on those of earlier years. The 1978 curve has two segments: below 350 watts the linear regulated supply is cheaper and its cost is shown; above 350 watts we show the cost of a switching supply. However, the fact that the switching supply only occupies 1.0 cubic inches per watt delivered compared with the 2.5 cubic inches per watt of the linear supply, must also be taken into account.

**Packaging.** Inflation has driven up both labor and material costs, and as a result cabinet and module mount costs have risen as estimated by Figures 4.11.10a and 4.11.11a.

**System costs.**

Using the cost factors from the previous figures, we can estimate the cost of a cabinet full of equipment, and compare the result with those compiled in DPT&E for previous years. We will assume the component mix shown in Table 4.11.7a, which includes, for every 100 components, a bipolar microprocessor, three of its supporting LSI components, a 64-bit RAM chip, five 4K PROM's (used for microprogram storage, and assumed to be equivalent to gates at the rate of 20 bits per gate), a mixture of 45 MSI and 45 SSI circuits, some low-power Schottky and some standard. Note that, with this mixture of components there are an average of

**TABLE 4.11.7a COMPONENT MIX IN 1978 SYSTEMS**

| Component | Cost ($) | Power (mw) | Logic Elements RAM bits | Flip-flops | Gates | Per 100 Components No. | Cost ($) | Logic Elements Bits | F/f | Gates | Power (mw) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LSI | | | | | | | | | | | |
| Microprocessor | 10.00 | 500 | 32 | 25 | 125 | 1 | 10.00 | 32 | 25 | 125 | 500 |
| Microprocessor Support | 5.00 | 300 | 0 | 7 | 35 | 3 | 15.00 | 0 | 21 | 105 | 900 |
| RAM (64-bit) | 1.50 | 400 | 64 | 0 | 0 | 1 | 1.50 | 64 | 0 | 0 | 400 |
| PROM (4K) | 5.00 | 500 | 0 | 0 | 205 | 5 | 25.00 | 0 | 0 | 1024 | 2500 |
| MSI | 1.02 | 150 | 0 | 2 | 22 | 45 | 45.90 | 0 | 90 | 990 | 6750 |
| SSI | .28 | 50 | 0 | 0.2 | 3.6 | 45 | 12.60 | 0 | 9 | 162 | 2250 |
| Total | | | | | | 100 | 110.00 | 96 | 145 | 2406 | 13300 |

**TABLE 4.11.8a SYSTEM AND TECHNOLOGY CHARACTERISTICS**

| | Units | 1974 | 1978 |
|---|---|---|---|
| **Components** | | Bipolar IC's MSI | Bipolar IC's LSI,MSI SSI |
| Flip-Flops/Package | no. | 4 | - |
| Gates/Package | no. | 8 | - |
| **Interconnect** | | | |
| Printed Circuit Boards | | | |
| Size | in. | 10x10 | 8.5x11.75 |
| Spacing | in. | .5 | .5 |
| Layers | no. | 4 | 4 |
| Line Width | in. | .015 | .012 |
| Pins | no. | 150 | 150 |
| Backwiring Technology | | AWW | AWW |
| **Power** | | | |
| Per Flip-flop | mw. | 50 | - |
| Per Gate | mw. | 6 | - |
| **One-Cabinet System** | | | |
| No. Modules | no. | 87 | 100 |
| Flip-Flops | no. | 6214 | 21690 |
| Module Area | sq. ft. | 60.4 | 69.4 |
| Flip-Flops/Module Area | no./sq.ft. | 102.9 | 312 |
| Total Power | watts | 945 | 1200 |
| per Flip-Flop | mw. | 152 | 55 |
| per Component | mw. | 119 | 133 |
| per Cabinet Volume | w/cu.ft. | 39.4 | 50 |

| | Units | 1974 | 1978 |
|---|---|---|---|
| Total Components | no. | 7954 | 9000 |
| per Flip-Flop | no. | 1.3 | 0.41 |
| per Module Area | no./sq.ft. | 132 | 130 |
| Signal Pins | no. | 12876 | 15000 |
| per Flip-Flop | no. | 2.1 | 0.7 |
| **Costs** | | | |
| Total Cost | $k | 12.67 | 17.42 |
| per Flip-Flop | $ | 2.04 | .80 |
| per Component | $ | 1.59 | 1.93 |
| Components | % | 45.3 | 56.8 |
| Power | % | 6.2 | 6.2 |
| Packaging | % | 8.4 | 9.5 |
| Interconnect | % | 38.5 | 26.0 |
| Printed Circuit Boards | % | 24.0 | 13.2 |
| Assembly & Test | % | 1.5 | 1.4 |
| **Labor Cost** | | | |
| Power Wiring | $ | 63 | 84 |
| Module Assy/Test | $ | 1033 | 1408 |
| Backwiring | $ | 107 | 65 |
| System Assy/Test | $ | 190 | 240 |
| Total | $ | 1393 | 1797 |
| per Flip-Flop | $ | 0.22 | .083 |
| per Component | $ | .175 | .200 |
| as percent | % | 11.0 | 10.3 |

(2406/145 =) 17 gates per flip-flop. Note also that each set of 100 components costs \$110 and dissipates 13.3 watts.

To determine how much electronics will fit in a cabinet, we need to know the IC density on modules, and the cabinet volume required for power and cooling fans. Figure 4.11.12a shows some recent data on IC packing on commercial electronic modules. We will assume that 90 IC's fit on 100 square inches (a difficult, but not impossible density to achieve), and that modules are separated by one-half inch. We will also assume use of a switching power supply which requires only 1.0 $in.^3$/watt of space, along with cooling fans which require 2.0$in.^3$/watt. Figure 4.11.12b presents a graphical solution to the equations

Power Required by Components = Power supplied by Power Supply

and

Volume of Components, P.S., and Cooling fans = Available Volume

Note we assume that only 25% of the 2 x 2 x 6 foot cabinet is available for modules, power supplies, and cooling fans; the other 75% is required for structural elements, wire and cables, and access space. We also assume one cubic foot of space is reserved for add-ons to be delivered after equipment is shipped. As shown, the remaining five cubic feet will house components dissipating 1.2 kw of power. (The dashed line in the figure is the power/cooling requirement line assuming linear regulated power supplies requiring 2.5 $in^3$/watt. The use of such supplies would reduce available component power—and therefore number of components per cabinet—by almost 17%.)

A ninety-component module dissipates 90 x 133 mw or almost 12 watts of power. Since the cabinet can support 1200 watts, it can house 100 modules, or 9000 IC's. Given these parameters and the cost data shown in previous pages, we can compute the cost of a cabinet of equipment. The result is shown in Table 4.11.8a and Figures 4.11.13a and 4.11.13b, where it can be compared with the results for previous years. Comments:

1. System cost per flip-flop (Figure 4.11.13a) continues to fall. System cost *per component* (Figure 4.11.13b) has stayed relatively constant since the introduction of the IC, and variations since then are mostly caused by variations in the prices of components themselves or by changes in interconnect technology, and especially printed circuit board costs.

2. In designing the 1978 system, we assumed a mixture of standard and low-power SSI and MSI IC's. We also assumed that a switching power supply would be used. The number of components which fit in a cabinet of a given size is determined by component power requirements and by power supply and cooling system volumetric efficiency, as we saw in Figure 4.11.12b. If we increased the proportion of low-power Schottky components in our mix, the left-hand slanted line in that figure would tilt down and the intersection of the component and power/cooling line would shift down and to the right—indicating that less power would be dissipated in the cabinet, and that more components could be housed there. The low-power components would cost more, but the increased cabinet density might justify the cost.

3. The assumed design makes use of a PROM for microcontrol; it effectively substitutes memory for gates. The use of PROM's or PLA's (programmable logic arrays) to replace SSI and MSI circuits for random logic is often advantageous because of a savings of space, even when the PROM/PLA is more costly than the components it replaces (See PhisM79).

4. In deciding what technologies to use for a new product, the engineer must take into account future trends as well as present costs. The price trends shown in Figures 4.11.5b and 4.11.5g illustrate the difficulty. A development project typically takes one to three years, and the resulting product may be manufactured over a five-year period. If the designer started a project in, say, 1974 and chose a 1K dynamic RAM chip as his memory component, on the grounds that the 1K RAM's were selling for \$3.30 each while 4K RAM's were selling for \$15.00, we see now he would have made a mistake. By the time his product reached manufacturing, in 1976, the price differential had dropped from (15-3.3=) \$11.70 to (5-2.4=) \$2.60, and by 1978 the 4K RAM was cheaper than the 1K. And of course the component cost per bit is only part of the cost. The bigger component occupies less cabinet space per bit and requires less power per bit than its smaller equivalent, and the packaging and power savings may offset its extra cost, if the designer decides to use it. (See Figure 4.13.11a and the accompanying discussion.)

But decisions based on ones estimate of the future of a technology are dangerous. A promising new technology may never reach the point where it is economically manufacturable, or the date of introduction may be delayed by unforeseen problems. Cryotrons, tunnel diodes, and plated wire memories have all at one time or another seemed likely computer components but have never been widely used. And

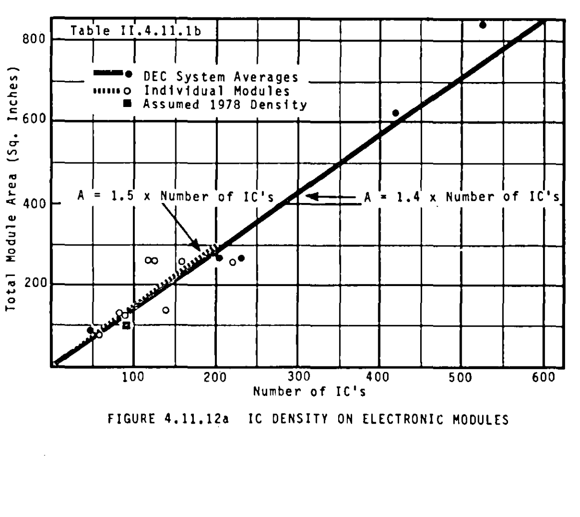



FIGURE 4.11.12a IC DENSITY ON ELECTRONIC MODULES

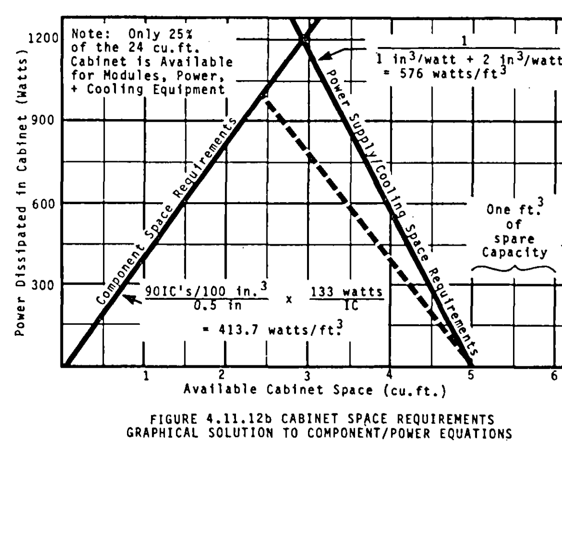



FIGURE 4.11.12b CABINET SPACE REQUIREMENTS
GRAPHICAL SOLUTION TO COMPONENT/POWER EQUATIONS

we need look no further than Figure 4.11.5i to observe an example of a product "delayed by unforeseen problems"—the 16K dynamic RAM, which was in unexpectedly short supply during 1976 and 1977 because of manufacturing difficulties. Today the CCD and magnetic bubble are widely touted as memory components of the future. Both have been built into new products, and both have developed more slowly than their proponents believed likely. One or both of them may join the long list of technologies which were not quite good enough.

How then, can the engineer best choose technology for a new product? The best rules would seem to be these:

a. If you must release the product to manufacturing under a tight development schedule, don't depend on a technology which is itself still under development.

b. Take advantage of promising new technologies by either conducting two parallel development projects, one of which uses the new and the other a tried-and-true technology; or else (if you haven't the resources for such a double project) design with the old technology but in such a way that the new one can later be substituted, if it becomes widely available. This latter approach is often used in designing an internal memory system.

## 4.12a INTEGRATED CIRCUIT COSTS

IC Technology has continued to improve in virtually all areas, and the improvement seems likely to continue at the same general rate for at least the next five years (see ICE78, NoycR76, AllaR77). Recent changes may be described by updating the DPT&E model.

**IC Geometry.** The four-inch wafer is coming into widespread use, and will be used as the basis for our calculations. I am modifying the model to provide a better estimate of chips per wafer (Figure 4.12.4a). The components used in logic circuits (Figure 4.12.5a) have continued to shrink in size, and those used in memory circuits have shrunk even faster—the memory components can be inherently smaller than components in random logic circuits because regular memory component interconnects are easy to lay out (HodgD75).

The stacking factor—defined for logic chips as the ratio of total component area to total chip area, and for memory chips as the ratio of memory array area to total chip area—varies substantially from unit to unit (Figure 4.12.6a). It can be argued that different factors should be used for different technologies, and in addition that there has been an improvement over the last five years. We shall, however, assume that the factor has held constant at 40%, for both memory and random logic IC's.

Using the appropriate assumed component areas, memory bit area, and stacking factors, we can compute circuit and bit density. The results are shown in Figure 4.12.7a and 4.12.8a, with various actual components plotted as points.

**The Cost Model.** Wafer costs have increased, but cost per unit area has again dropped with the increase in wafer size (Figure 4.12.10a). Defect density k has continued to fall, with the result that the process yield at any given chip edge continues to rise (Figure 4.12.11a). Package costs (Figure 4.12.13a) have changed substantially as a result of the ready availability of plastic DIP's with cavities large enough to hold LSI chips. Thus large chips which required expensive ceramic packages five years ago can now be mounted in low-cost plastic DIP's.

As explained in DPT&E, the IC cost model predicts that, at any time, there will be an optimum chip size having a minimum cost per gate. The minimum occurs because at small chip sizes assembly and test costs establish a fixed component cost and thus a high cost-per-gate; while at large chip sizes process yield falls faster than gates per chip rises. The bipolar cost curves are shown in Figures 4.12.17a and 4.12.18a, based on the revised model, with the characteristics of optimum chips noted. Comments:

1. The discontinuity in the 1974 curves comes about because a larger-than-130 mil chip would not fit in the then-standard dual in-line package, but required a special—and expensive—DIP. (A similar discontinuity should appear in the 1966 and 1970 curves.) By 1978 the widespread use of large chips had caused package manufacturers to increase production and reduce the price of these large DIP's.

2. The increase in fixed cost for small chips between 1970 and 1978 (see Figure 4.12.18a) comes about because of increases in the cost of connecting chip to pins and of testing the finished product—both increased because of increasing chip complexity.

3. Comparing Figures 4.12.17a and 4.12.18a with the corresponding Figures 4.12.17 and 4.12.18 of DPT&E we see that the changes in the model have led to a revision in our view of the per-gate cost of the optimum 1974 chip: it is larger than we previously computed because of the revision in the stacking factor (from 0.6 to 0.4).

4. The optimum MOS chip may be computed in the same way. The minimum costs per gate occur at the same chip

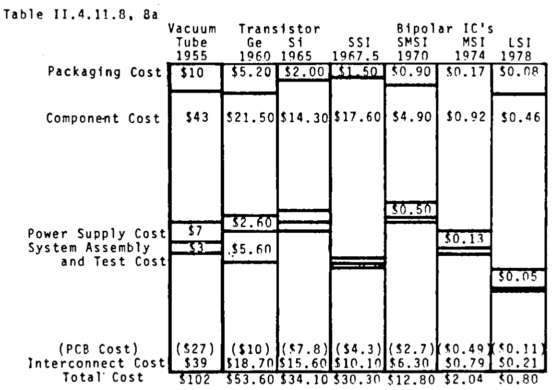



FIGURE 4.11.13a SYSTEM COST OF FLIP-FLOP IN DIFFERENT TECHNOLOGIES

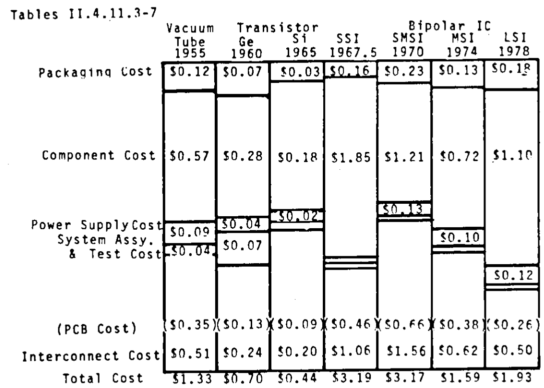



FIGURE 4.11.13b SYSTEM COST OF A COMPONENT IN DIFFERENT TECHNOLOGIES

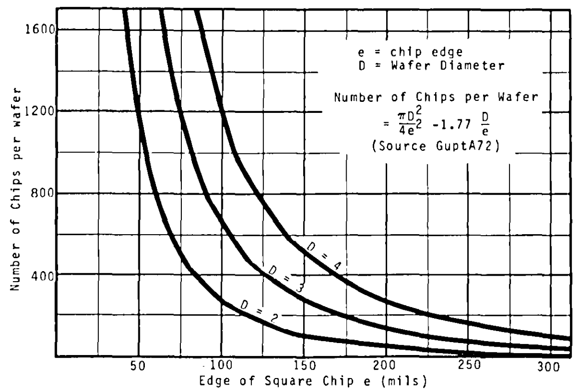



FIGURE 4.12.4a INTEGRATED CIRCUIT GEOMETRY I
NUMBER OF CHIPS WHICH FIT ON A WAFER

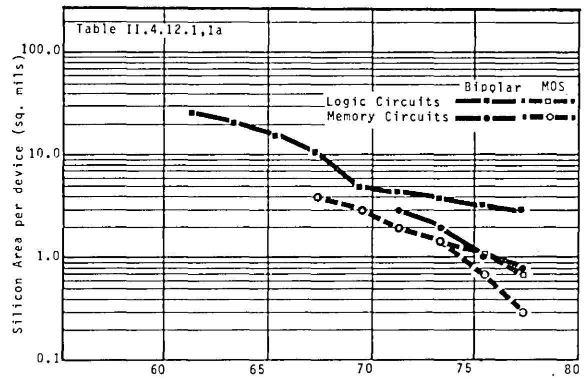



FIGURE 4.12.5a INTEGRATED CIRCUIT GEOMETRY II
TRENDS IN COMPONENT AREA REQUIREMENTS

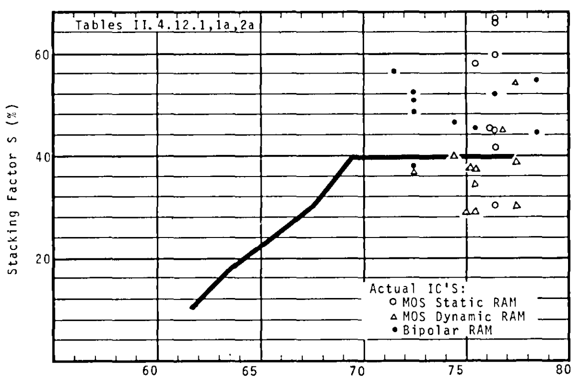



FIGURE 4.12.6a INTEGRATED CIRCUIT GEOMETRY III
TRENDS IN LAYOUT EFFICIENCY

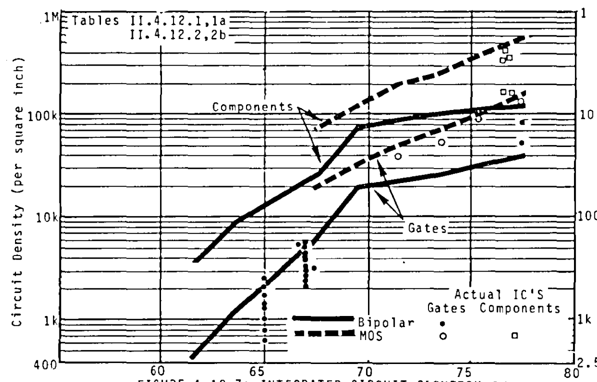



FIGURE 4.12.7a INTEGRATED CIRCUIT GEOMETRY IV
LOGIC CIRCUIT DENSITY--GATES AND COMPONENTS PER SQUARE INCH

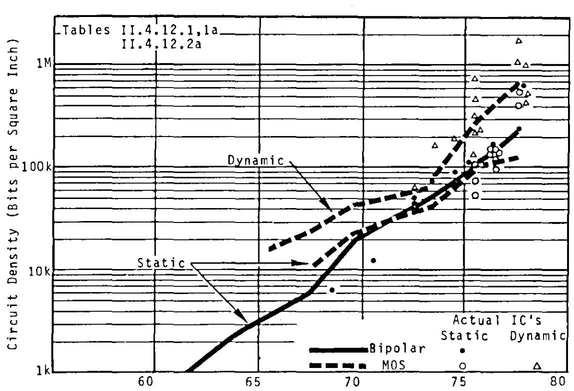



FIGURE 4.12.8a INTEGRATED CIRCUIT GEOMETRY V
MEMORY CIRCUIT DENSITY -- BITS PER SQUARE INCH

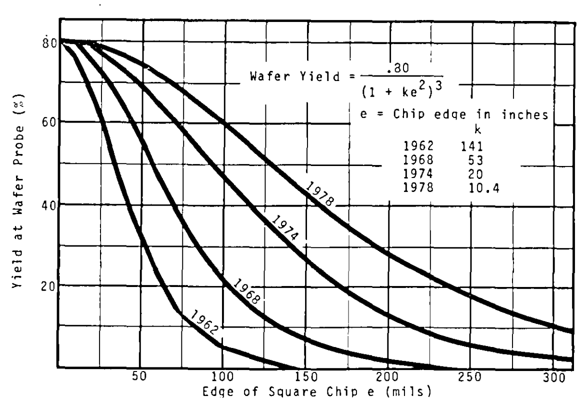



FIGURE 4.12.11a WAFER YIELD

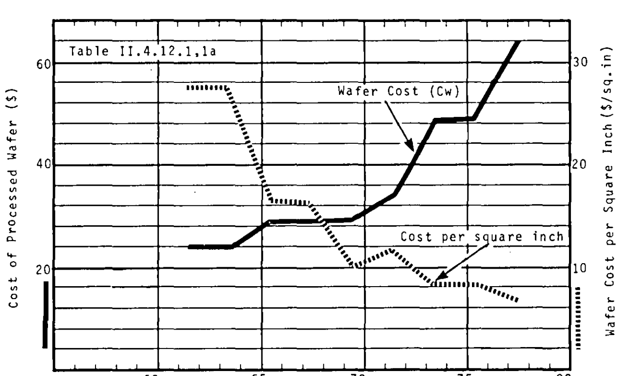



FIGURE 4.12.10a COST OF PROCESSED WAFER

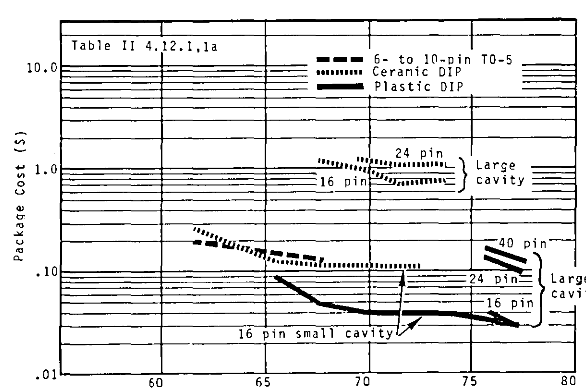



FIGURE 4.12.13a PACKAGE COSTS

sizes as for bipolar, but the cost per gate is smaller because the component area is smaller. For the years 1970, 1974, and 1978 the MOS costs per gate are 0.24, 0.067, and 0.028 cents, respectively. The gates per chip are 350, 1042, and 6350.

5. If we apply our model to the bipolar SSI and MSI circuits discussed in Section 4.11a (see Figures 4.11.5a through 4.11.5c), we are struck with an anomaly. The average MSI IC in the sample contained the equivalent of about 40 gates (taking one flip-flop as equivalent to 7 gates), the average SSI IC about 5 gates. Figures 4.12.18a indicates that, in 1966, there was a substantial difference in manufacturing cost between a 40- and a 5-gate circuit. But in 1970 and later, the cost difference had disappeared—virtually the entire manufacturing cost is in the fixed costs of connecting, packaging, and testing, and the silicon costs of such small chips was negligible. And yet (Figure 4.11.5b) buyers still pay a substantial premium for the MSI circuits. Why is this? Certainly there are some cost factors not included in the model. An MSI circuit will cost somewhat more to test than an SSI circuit, and some require larger and slightly more expensive DIP packages. The SSI volume manufactured and sold is higher per part number than the MSI volumes, and this extra volume leads to some manufacturing efficiencies. It also reduces the effect of distribution and development costs. But these factors cannot by themselves account for the observed price differentials, and it appears likely that IC manufacturers earn a larger profit on MSI than on SSI components.

The revised model, applied to memory component manufacturing costs, gives rise to the costs shown in Figure 4.12.19a. For 1978 the model predicts that the 16k dynamic MOS RAM should be just crossing the $1 cost barrier, which implies high volume and wide sales. The model predicts a 16k bipolar cost too high to be plotted, and shows the 64k dynamic MOS circuit with a cost around $10, implying that 64k components are not far away. (In fact, model parameters were established with the knowledge that IBM and Texas Instruments had both announced 64k chips to be available in 1979—see Table II.4.12.1a.)

It is useful to check the model by using it to determine the number of components contained in, the memory capacity of, and the area of a constant-cost IC. The results are shown in Figures 4.12.19b and 4.12.19c, where they are compared with curves taken from various technical papers. The agreement is moderately good, though the model is a little more pessimistic about growth rates than are most of the published summaries. Note the lower curve in Figure 4.12.19b, labelled "Increase due to increase in chip area". It was found by taking the constant-cost area in each year (the dots in Figure 4.12.19c), and assuming the stacking factor and component area did not change from their 1962 values. The difference between this lower curve and the upper ones (drawn so as to provide an approximate fit to the computed data points) represents improvements in stacking factor and in component and circuit geometry—i.e. in ingenuity and inventiveness.

The above analysis is based on the use of the DIP package. It is still by far the most widely used package, despite the fact it is inefficient in the amount of board space it occupies. It is widely used in part because it can be used with automatic component insertion equipment to manufacture modules. But in part it is used simply because the industry has not yet invented and agreed upon an alternative and better standard package. A new package called the "chip carrier" (LymaJ77) looks like it may become a standard. Its use would help solve the printed circuit board area problem (see Figure 4.12.20a), but like the DIP, it has the property that its area-efficiency falls as its pin count rises. The technology for hybrid circuits, which potentially provide a space-efficient alternative, is still not practical for widespread industry use.

**Costs and Prices.** IBM has announced that its 64K RAM chip has an area of .0625 in.$^2$, the model predicts a manufacturing cost, for such a chip, of about $3.25. This is, however, the expected steady-state manufacturing cost. Manufacturing start-up problems generally result in a cost far higher than that predicted by the model, during the first months of production. Figure 4.12.23a provides a possible scenario for the cost and price of a chip that size, as supplied by an IC manufacturer such as Motorola or Intel.

When an IC first enters manufacturing, wafer, connection, and test costs are higher than standard, and wafer yield may be slow to reach its predicted value. Manufacturing may then have to make changes in masks or in process physics and chemistry to solve the yield problems. As shown by the solid line in Figure 4.12.23a, manufacturing costs may be $30 or more during the first months (with yields 2% or less), and production samples are available at a premium price.

After perhaps six months, wafer and other yields improve somewhat, and there are enough wafers in process to make it possible for the manufacturer to supply parts in quantity. He then lowers the price to the point where it will be attractive to a wide range of buyers. But his yields, though improving, are still low and so parts are in relatively short supply compared with demand. During the next months there is thus a sellers' market and the price holds steady.

Ultimately yield increases further and the part shortage is alleviated. In addition, the success of this IC attracts competitors, and their yields increase to the point that production capacity exceeds demand. Users can get parts from any of several vendors, and make a choice based on price. There thus ensues a buyers' market, and prices fall with increasing frequency. Meanwhile, manufacturing cost approaches its steady-state value. But to cover his overhead and sales costs, and to recover his development costs and make a profit, the manufactuerr *must* hold his price at a value two to four times his costs.

Cost trends during start-up will of course not be smooth, continuous functions like that shown by the solid line in Figure 4.12.23a. And start-up problems may be solved in six months, or may last more than three years. IBM's 64k chip is an ambitious venture by a company which doesn't often take chances in technology. It will be surprising if the venture meets its schedule.

**CCD and Magnetic Bubble technologies.** The charge-coupled device (CCD) and magnetic bubble device are potentially cheap memory components characterized by having relatively long access times. In addition, bubble devices are non-volatile—the data is retained in the device even after power is removed, unlike CCD, MOS, and bipolar devices. In March of 1977 TI introduced the first bubble component—a 92,304-bit device costing $200 with an average access time of 4 ms. In 1974 and 1975 a number of 16k-bit CCD devices were announced, and in March of 1977 Fairchild announced a "second-generation" CCD—a 65,360-bit device costing $97 with an average access time of 0.4 ms.

But new technologies do not easily enter the marketplace.

The bubble memory employs a technology very different from the IC in many ways—it employs a different basic material, and requires an external magnetic field. Although TI has announced a 256k-bit bubble device, its delivery of that device will be a year later than was originally planned. And the price of the original 92k device is (at the end of 1978) still around $100, far more than the $20 TI predicted at announcement time.

The CCD employs conventional IC manufacturing technology, so it requires less development risk than does the bubble. Its advantage over MOS memory technology comes from its greater density—from 2 to 7 times greater than dynamic MOS. Its disadvantages are its slow access time, and

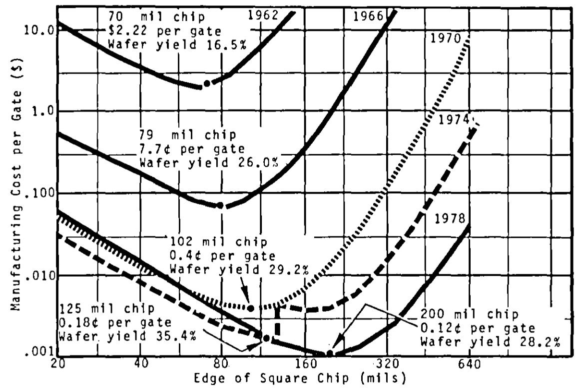



FIGURE 4.12.17a BIPOLAR IC COMPLEXITY AND COST
COST PER GATE VS. CHIP SIZE

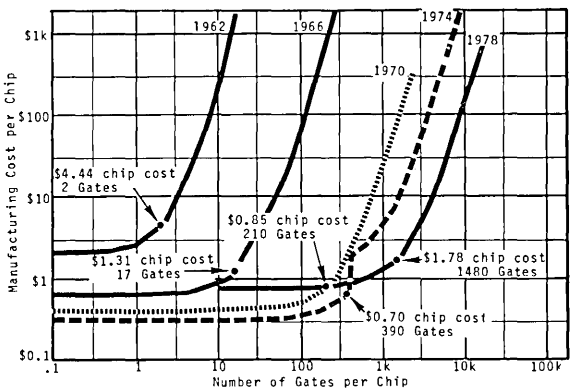



FIGURE 4.12.18a BIPOLAR IC COMPLEXITY AND COST
CHIP COST VS. GATES PER CHIP

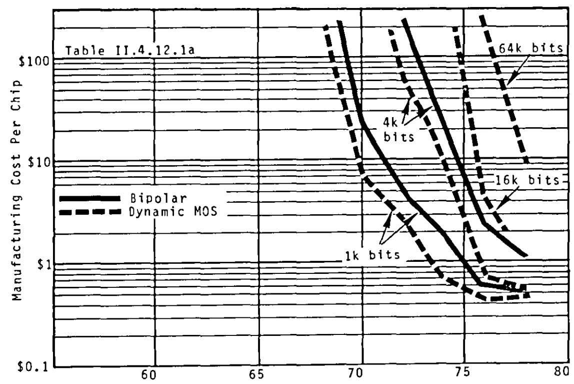



FIGURE 4.12.19a MANUFACTURING COSTS OF MEMORY IC'S

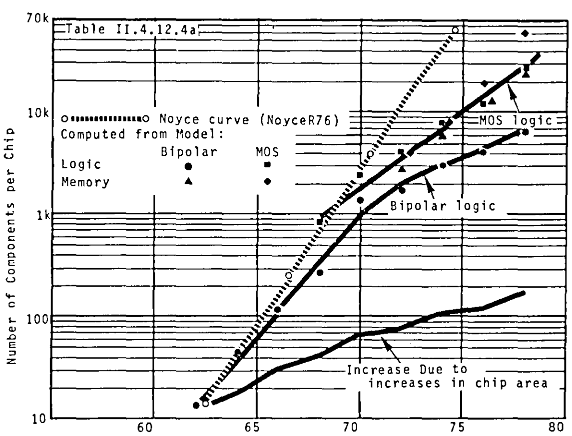



FIGURE 4.12.19b NUMBER OF COMPONENTS IN A CONSTANT-COST CHIP

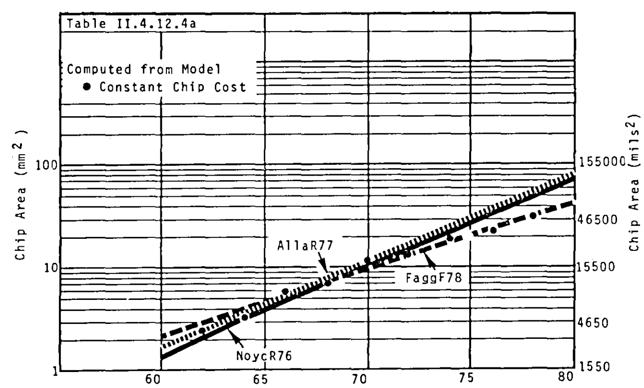



FIGURE 4.12.19c AREA OF A CONSTANT-COST CHIP
MODEL COMPARED WITH PUBLISHED CURVES

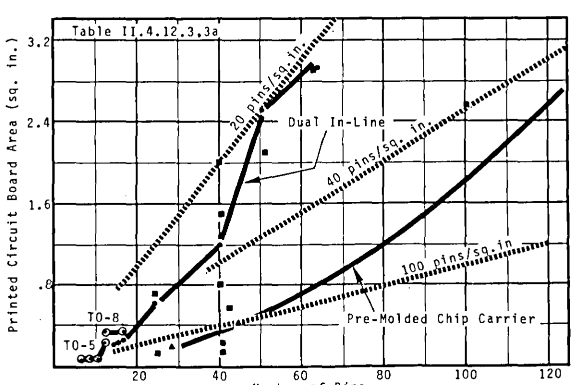



FIGURE 4.12.20a INTEGRATED CIRCUIT PACKAGES
PRINTED CIRCUIT BOARD AREA REQUIREMENTS VS. NUMBER OF PINS

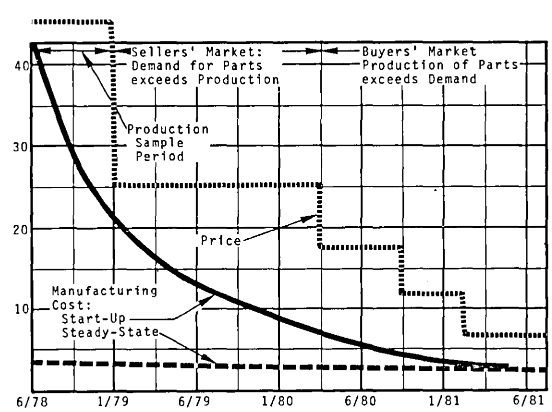



FIGURE 4.12.23a IC PRICES AND MANUFACTURING COSTS
PRODUCTION START-UP OF A COMPLEX NEW IC

the fact that it must compete with a constantly-improving MOS technology. Plated wire and thin-film magnetic technologies never caught up with the always-improving magnetic core. And if the CCD density advantage holds at 2 rather than 7, it seems unlikely it will replace the MOS memory.

### 4.13a INTERNAL MEMORY COSTS

In the years since 1972, the IC memory has supplanted the magnetic core memory in most computer products. Figure 4.13.11a shows manufacturing cost trends, for the magnetic core memory (from DPT&E, p. 197), and for the IC memory based on the Dynamic MOS chip. Each IC memory design assumes 64 memory chips, plus assorted support chips mounted on a 100 square inch module, in a system whose support costs are identical to those discussed in Section 4.11a and described by Table 4.11.8a (Assumptions and calculations are given in detail in Part II in the notes to Table II.4.13.3a.) Note that system cost per bit and IC cost per bit are two different things, and the more expensive IC may provide the less expensive system. For example, in 1978, the 16K IC cost $10, or .061 cents per bit while the 4K chip was only $2, or .048 cents per chip—but the 16K chip made the cheaper memory.

## 4.2 Development Costs

### 4.20a INTRODUCTION

The past few years have seen the establishment of a remarkable new theory called "Software Science", which is applicable to both hardware (logic design) and software development. It was conceived by the late Professor Maurice H. Halstead of Purdue University (HalsM77), though investigators at various other institutions have made contributions. It treats the logic elements (instructions or statements in software, gates or IC's in hardware) and variables (signals in hardware) quantitatively, and establishes measures which can be used to compare designs, and which can predict development parameters. The theory has been tested independently by various organizations, and appears to be supported by experimental evidence, though most experiments have been conducted in the software area, with small programs.

The theory starts by defining some fundamental and measurable properties of the designed product, as follows:

$n_1$ = Number of unique and distinct *operators* appearing in the product.

Examples of operators are the equal sign, parentheses, and arithmetic operators +, -, *, and /, the logical operators "and", "or", "exclusive or", and the delimiter, which separates individual portions of a design.

$n_2$ = Number of unique and distinct *operands* appearing in the product.

Each different operand (or signal, in hardware) must be counted, including constants.

$N_1$ = Total usage of all the operators appearing in the product.

$N_2$ = Total usage of all the operands appearing in the product.

Obviously, each operator and each operand must appear at least once, so that

$$N_1 \geqslant n_1 \text{ and } N_2 \geqslant n_2$$

Next, Halstead defines

$$n = n_1 + n_2$$

$$N = N_1 + N_2$$

Once a design is complete, embodied in a particular set of logic elements (a particular programming language, or a particular family of electronic components) the operators and operands may be counted, and the above parameters may be computed. If the design is repeated with a different set of elements (in a different language, or with different components), the parameters will of course change. And obviously, if the designer starts over and completes the design *using the same language*, his new product will probably be somewhat different and improved, and the parameters will again change.

Halstead next defines a product's *volume* V, as the length of its description, in bits, based on the assumption it is coded in the optimum way. Since there are n different operators and operands, they could be coded with $\log_2 n$ bits. And since these n operators and operands appear a total of N times, the volume is

$$V = N \log_2 n$$

We may now ask ourselves, what is the minimum volume necessary to complete a particular design? The answer is quite straightforward: minimum volume will occur if there is a single logic element which embodies the desired design, and for which there are required only two operators—the verb naming that logic element, and a grouping symbol which sets off the operands—and as many operators as there are input and output variables. Calling this minimum value V*, and the number of input and output variables $n_2$*, we have

$$V^* = (2 + n_2^*) \log_2 (2 + n_2^*)$$

Table 4.20.1a provides examples of these calculations for two simple problems: a program which is to form the square of the sum of two numbers; and an electronic device which is to provide a binary sum and carry bit, given addend, augend, and carry-in bits. The first implementation of the software problem is carried out in a simple assembly language and has a volume of 44.4 bits. In Fortran (the second implementation) the value drops to 24 bits. And the minimum value, presuming a language in which precisely this function is an operator, is 11.6 bits.

For the hardware column, the first implementation of the adder uses individual "and" and "or" gates and has a value of 284.6 bits. We can achieve the same end with two small-scale-integration IC's, making use of two 7451's, each of which contains four "and" and two "nor" gates—so that

$$Z_1Z_2 = 7451\ (ABCDEFGH)$$

can be described by the Boolean equations

$$Z_1 = \overline{AB + CD} \qquad Z_2 = \overline{EF + GH}$$

Using these circuits, the volume drops to 136.7 bits. And the minimum volume, using a full-adder IC, would be 19.7 bits.

Figure 4.20.1a shows how $n_2$* and V* are related.

Now for a given problem, and therefore a given $n_2$* and

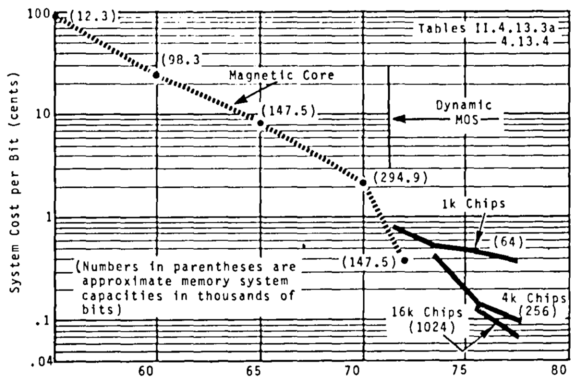



FIGURE 4.13.11a INTERNAL MEMORY COSTS COST PER BIT VS. TIME

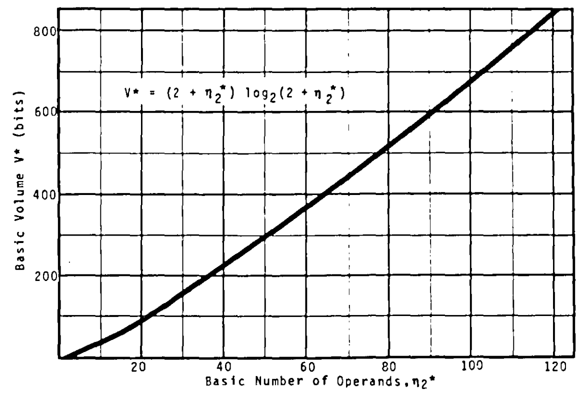



FIGURE 4.20.1a MINIMUM PROGRAM VOLUME VS. NUMBER OF OPERANDS

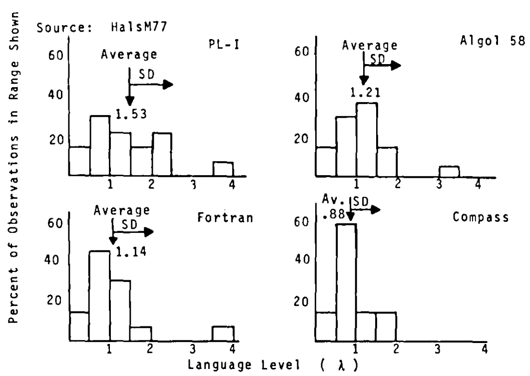



FIGURE 4.20.2a FREQUENCY DISTRIBUTION OF LANGUAGE LEVEL FOR FOUR DIFFERENT LANGUAGES

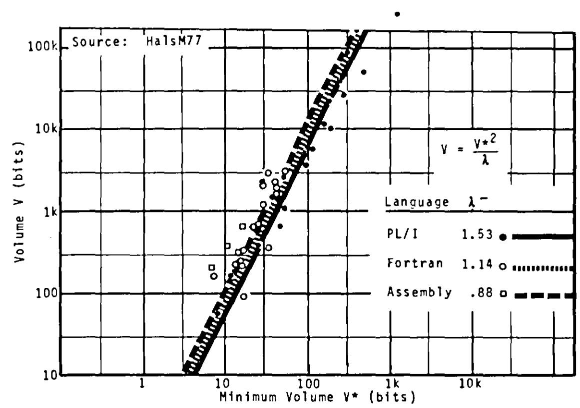



FIGURE 4.20.3a ACTUAL VOLUME VS. MINIMUM VOLUME SOME DATA PLOTTED WITH THEORETICAL FORMULA

## TABLE 4.20.1a SOFTWARE SCIENCE VOLUMES

| Designs | Software: Square of a Sum | Hardware: Full Adder |
|---|---|---|
| Implementation 1 | | |
| Design | LDA X; ADD Y;<br>STA T; MUL T;<br>STA R | $Y_1 = A\cdot B\cdot C$; $Y_2 = A\cdot\bar{B}\cdot\bar{C}$; $Y_3 = \bar{A}\cdot B\cdot\bar{C}$; $Y_4 = \bar{A}\cdot\bar{B}\cdot C$;<br>$Y_5 = A\cdot B$; $Y_6 = B\cdot C$; $Y_7 = A\cdot C$; $C_0 = Y_5 + Y_6 + Y_7$;<br>$S = Y_1 + Y_2 + Y_3 + Y_4$ |
| Operators | LDA ADD STA MUL ; | = + · ; |
| $n_1$ | 5 | 4 |
| Operands | X Y T R | A B C $\bar{A}$ $\bar{B}$ $\bar{C}$ S $C_0$ $Y_1$ $Y_2$ $Y_3$ $Y_4$ $Y_5$ $Y_6$ $Y_7$ |
| $n_2$ | 4 | 15 |
| $N_1$ | 9 | 33 |
| $N_2$ | 5 | 34 |
| V | $14 \log_2 9 = 44.4$ | $67 \log_2 19 = 284.6$ |
| Implementation 2 | | |
| Design | R = (X + Y)**2 | $Y_1, Y_2 \doteq 7451\ (B\bar{C}, \bar{B}C, BC, \bar{B}\bar{C})$;<br>$C_0, S = 7451\ (\bar{A}Y_2, \bar{B}\bar{C}, \bar{A}Y_1, AY_2)$ |
| Operators | = + () ** | = 7451 () , ; |
| $n_1$ | 4 | 5 |
| Operands | R, X, Y, Z | $C_0$, S, $Y_1$, $Y_2$, A, B, C, $\bar{A}$, $\bar{B}$, $\bar{C}$ |
| $n_2$ | 4 | 10 |
| $N_1$ | 4 | 15 |
| $N_2$ | 4 | 20 |
| V | $8 \log_2 8 = 24.0$ | $35 \log_2 15 = 136.7$ |
| Minimum Implementation | | |
| Design | SQDSUM (X Y R) | FULLADD (A B C S $C_0$) |
| Operators | SQDSUM () | FULLADD () |
| $n_1$ | 2 | 2 |
| Operands | X Y R | A B C S $C_0$ |
| $n_2^*$ | 3 | 5 |
| $N_1$ | 2 | 2 |
| $N_2$ | 3 | 5 |
| V* | $5 \log_2 5 = 11.6$ | $7 \log_2 7 = 19.7$ |

$V^*$, the required volume will decrease as the implementation logic elements get more complex. Assembly language and SSI implementations will, for example, require more bits and thus a larger volume than Fortran and MSI implementations. Halstead argues that the ratio $V/V^*$ is a measure of the difficulty of implementing a problem with a given set of logic elements. He then provides some experimental evidence (in the software realm only–little work has been done applying the theory to hardware) to show that if we are executing designs with a given set of logic elements, *the program difficulty increases proportionately with $V^*$*. He calls the constant of proportionality $1/\lambda$, so that

$$\text{Difficulty} = V/V^* = (1/\lambda)V^*$$

or

$$V = (1/\lambda)V^{*2}$$

where $\lambda$ is characteristic of the logic elements, and is called the language level.

The value of $\lambda$ has been calculated for various programs in several languages, and the frequency distributions for PL-I, Algol 58, Fortran, and Compass (a CDC 6500 assembly language) are shown in Figure 4.20.2a. Although the average value of the factor $\lambda$ does increase, as expected, with increasing language complexity, note the standard deviation (SD) from that average value is large. Computed values for V and $V^*$ for a number of specific programs written in PL-I, Fortran, and Compass, are shown in Figure 4.20.3a, plotted along with the theoretical formulae.

We should be careful in interpreting this formula. It is intended to describe average conditions, and is obviously not meant to state that every design having a given $V^*$ and implemented with given logic elements will have the same volume. Each of the following four problems have two operands (an argument and a result) and therefore have $n_2^* = 2$ and $V^* = 8.0$.

1. $y = x + 1$
2. $y = x^x$
3. $y = \ln(\sin x)$
4. $y =$ the $x^{th}$ prime number

But clearly their implementations would have different volumes–whether we build special hardware to do the computations, or write the programs.

So far, we have been dealing only with designs. Halstead next attempts to estimate design time, and the expected number of errors in a just-completed design, from the basic entities he has defined. He suggests that, in carrying out a design, we select N elements (operators or operands, instructions or numbers, IC's or signals) from a vocabulary of n elements. He further argues that an efficient way to make that selection is with a binary search of the vocabulary, and concludes that one generates a design by making N ($\log_2 n$) mental comparisons. And since

$$V = N \log_2 n$$

he concludes that V is a count of the number of mental comparisons we make in carrying out a design. Next, he argues that each of these comparisons requires a discrimination equal to the program difficulty $V/V^*$ as discussed above. And finally he calls attention to the work of psychologist John Stroud, who reported that the brain makes between 5 and 20 elementary discriminations per second.

Calling the discrimination rate S, for Stroud number, we can estimate the design time as

$$T = \frac{(\text{Number of comparisons}) \times (\text{Number of discriminations per comparison})}{\text{Number of discriminations per second}}$$

$$= V \times (V/V^*) \times 1/S = V^2/(V^*S)$$

Substituting $V = V^{*2}/\lambda$, we find

$$T = V^{1.5}/(\lambda^{0.5}S), \text{ or } T = V^{*3}/(\lambda^2 S)$$

Finally, we turn to Halstead's estimate of the number of errors in a just-completed (but not yet debugged) design. He argues that the number of errors should simply be proportional to the number of comparisons made by the designer, which we have seen is equal to V. He finds experimentally that about 3000 comparisons are made between errors, so that the number of bugs in a design is given by

$$B = V/3000 = V^{*2}/3000\lambda$$

Once again we must remember that these last two equations, expressing design time and number of errors as a function of minimum volume $V^*$, are average figures, and that two problems having the same $V^*$ may still differ in complexity and thus require greater (or less) design time than the average, and involve fewer or more errors.

One way of testing Halstead's theory is by comparing it with the rules of thumb we conventionally use in design. The results are shown in Figure 4.20.4a and 4.20.5a. The assumptions made in plotting these curves are shown on the figures. Specifically

a. Halstead shows how volume V may be computed from language level $\lambda$ and from the total number of operators and operands, N. The equations used are transcendental, but the exponential relationship shown in the figure is a good approximation over the range $10 \leq n_2^* \leq 200$.

b. The number of logic elements P in the program is assumed to be a linear function of N.

Comments:

1. Halstead's estimates look fairly reasonable compared with conventional rules of thumb. (Note that "logic elements" in programming are statements or instructions.) Compare Figure 4.20.4a with Figure 4.22.19, where we compared hardware and software development. See also the comment at page 218b of DPT&E on initial error rates.

2. Halstead predicts that errors and design resources required increase faster than linearly with increasing program size–a result the industry has long suspected, without being able to prove (See Figure 4.22.13 in DPT&E.)

3. The equations predict that PL-I productivity in source instructions per man-month will be less than half that for assembly language, assuming the Stroud number is the same for both design activities. Industry data (see Tables 4.22.4, II.4.22.1 in DPT&E) confirms that procedure-oriented languages display lower productivity rates than do machine-oriented languages, though a ratio of two to one seems high.

## 4.21a HARDWARE DEVELOPMENT COSTS

Hardware development costs per unit time have increased, as shown in Table 4.21.1a.

In 1978 DEC published an extraordinary new book entitled *Computer Engineering*, organized and largely written by C.G. Bell (DEC's Vice President for Engineering), J.C. Mudge, and J.E. McNamara (BellC78). Anyone interested in the development of electronic products and in the evolution of computers will be delighted with this book, which reviews the history of DEC processor products and discusses, in candid and refreshing detail, many of the considerations which affected DEC product planning and design.

With regard to the productivity of the development organization, Bell and his co-authors are largely silent. But with the help of some data given in the book, and reproduced as lines 1-11 of Table 4.21.2a, we can make some estimates. For five members of DEC's 18-bit computer family (the first five columns), BellC78 gives the module area occupied by the processor (line 7), together with an indication of the module technology used (lines 9-11). If we make the assumptions on line 12 as to the average number of logic elements per module—and thus per unit area—we can estimate the number of logic elements per processor. And since the book states the number of bays (i.e. cabinets) required, we can estimate logic elements per bay on line 15. For example, the PDP-1 used 5.25 x 4-inch modules averaging two logic elements per module, and required 8900 module square inches in four bays. We therefore estimate the PDP-1 contained 8900 x 2/(5.25x4) = 848 logic elements, or 848/4 = 212 logic elements per bay. For the 36-bit computers (PDP-6, KA10, and KI10) we can make a riskier estimate of logic elements based on a guess as to the number of logic elements packaged per bay (BellC78 did not provide data to fill in line 7 for these systems). Figure 4.21.5a shows logic elements *per $100k processor price* plotted against time

**TABLE 4.21.1a HARDWARE DEVELOPMENT OVERHEAD**

| | Units | 1974 | 1976 | 1978 |
|---|---|---|---|---|
| Salaries & Wages | | | | |
| 1.0 Engineers | $/wk | 390 | 463 | 521 |
| 1.2 Draftsmen, Techn. | $/wk | 240 | 283 | 323 |
| 0.2 Secretaries, Clerks | $/wk | 34 | 37 | 41 |
| 0.2 Production Workers | $/wk | 36 | 39 | 41 |
| 0.4 Managers | $/wk | 234 | 278 | 313 |
| Subtotal Salaries | $/wk | 934 | 1100 | 1239 |
| Other Costs | | | | |
| Fringe Benefits—Rate | % | 16 | 17 | 18 |
| Cost | $/wk | 149 | 187 | 223 |
| Materials, Computer Time | $/wk | 165 | 196 | 221 |
| Totals | | | | |
| Weekly | $/wk | 1248 | 1483 | 1683 |
| Monthly | $k/mo | 5.41 | 6.43 | 7.29 |
| Annual | $k/yr | 64.9 | 77.1 | 87.5 |
| Overhead Rate | % | 220 | 220 | 223 |

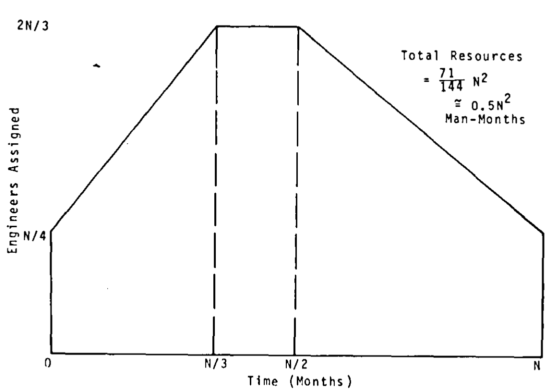


FIGURE 4.21.7a A GENERAL HARDWARE DEVELOPMENT SCHEDULE ESTIMATING RESOURCES FROM PROJECT DURATION, AND VICE-VERSA

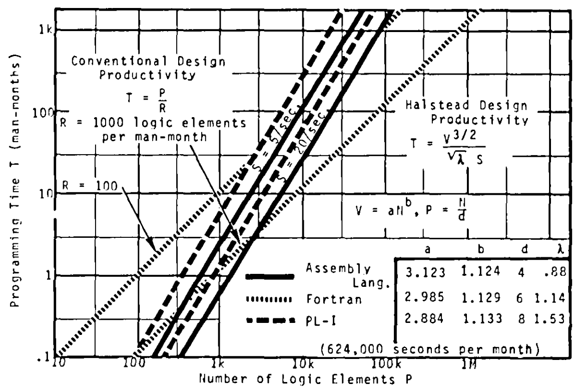


FIGURE 4.20.4a COMPARISON OF DESIGN PRODUCTIVITIES HALSTEAD VS. CONVENTIONAL (LINEAR) MODELS

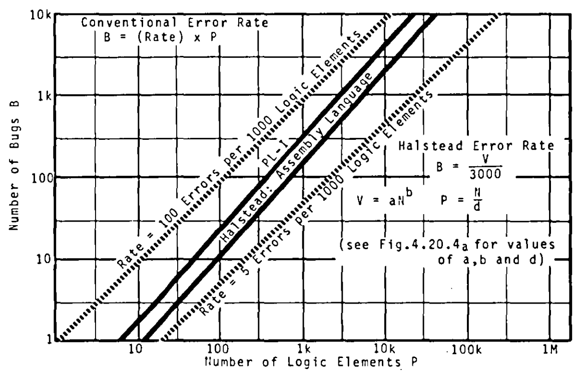


FIGURE 4.20.5a COMPARISON OF ERROR RATES HALSTEAD VS. CONVENTIONAL (LINEAR) MODELS

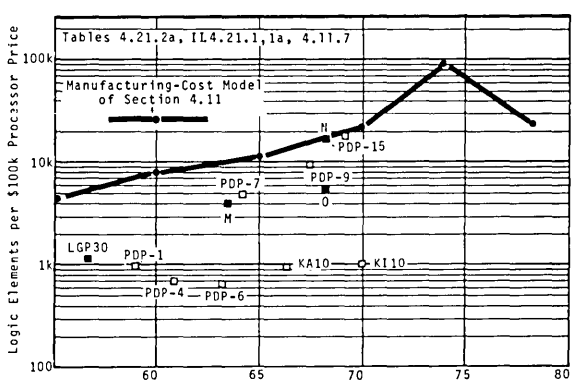


FIGURE 4.21.5a HARDWARE PRODUCT COMPLEXITY NUMBER OF LOGICAL ELEMENTS IN A $100,000 PROCESSOR

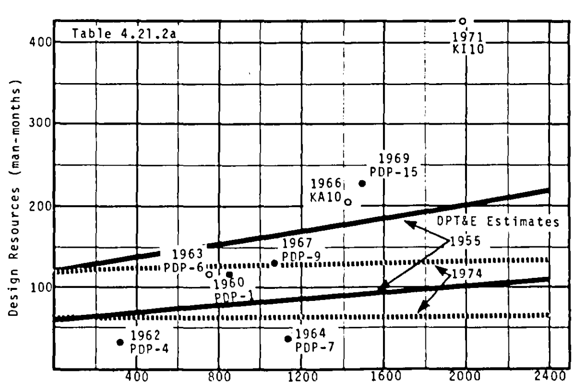


FIGURE 4.21.8a HARDWARE DEVELOPMENT COSTS PROJECT MAN-MONTHS VS. LOGIC ELEMENTS IN PROCESSOR

for these computers, for four computers from DPT&E's Table 4.11.7, and for the systems described by the manufacturing-cost model of Section 4.11.

We can also estimate development resources in man-months, based on the data given on project duration, on line 3. We estimate resources from duration by making use of the argument that *the peak number of engineers assigned to a development project is proportional to project duration.* Specifically, I make the assumption shown in Figure 4.21.7a, and conclude we can estimate resources in man-months by halving the square of project duration, in months. Using that formula we can compute the design effort required for each project (line 16), and from that and our estimate of logic elements per processor, we can estimate productivity (line 17).

The productivity figures range from 4.8 to 9.8 logic elements per man-month except for the PDP-7, which comes to 35.5 le/mm. Curiously, the PDP-7 is the only system for which the authors specified the actual development costs—"$100,000 from the start of the project to completion of the first prototype (excluding module and labor costs)" (BellC78, p.151). From Table 4.21.1, p. 201 of DPT&E, we see the 1965 labor rate was $819 per man-week *including* prototype construction. Subtracting out the $24/wk production labor and $56/wk materials (assumed half of materials plus computer time), we estimate $739/wk or $32000/mo for development costs. And multiplying that by our estimate of 32 man-months for the PDP-7 development, we get $103K—magically close to DEC's $100,000. Comments:

1. The PDP-7 productivity seems particularly high in view of the fact that it was apparently the first product designed making use of the new B series modules. Usually productivity is low during the time engineers are learning a new technology. It is likely that the PDP-7 project was an unusually efficient one. The authors mention that "the entire logic implementation was undertaken by (two engineers)", where the model of Figure 4.21.7a estimates a peak labor force of over five for an eight-month project. "Time was considered a very important factor in the design," and in such circumstances a company assigns its best engineers, expects them to work 60-hour weeks, and provides them with all possible resources to help them do the job.

2. DPT&E proposed a development resource model of the form

$$\text{Resource man-months} = m_0 + ((\text{Number of logic Elements})/p_h)$$

and postulated that productivity, as measured by the coefficient $p_h$, improved substantially between 1955 and 1974. The 1955 and 1974 estimates are shown as solid and dotted lines in Figure 4.21.8a, along with plots of our DEC estimates, from Table 4.21.2a. If we were to develop a model based solely on the DEC data, we might conclude a) $m_0$ should be zero, and $p_h$ should be only about 6.6 logic elements per man-month; b) there seems to be no apparent improvement in productivity with time. However, we must remember the large number of assumptions we had to make in deriving the DEC productivity data. The numbers for the PDP-6, KA10, and KI10 are particularly suspect, since they are not based on module area but on number of "bays" or cabinets. And we might alternatively conclude that the DEC data *does* agree with the model, but that the PDP-4 and PDP-7 were particularly efficient, and the KA10, PDP-15, and KI10 particularly wasteful projects.

## 4.22a SOFTWARE DEVELOPMENT COSTS

A number of industrial organizations have published the results of analyses of their software development activities over the past few years. We will review some of this data, and will conclude by describing a detailed, quantitative model for the software-development process.

**TABLE 4.21.2a DEVELOPMENT TIME FOR DEC COMPUTERS**

| | | Units | PDP-1 | PDP-4 | PDP-7 | PDP-9 | PDP-15 | PDP-6 | KA-10 | KI-10 | KL-10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Design Start | | 8/59 | 11/61 | 4/64 | 8/66 | 5/68 | 3/63 | 1/66 | 12/69 | 1/72 |
| 2. | First Ship | | 11/60 | 7/62 | 12/64 | 12/68 | 2/70 | 6/64 | 9/67 | 5/72 | 6/75 |
| 3. | Duration | (mos.) | 15 | 8 | 8 | 16 | 21 | 15 | 20 | 29 | 42 |
| 4. | Processor Size | | | | | | | | | | |
| 5. | Bays | | 4 | 2 | 3 | 1.5 | 1 | 2 | 2 | 2+ | 0.5 |
| 6. | Modules | | 450 | 150 | 384 | 352 | 128 | | | | |
| 7. | Area | (sq.in.) | 8900 | 3300 | 3300 | 3100 | 2100 | | | | |
| 8. | Module Type | | 1000 | 4000 | B | B | M | | R,S,W, | R,S,W,M | |
| 9. | Size | (in.) | 5.25x4 | 5.25x4 | 2.25x5 | 2.25x5 | 2.25x5 | 9x11 | 5.25x5.5 | 5.25x5.5 | 8x16 |
| 10. | Logic | | trans | trans | trans | trans | SSI | trans | trans | trans.MSI | ECL |
| 11. | Logic Elements | | f/f,gate | f/f,gate | f/f,gate | f/f,gate | f/f,gate | f/f,gate | f/f,gate | IC | IC |
| 12. | per module | | 2 | 2 | 3 | 3 | 8 | | 3 | 6 | |
| 13. | per area | (le/sq.in) | .0952 | .0952 | .344 | .344 | .711 | | .104 | .208 | |
| 14. | per processor | | 848 | 314 | 1135 | 1067 | 1493 | 756 | 1422 | 2000 | |
| 15. | per bay | | 212 | 157 | 378 | 711 | 1493 | 378 | 711 | 1000 | |
| 16. | Design effort | (man-mo) | 113 | 32 | 32 | 128 | 221 | 113 | 200 | 421 | 882 |
| 17. | Productivity | (le/mm) | 7.5 | 9.8 | 35.5 | 8.3 | 6.8 | 6.7 | 7.1 | 4.8 | |
| 18. | Total Price | $ | $120k | $65.5k | $45k | $19.8k | — | — | — | | |
| 19. | Processor Price | $ | $85k | $45.5k | $23.7k | $11k | $7.8k | $120k | $150k | $200k | $250k |
| 20. | Log.Elements per $100k | | 1000 | 690 | 4790 | 9700 | 19140 | 630 | 948 | 1000 | |

**Support Costs (Overhead).** Table 4.22.1a brings the development overhead model up to date. (Note it also corrects an arithmetic error, for 1974, in the original table on p. 211 of DPT&E.)

**Product Development.** Several studies provide data collected on programming errors, with the general result shown in Table 4.22.2a. Endres' study, of the large body of code written and modified to create IBM's DOS/VS (Release 28) was mentioned in DPT&E. Programs were written in DOS Macro Assembler Language, and averaged 6.0 errors per 1000 lines of code written. However, the only errors counted were those found during a formal five-month test period, when the 422 modules which comprise the system were integrated into a whole. Thus, errors found while those modules were individually assembled and tested, are not included. Furthermore, the system underwent additional tests, including a performance study and special tests for remote data processing, before being released; and any errors discovered during these tests were not counted.

Fagan's paper mentioned a single COBOL application program containing 4439 non-comment source statements which had an average of 10.4 errors per 1000 statements. The project made use of design and code inspections, or reviews, during the development process, and the error rate was thought to have been lower than normal for that reason.

The data presented by Walston (and co-author Felix) provides a fascinating look at a variety of IBM program projects. But the median error rate was only 3.1 errors per 1000 lines (see Table II.4.22.5a and Fig. II.4.22.1 for more data). All errors reported "during the development phase" are included. A partial explanation for the low rate might be the fact that the authors include all lines input to the language processor, in counting lines of code. Thus comment lines are included by Walston, where they were not included by Thayer.

Finally, a TRW study reported by Thayer, Lipow, and Nelson (ThayT76) supplies a notable analysis of errors on four military command and control projects. The results are summarized at the bottom of the first part of Table 4.22.2a, and are presented with more detail in the second part. The authors are careful to distinguish a problem, which is a registration of dissatisfaction of some kind on a formal problem report, from a fault (or bug) in the software. Many problems lead to the discovery (and subsequent correction) of faults. But other problems are really just questions, or requests for changes in documentation, or complaints about operator errors. Note that the fault rate (or error rate, to return to the less precise language we have been using) is substantially higher for these TRW-reported projects than it was for the projects reported in the IBM studies. It's not clear why this is so. The TRW projects included two command and control systems (Projects 2 and 3), a generalized information processing system (Project 4), and a real-time data processor, operating system, realtime simulator, dynamic path analyzer, code auditor, and code structure analyzer (all part of Project 5). These are surely complex programs. But so was DOS/VS, and so were many of the programs included in Walston's study (e.g. several process control systems, and two special-purpose operating systems). Probably the error rates reported by Thayer are high because the applications were relatively new, compared to the IBM projects. Certainly the Walston applications include a number of simple batch systems which were very similar to other programs IBM's people had written before, and (see Table II.4.22.6a) "previous experience with an application of similar or greater size and complexity" was an important factor in explaining productivity differences in the IBM study.

Figure 4.22.1a shows how the fault rates varied from module to module of Thayer's Project 3, as a function of module size. Note that most routines had fault rates in the range between 10 and 25 per 1000 statements. The figure also shows the median and 25/75 percentile fault rates for the 61 IBM programs described by Walston, plotted at the median program size of 20,000 statements. Presumably an estimated fault incidence of 1 to 25 per 1000 instructions, with a "most likely" ratio in the range 3 to 10, would be reasonable.

Errors have a very direct impact on the cost of program development. Program checkout typically uses up 35% of program development resources (Table II.4.22.2), and most of that time is spent diagnosing and curing errors. Boehm estimates that the cost of fixing an error increases remarkably with time—that an error which would cost $1000 to fix if detected during coding will cost $2000 to fix if found during development test and $10,000 if found during operation (BoehB76). If it is found and corrected during the design stage, before coding, it would only cost $500. There is thus every motive to study program errors, and to detect them as early as possible in the design process.

**Development Time and Cost.** Programming managers and research groups have proposed several techniques aimed at improving the programming process. The objectives have

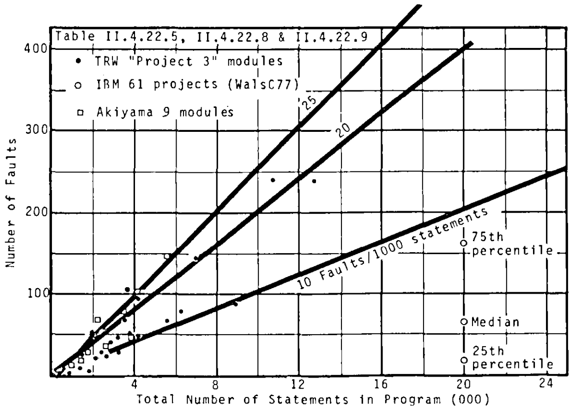


FIGURE 4.22.1a FAULTS IN PROGRAMS

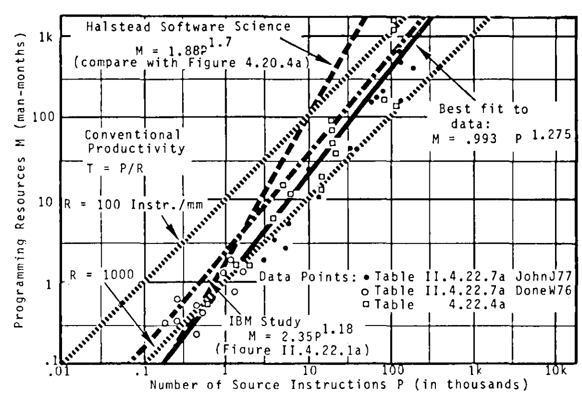


FIGURE 4.22.2a PROGRAMMER PRODUCTIVITY I

been to reduce programming design and maintenance costs, to improve program products, and to insure that development schedules are met. Many of these techniques have been experimented with, and some adopted, in commercial settings. Some of the published results are given in Table 4.22.4a and Figure 4.22.2a. Note that the data points plotted in the figure come from three tables, and represent a mixture of individual programs (from JohnJ77 and Table 4.22.2a), program types (from DoneW76), and groups of programs (from Table 4.22.4a). Comments:

1. There continues to be an enormous variability in stated productivity, from organization to organization, and within organizations. The variability arises from some combination of non-comparable definitions and data, programmer adeptness, problem complexity, and organizational or managerial proficiency. The IBM study (WalsC77) contains the best quantitative analysis of this variability that I have seen. (See below.) Productivity figures as low as 57 and as high as 2476 statements per man-month appear in the plotted data of Figure 4.22.2a.

2. Several things point to a non-linear relationship between program resources and program size. The solid line in Figure 4.22.2a is the least-squares best fit to the data points, and shows resources vary as the 1.275 power of program size. The IBM study fitted a similar curve to the data on 60 programs, with the result shown as a dot-dash line—resources varying as the 1.18 power of program size (the least-squares fit minimizes the orthagonal, not the y-axis or x-axis distance, from points to line. See the notes to Figure II.4.22.1 in Part II for a discussion.) Halstead's Theory, discussed in Section 4.20 above, predicts a 1.7 power and is plotted as a dashed line. Note that the conventional linear theory (dotted lines) underestimates productivity for small programs and overestimates it for large ones. Figure 4.22.3a shows how productivity varies with program size, based on the IBM and "best-fit" formulas.

3. It's not possible to draw conclusions from this data regarding the usefulness of the new programming techniques. However, in his 1974 survey (BoehB75) Boehm reported, "Savings of over 50 percent have been achieved (through the use of these techniques) relative to previous performance on similar projects. IBM's extensive data base of software experience indicates an average savings of 40 percent; however, productivity varied by a factor of 5 between projects, both within the group of projects that used (the new techniques) and those that didn't." In another article (BabeF75) Baber at IBM reported, "It is not possible, because it would reveal valuable business data, to present significant amounts of quantitative information (on productivity) in this paper . . . (But) a weighted least squares fit (to a graph plotting productivity vs. the percentage of structured code in the finished product) shows a better than 1.5 to 1 improvement in the coding rate from projects which use no structured programming to those employing it fully." Baber uses the term "structured programming" to describe various techniques employed by IBM. In an NCC paper (HugoI77), Hugo reported on an international survey of 309 computer users who were to some extent using "structured program" techniques. The respondents were generally favorably disposed toward use of the techniques, but very few of them had any quantitative measures to report.

4. The Walston/Felix paper (WalsC77) contains a very interesting attempt to correlate various program cost factors (including pages of documentation and computer cost) with program size (see Figure II.4.22.1). They report a 35% to 45% difference in productivity between projects which did and did not make some use of the chief programmer team, structured programming, top down development, and design and code inspection techniques. (See Table II.4.22.6a.) However, they also reported much larger gains attributed to other factors: customer interface complexity (75%); personnel qualifications (68%); previous experience of programmers

**TABLE 4.22.1a SOFTWARE DEVELOPMENT OVERHEAD**

| | Units | 1974 | 1976 | 1978 |
|---|---|---|---|---|
| **User Overhead** | | | | |
| 0.58 Programmers | $/wk | 162 | 185 | 211 |
| 0.42 Systems Analysts | $/wk | 151 | 168 | 197 |
| Subtotal, P&SA | $/wk | 313 | 353 | 408 |
| 0.1 Secretaries, Clerks | $/wk | 17 | 19 | 21 |
| 0.2 Managers | $/wk | 94 | 106 | 122 |
| Subtotal Salaries | $/wk | 425 | 478 | 550 |
| Fringe Benefits—Rate | % | 16 | 17 | 18 |
| Cost | $/wk | 68 | 81 | 99 |
| Total Cost—Weekly | $/wk | 493 | 559 | 649 |
| Monthly | $k/mo | 2.13 | 2.42 | 2.81 |
| Annually | $k/yr | 25.6 | 29.1 | 33.8 |
| Overhead Rate | % | 57 | 58 | 59 |
| **Supplier Personnel** | | | | |
| 1.0 Programmer | $/wk | 390 | 463 | 521 |
| 0.1 Secretaries, Clerks | $/wk | 17 | 19 | 21 |
| Technical Writers—Number | | .80 | .85 | .90 |
| Cost | $/wk | 160 | 201 | 242 |
| 0.2 Managers | $/wk | 117 | 139 | 156 |
| Subtotal Salaries | $/wk | 684 | 821 | 940 |
| Fringe Benefit—Cost | $/wk | 109 | 140 | 169 |
| Total Cost—Weekly | $/wk | 793 | 961 | 1,109 |
| Monthly | $k/mo | 3.44 | 4.16 | 4.81 |
| Annually | $k/yr | 41.3 | 50.0 | 57.7 |
| Overhead Rate | % | 103 | 107 | 113 |

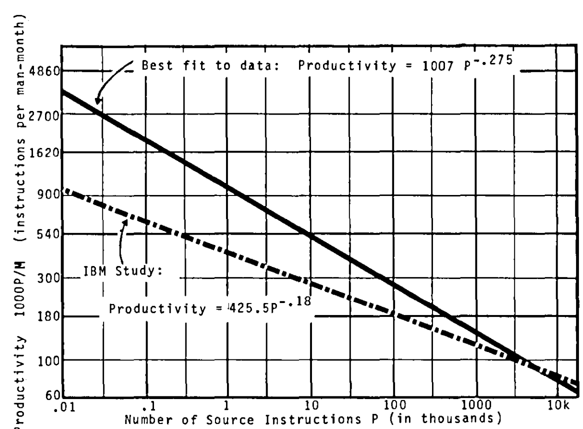



FIGURE 4.22.3a PROGRAMMER PRODUCTIVITY

### TABLE 4.22.2a ANALYSIS OF PROGRAMMING ERRORS I

| Source | Description | Program Size | Number of Errors | Errors per 1k |
|---|---|---|---|---|
| EndrA75 | New code | 53k | 254 | 4.8 |
| | Modified programs | 33k | 258 | 7.8 |
| | Total | 86k | 512 | 6.0 |
| FagaM76 | Appl. program | 4.439k | 46 | 10.4 |
| WalsC77 | 60 programs | | | |
| | median | 20k | | 3.1 |
| | quartiles | 10k-59k | | 0.8-8.0 |
| ThayT76 | Project 2 | 96931 | 1232 | 12.7 |
| | Project 3 | 115346 | 2019 | 17.5 |
| | Project 5 | 28564 | 689 | 24.1 |

### TABLE 4.22.2a ANALYSIS OF PROGRAMMING ERRORS II

| | Project 2 | Project 3 | Project 4 | Project 5 |
|---|---|---|---|---|
| Language | Jovial J4 | Jovial J4 | PWS | Fortran Assembly |
| Size (source statements) | 96931 | 115346 | * | 11105 F<br>17459 A |
| Number of routines | 173 | 249 | 190 | 531 |
| Av. statements/routine | 560 | 463 | | 54 |
| Operating Mode | Batch | Batch | On-line or Batch | Real-time and Batch |
| Number of Problems—Total | 1498 | 4439 | 539 | |
| Number of Faults—Total | 1232 | 2019 | 405 | 689 |
| Faults per Problem | .82 | .45 | .75 | |
| Problems per 1000 Statements | 15.5 | 38.5 | | |
| Faults per 1000 Statements | 12.7 | 17.5 | | 24.1 |

Notes: Source = ThayT76. *The Program Word Standard Macro Language used for Project 4

### TABLE 4.22.2a PROGRAMMING ERRORS II (cont)

| Project: | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Problem Distribution—% | | | | |
| Computational | 10.8 | 8.0 | 1.3 | |
| Logic | 17.1 | 21.1 | 26.0 | |
| I/O | 10.4 | 16.2 | 6.7 | |
| Data Handling | 10.9 | 13.8 | 20.4 | |
| Operating System | 0.1 | 0.1 | 0 | |
| Configuration | 1.1 | 1.9 | 0 | |
| Interfaces | 13.3 | 14.4 | 16.9 | |
| User Requested Changes | 0 | 0 | 20.6 | |
| Preset Data Base | 7.4 | 8.3 | 1.7 | |
| Global Variable | 3.7 | 1.1 | 2.2 | |
| Recurrent | 1.6 | 1.8 | 0 | |
| Documentation | 11.5 | 4.4 | 4.2 | |
| Requirements Compliance | .7 | 1.1 | 0 | |
| Unidentified | 5.3 | 4.0 | 0 | |
| Operator | 5.7 | 2.7 | 0 | |
| Questions | .3 | 1.1 | 0 | |
| Faults Distribution | | | | |
| Computational | | 9.0 | 1.7 | 12.0 |
| Logic | | 26.0 | 34.5 | 24.5 |
| Data Input/Output | | 16.4 | 8.9 | 7.8 |
| Data Handling | | 18.2 | 27.2 | 11.0 |
| Interface | | 17.0 | 22.5 | 7.0 |
| Data Definition | | 0.8 | 3.0 | 8.9 |
| Data Base | | 4.1 | 2.2 | 16.3 |
| Other | | 8.5 | 0 | 12.5 |
| Sources of Faults | | | | |
| Requirements | | | | 6.5 |
| Design | 59.7 | 62 | | 43.3 |
| Code | 40.3 | 38 | | 41.5 |
| Maintenance | | | | 3.2 |
| Unknown | | | | 5.5 |

### TABLE 4.22.4a EVALUATION OF NEW PROGRAMMING TECHNIQUES

| Date | Program Language | Organi-zations | Number of Programs | Programming Techniques Used* | Programming Prod. Source Instructions per man-month | Av. Length of Source Programs | Programming Resources (mm) | Reference |
|---|---|---|---|---|---|---|---|---|
| 1970-1977 | COBOL | Hallmark | 14 | None mentioned | 852 | 120,000 | 104.8 | JohnJ75 |
| | PL-I | Hallmark | 2 | None mentioned | 494 | 82,000 | 166.0 | |
| 1970's | COBOL | Harris Corp. | 12 | None Mentioned | 1156 | 622 | 0.5 | DoneW76 |
| 1972-1977 | (Various) | IBM | 61 | CP, HIPO, PPL, SC, DCI, TDD | 274 | 20,000 | 73.0 | WalsC77 |
| 1970's | Machine Language | GTE | unk. | None mentioned | 329-399 | 5000-20000 | 15.2-50.1 | DalyE77 |
| | unk. | GTE | 1 | None mentioned | 57 | 160,000 | 2807 | |
| | unk. | GTE | 1 | None mentioned | 75 | 117,000 | 1560 | |
| | unk. | GTE | 1 | None mentioned | 92 | 111,000 | 1207 | |
| | unk. | GTE | 20 | None mentioned | 260 | 20,000 | 76.9 | |
| 1973 | COBOL | McDonald Douglas | 5 | CP, PPL, SC, TDP, WT, HIPO | 300-500 | 5000-6000 | 16.7-12.0 | BochB75 |
| 1974 | COBOL | McDonald Douglas | 1 | SC, TDD, TDP, WT, HIPO | 780 | 1300 | 1.7 | |
| | COBOL | | 1 | SC, TDD, TDP, WT, HIPO | 1257 | 2000 | 1.6 | |
| | COBOL | | 1 | SC, TDD, TDP, WT, HIPO | 672 | 3875 | 5.8 | |
| | COBOL | | 1 | SC, TDD, TDP, WT HIPO | 1061 | 14,500 | 13.7 | |
| 1972-73 | SIL | CF&G | 1 | SC, TDP, PPL | 560 | 21,200 | 37.9 | BoehB75 |
| 1974-75 | PL-I | | 1 | SC, TDP, PPL | 760 | 14,800 | 19.5 | |
| 1973-74 | Fortran,AL | HAC | 2 | SC, TDD, TDP | 150-250 | 19,000 | 95.0 | BoehB75 |

*: CP Chief Programmer; DCI Design/Code Inspections; HIPO Hierarchy plus Input-Process-Output; PPL Program Production Library; SC Structured Code; TDD Top-Down Design; TDP Top-Down Programming and Testing; WT Walk-Throughs.

with applications of similar or greater complexity (64%); user participation in the definition of requirements (58%); etc.

Taking all this data into consideration, and making use of appropriate estimates of computer and personnel costs, and of trends in the use of higher level languages, we arrive at Figure 4.22.10a. It was derived assuming there was a substantial improvement in the rate of change of productivity since 1974—from the 3.5% per year which formed the basis for the curves up to 1974, to 5%, 8%, 12%, and 14% for the four most recent years. The result is an increase in productivity great enough to overcome the continuing increases in labor cost, and thus to reduce the cost per instruction.

Of course, the tools which have received so much recent publicity may, in fact, not be effective; or being effective, they may not be widely applied. And in any event, since much programmer time is spent maintaining old programs (see Table II.4.22.12a), the effectiveness of new tools is less important than one might think. But managers who have not tried to improve programmer effectiveness would do well to estimate the trends in per-instruction costs in their own organizations, and to compare them with the (optimistic) estimate shown here.

**Program Checkout.** When coding is complete, the debugging and product verification stages of design commence, and the designers identify and correct mistakes and oversights. Three studies published in the past few years (AkiyF71, MusaJ75, and ShooM75) give some insight into this process. All three treat assembly-language programs—Musa's a real-time interactive program at Bell Labs, Akiyama's a program written at Fujitsu to run under their operating system, and Shooman's a control-type program also written at Bell Labs. Faults found vs. elapsed calendar time for these three projects are plotted in Figure 4.22.12a (the plots are approximate, derived from graphical data given in various formats in the original papers. Only Akiyama's data was originally given in the form shown here.) Comments:

1. The three projects show markedly different numbers of faults per 1000 instructions, though of course all lie in the range we expect to see. (Compare Figure 4.22.1a, which among other things shows the 9 components of Akiyama's program.) The Akiyama fault rate is highest, but he notes that project personnel included an unusually high proportion of inexperienced people.

2. The two Bell Labs projects indicate that checkout takes place in two stages. Musa noted this, discussed it at length, and included the effect in his model of the checkout process. He argued that "the pace of testing is constrained by three limiting resources: failure identification personnel, failure correction personnel, and computer time." During the initial stages of checkout, he contended that the availability of failure correction personnel is usually the limiting factor, while during later stages either detection personnel or computer time will limit. However, this contention doesn't seem to conform well with the data, which shows a second-stage increase in the rate at which faults are experienced. If that ratio is limited, during the early stage, by the number of failure correction personnel, how was it possible for faults to be corrected at a higher rate during the second stage? It seems more likely that the limitation in the first stage, in both Bell Labs projects, was detection personnel or computer time (or perhaps something we all experience, like inefficiency or lack of planning); and when that limitation was removed, faults were detected and corrected at a substantially higher rate. Note that the existence of the "first stage" introduces a substantial delay in checkout. If the Musa project started at time t = 0 with the higher checkout rate, 90% of the failures would have been cured in about 40 days, instead of the 89 actual days.

**A Software Development Model.** The next few figures show the end result of a mathematical model of the programming process. The model is too complicated to present here (it will be submitted to the *IEEE Trans. on Software Engineering* for possible publication there). But it is interesting enough that it seems to be worth summarizing.

The model consists of four sub-models.

1. Resources. People are assigned to a project. The effective man-hours they are able to apply are less than the actual man-hours recorded on their time cards. The model takes into account losses of effective time caused by learning and by communicating with other team members.

2. System Design. The resources required for system design are a function of the length of the program, P, and the number of modules the program is divided into. Each of n team members ultimately will code S modules of length P/nS, and the model shows how to determine total system design man-months, given n, and S, and P.

3. Coding. The resources required for coding are a function of the programming language used, the number of modules, and the average module length. The model makes use of Halstead's Software Science (see Section 1.20a) to establish this function.

4. Checkout. The resources required for checkout are a function of the number of faults (bugs) originally in the just-completed coding, and of the rates at which they can be detected and corrected. The model assumes that the initial number of bugs is a function of the number and average size of the modules (again using Halstead's theory), and that the rate at which failures are cured is proportional to the number remaining (see Figure 4.22.14). It also assumes that personnel are withdrawn from the project as the error rate diminishes, and that the project is complete when a specified fraction of the presumed initial number of bugs has been removed.

Application of the model leads to the results plotted in Figures 4.22.20a to 4.22.22a. The first of these shows project duration for a 20,000-statement Fortran program for various team sizes (n = 1,2,4,8...128 people), and, for each size, for

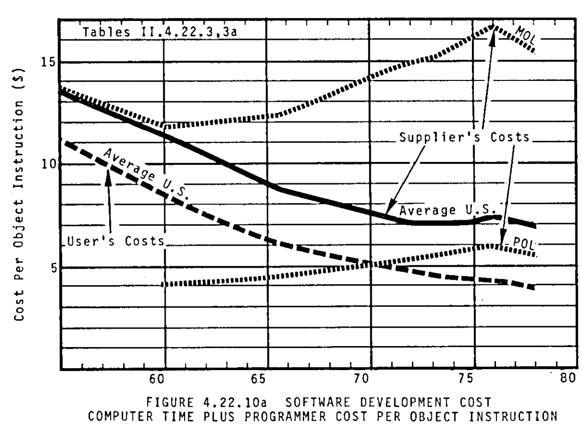



FIGURE 4.22.10a SOFTWARE DEVELOPMENT COST
COMPUTER TIME PLUS PROGRAMMER COST PER OBJECT INSTRUCTION

various numbers of modules. Note there is a module size which minimizes duration, for each team size—the model suggests a 20,000-statement Fortran program should be coded in 1250-statement segments. If the segments are too large, too much time is spent in coding; if too small, too much time in system design.

The other two figures show how productivity, in statements per time card man-months, varies with project duration. Figure 4.23.21a covers four Fortran programs (solid lines) of size P = 1000, 4000, 20,000, and 100,000 statements, with teams ranging in size from one to 256 people. (For each of the points plotted, optimum module size is assumed). Note that, as people are added to a project, project duration drops but at a slower and slower rate until finally duration increases with further increases in personnel. Note also the results of the IBM study described in connection with Table II.4.22.1a, plotted as a dashed line connecting squares in the figure. The squares represent the IBM results for the same four values of P as are plotted as solid lines from the model, and all except the smallest (P = 1k) agree well. Note also that the IBM curve lies roughly at the knee of the productivity/duration curve—an operating region which appears to be a good compromise between efficiency and urgency.

Finally, Figure 4.22.2a shows the productivity/duration plot for three 20,000-statement programs written in three different languages. The model predicts that assembly language productivity should be around 1.5 times that of Fortran productivity (measured in source, not object instructions per man-months), and this result agrees fairly well with the Nelson experiments given in Table II.4.22.1 (page 503 of DPT&E).

The model isn't complete—doesn't include documentation, or program verification, for example. Nevertheless, I venture the following observations:

1. Module size is probably a very important intermediate variable, and should be explicitly planned when a programming project is set up. It influences the resources required throughout the process—for system design, coding, and checkout. It should not be left to the discretion of individual programmers. For example (assuming the present model is moderately accurate), if four people are assigned to write a 20,000-instruction program, the project manager should see to it that, when coding begins, each team member has 2 to 8 modules each with perhaps 750 to 2500 instructions. It is not likely to be profitable for one programmer to be working on a 6000-instruction module, or for another to be coding 40 100-instruction modules.

2. Considerable time and manpower can be wasted in checkout, unless the project manager is careful to see to it that faults are detected at a rate fast enough to keep the entire staff busy correcting them. The experimental evidence (see e.g. the Musa and Shooman data of Figure 4.22.12a) indicates that may not be easy to do. It obviously takes careful preparation of test runs, plus plenty of computer time. (Incidentally, one weakness of the model is that it does not explicitly include the resources necessary for checkout preparation.)

3. We often ascribe differences in programmer productivity, from one project to the next, to differences in program

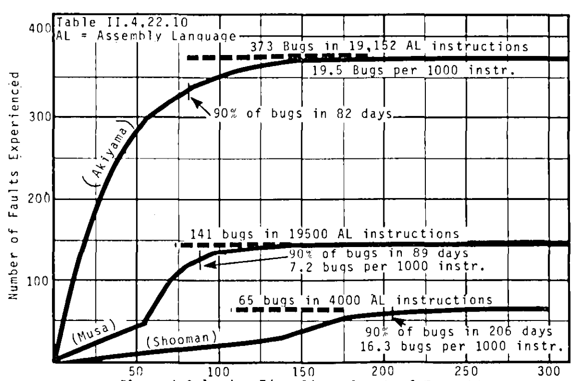



FIGURE 4.22.12a FAULTS VS. TIME DURING CHECKOUT

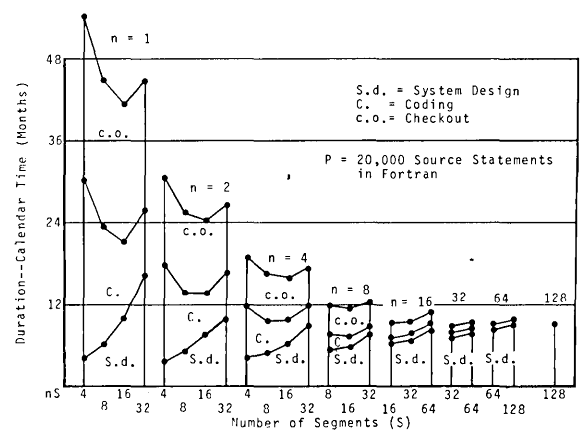



FIGURE 4.22.20a PROJECT DURATION VS. NUMBER OF SEGMENTS WITH DIFFERENT TEAM SIZES n, FOR A 20k-STATEMENT FORTRAN PROGRAM

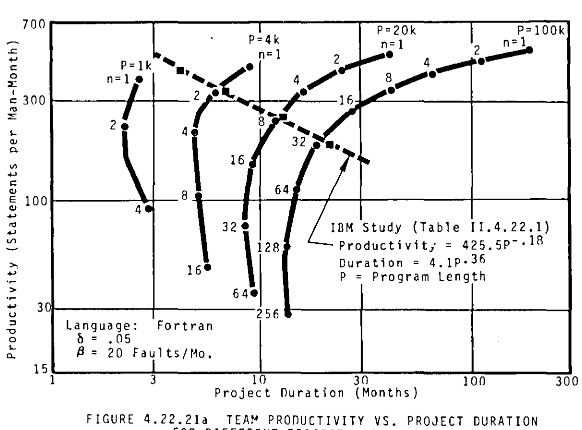



FIGURE 4.22.21a TEAM PRODUCTIVITY VS. PROJECT DURATION FOR DIFFERENT PROJECT TEAM SIZES n

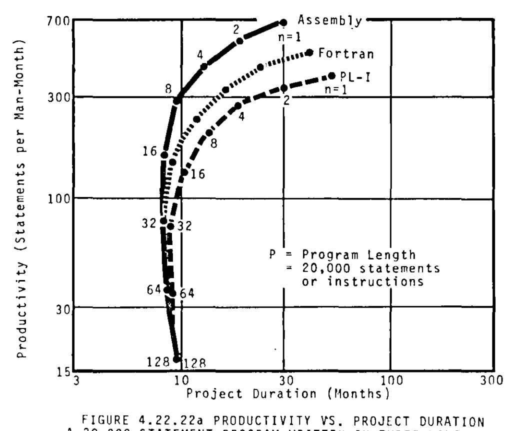



FIGURE 4.22.22a PRODUCTIVITY VS. PROJECT DURATION A 20,000-STATEMENT PROGRAM WRITTEN IN THREE LANGUAGES

complexity and in individual programmers. The model makes it clear that, even if all programs were uniformly complex and all programmers uniformly able, large variations in productivity can come about simply from differences in the way projects are managed. Figure 4.22.21a reminds us that management can trade off productivity and project duration. Figure 4.22.20a reminds us that different module sizes give rise to different productivities. And we have already noted that we will waste resources in checkout (and therefore lower productivity) if bugs are detected too slowly to keep the staff busy correcting them.

4. Improved, detailed models can give us new insight into the development process, and can help us plan and direct the programming effort more efficiently.

## 4.4a Maintenance Costs

### MAINTENANCE PRICES

IBM maintenance prices have continued their upward trend, and the relationship between prices for units of different kinds has remained about the same, as shown in Figures 4.4.1a to 4.4.4a. All-electronic equipment (processors, controllers, memories) still costs the least to maintain, per dollar value of equipment. Magnetic tape units and moving-head files are next, at double the cost of electronic units; and unit record equipment is most expensive, 25% higher than electromechanical memory.

However, the ratio of maintenance to purchase price plotted in the figures is a function of many things—purchase price adjustments, the effect of inflation, and equipment reliability being among the most important. Before we explore these factors let us bring the maintenance cost model up to date.

### A MAINTENANCE COST MODEL

The cost model of DPT&E has been brought up to date to 1978, with the result shown in Figure 4.4.6a. The most notable change in model parameters is the increase in the CE hourly rate—from $5.85 per hour in 1974 to $8.00 per hour in 1978. The dots are again intended to represent the characteristics of a "typical" system. However, I have found no new data reporting actual equipment reliability, and thus the "percent down time" assumption is nothing more than a presumption—see further comments below in connection with Figure 4.4.16a.

**Another Look at Maintenance Prices.** The updated model predicts an increase in maintenance costs, and the analysis of IBM maintenance prices indicates that an increase has in fact occurred since 1974. What more can be said about the increases?

It is helpful to try to separate the effects of inflation from changes which occur because of changes in equipment reliability and maintainability. One way of looking at inflationary effects is to trace the maintenance price history of a number of products—as was done in Figure 2.11.13a to 2.11.16a. For any sample of products, we expect a manufacturer to change his maintenance prices from time to time to reflect changes in equipment reliability/maintainability, and in those costs (like salaries and parts costs) which are independent of reliability. If we examine a big enough sample, we may hope that the reliability effect will balance out—price increases to account for equipment found to be less reliable than anticipated will be offset by price decreases in unexpectedly reliable units—and that the result will measure changes in inflation-affected costs. Figure 4.4.11a shows the result of such an analysis. The solid line shows the US Government's GNP deflator, set so that its value in 1961 was 1.00. Each dotted line shows the price of an IBM unit relative to its price when it was first introduced, with that introductory price taken as equal to the GNP deflator in that year. The IBM System 3/10, for example, was introduced in 1969. At that time the maintenance price for Model A6 was $30 per month. In 1969 the GNP deflator was 1.226 times what it had been in 1961, so we set the System 3/6 relative price at 1.226. By 1971 IBM had raised the maintenance price for the System 3/10-A6 from $30 to $56; and so we plot, for 1971, the value 1.226 x (56/30) = 2.288. A total of 31 different units are included in the analysis, though the most that appear in any one year is 21. Note that only ten of the 32 are plotted—generally those which at some time between 1961 and 1978 represented an extreme high or low.

The dashed line is the average of the various IBM prices, and thus gives some measure of the effect on IBM of inflation. For this small sample, at any rate, it appears that IBM's prices moved up faster than the inflationary forces would lead us to expect between 1963 and 1967, and more slowly between 1967 and 1973. Since 1973, prices have risen at about the same rate as the GNP deflator has risen, but a year or two behind the inflation rise.

Next let's look at the history of processor maintenance prices. Figure 4.4.11b shows maintenance price per $100k vs. purchase price, at or near the year of introduction for third and fourth generation systems. Note the System 3 maintenance prices are much higher than the maintenance prices for the similarly-priced 360's (except for the System 3/10, whose maintenance price was increased not long after its introduction—see Figures 2.11.13a and 4.4.11a). Note also that the 370/1x5 prices generally lie between 360 and System/3 prices, and the 370/138/148 prices are substantially higher than the 370/1x5 prices, while the 370/158/168 prices are substantially lower. Finally, observe the new 303x maintenance prices range between the /155/165 and the /138/148. Note also the peculiar trend of maintenance prices with system size: with the 360, System/3, and 370/138/148, maintenance prices per $100k generally decrease as one moves up towards more powerful models; with the 370/1x5 and 370/158/168, maintenance prices increase with increasing power; and with the 303x, the trend is strangely mixed.

We started this discussion with the remark that it is useful to try to separate the effects of inflation from changes in the inherent reliability and maintainability of equipment. Let's now try to make a judgement about IBM equipment reliability. In Figure 4.4.11c we show the processor data of Figure 4.4.11b plotted against time. Figure 4.4.11c seems to indicate that processor/memory maintenance prices have increased faster than the inflation rate. The lower dashed line, which roughly passes through points representing early maintenance prices for the 1401 and 360 family, doubles in value by 1977. The System 3/10 and the 370/115, 125, 158, 168 all lie close to that line. But the rest of the System 3's and 370's and the new 303x machines, all have far higher maintenance prices than can be explained by inflation—especially so, when we remember that this ratio (of maintenance price to purchase price) should not be affected so much by inflation anyway.

For comparison purposes I've also plotted the maintenance prices for IBM's moving-head files (squares connected by dotted line), along with an inflation curve (dot-dash line) which shows how the 1311's initial maintenance price would grow with inflation. The 2311, 2314, and 3330 all reflected prices growing much too fast to be explained by inflation only; the 3340 and 3350 were more nearly in line with the inflated-1311 curve.

It seems clear that IBM maintenance prices per $100k purchase price have increased much faster than inflationary factors warrant. One reason may be that IBM purchase prices have perhaps not kept up with inflation. We don't know for certain whether that is true, but we do know that the ratio of purchase to rental prices has fallen since 1963, from over 50 to around 35. (see Tables II.2.11.3 and II.2.11.3a). The drop in the ratio can partly be explained by the increase in

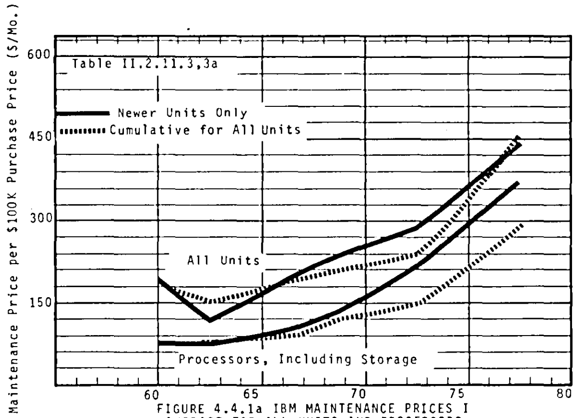



FIGURE 4.4.1a IBM MAINTENANCE PRICES I
AVERAGE FOR ALL UNITS AND PROCESSORS

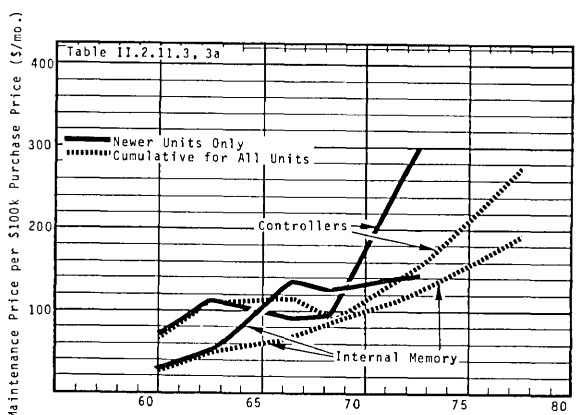



FIGURE 4.4.2a IBM MAINTENANCE PRICES II
INTERNAL MEMORY, AND CONTROLLERS

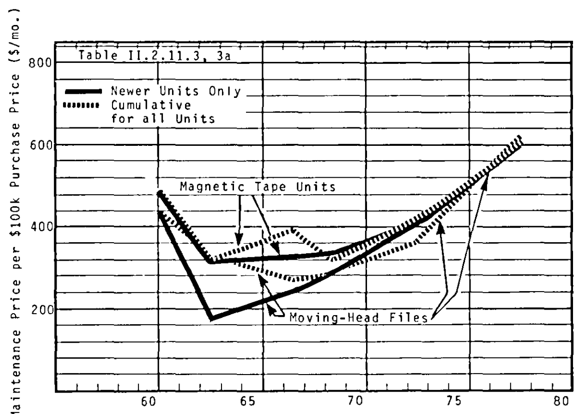



FIGURE 4.4.3a IBM MAINTENANCE PRICES III
MAGNETIC TAPE UNITS, AND MOVING-HEAD FILES

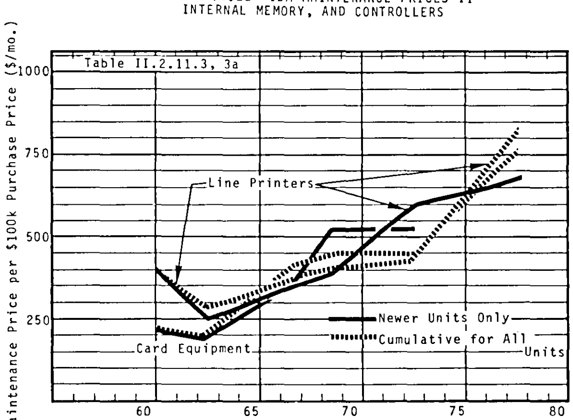



FIGURE 4.4.4a IBM MAINTENANCE PRICES IV
CARD EQUIPMENT, AND LINE PRINTERS

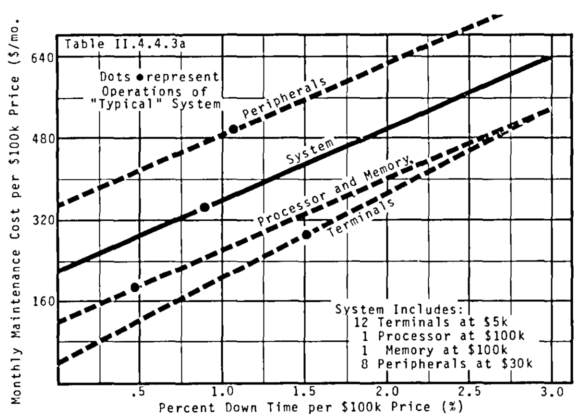



FIGURE 4.4.6a MONTHLY MAINTENANCE COSTS I
THE EFFECT OF MAJOR SYSTEM COMPONENTS

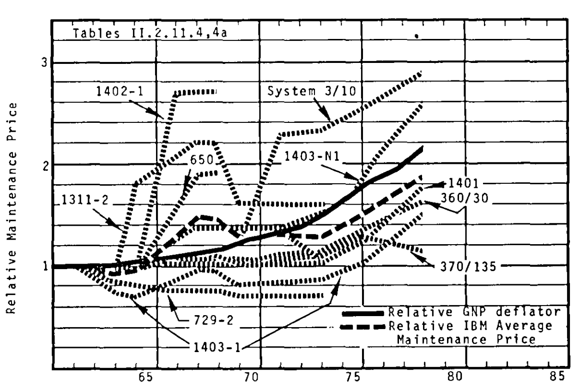



FIGURE 4.4.11a IBM MAINTENANCE PRICES IVa
PRICE CHANGES AND INFLATION

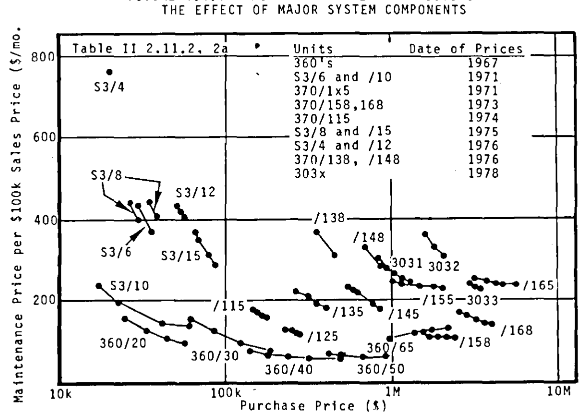



FIGURE 4.4.11b IBM MAINTENANCE PRICES VIc
MAINTENANCE VS. PURCHASE PRICES FOR PROCESSORS

maintenance costs, which have to be covered by the rental price. Another contributor is the increase in interest rates, which increases the cost of financing the lease base, and thus increases rental costs. If these two factors taken together don't account for the large drop in purchase price/rental ratio, it may be that part of the change is caused by a change in the relative profitability of leases and sales.

If we plot the ratio of maintenance price to *rental*, rather than to purchase price, we get a slightly different picture. But the differences aren't enough to change our conclusion that:

a) Processor maintenance prices in general, and especially those for the 370/135-165, 138, 148, 303x, and System/3 have increased much more than can be explained by inflationary factors.

b) Processor maintenance prices in general have increased more rapidly than have moving-head-file maintenance prices. In fact, Figures 4.4.1a to 4.4.4a indicate that processor maintenance prices have also increased faster than magnetic tape unit and line printer prices.

One hypothesis which might explain this data is that processor reliability, or at least that aspect of system reliability charged to the processor (e.g. software problems, and perhaps some "unexplained" problems), has deteriorated in the past 15 years. The trouble is, I have seen no direct statistical evidence about the reliability of IBM (or any other manufacturer's) equipment. So I can only conjecture. One thing seems clear: if IBM equipment reliability has *improved*, then the increasing prices seem to imply either that IBM is increasing its profits on maintenance, or that its maintenance activities are increasingly inefficient.

Turning now to the specific magnetic tape units discussed in DPT&E, we find (Figure 4.4.12a and 4.4.13a) maintenance prices in 1978 higher than they were in 1971 (figures 4.4.12 and 4.4.13, p. 233), but that the relationship between the prices of various devices is almost exactly the same. The only really noticeable change is the very substantial reduction in the purchase price of the System 3/10, shown for reference purposes. The purchase prices of the 3410 and 3420 also dropped modestly, but those of the other tape units and control units actually rose—as did all the maintenance prices.

Finally, we can add the 1978 application of the maintenance model (Figure 4.4.6a) to our chronology of maintenance costs, with the result shown in Figure 4.4.16a. As mentioned earlier, my estimate of down time is arbitrary, for I've seen no statistics which tell whether reliability has increased or decreased over the past years. But labor costs have continued to rise, becoming a larger proportion of total costs (60.1% of total costs in 1978 compared with 52.5% in 1970—from Tables II.4.4.3 and II.4.4.3a—both including overhead) and driving up both the slope and the y-intercept of the cost/down-time line. The average cost predicted by the model would have been even higher, if it weren't for the assumption that one peripheral was replaced by six cheaper-to-maintain terminals.

Those two trends—increasing maintenance labor costs, and increased system value in terminals or other low-cost subsystems at sites remote from the "main" computer—are of course likely to continue during coming years. And system and equipment designers must find how to hold costs down in this changing environment.

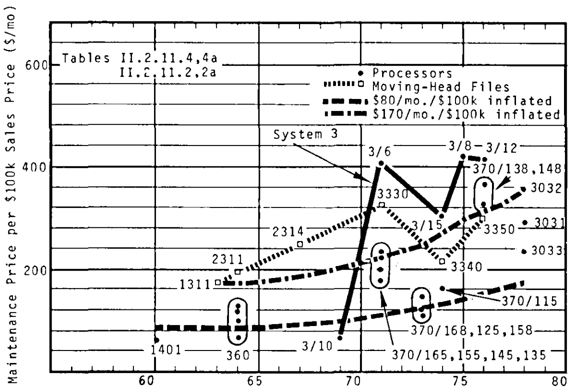



FIGURE 4.4.11c IBM MAINTENANCE PRICES VId
TRENDS IN PROCESSOR AND MOVING-HEAD FILE MAINTENANCE PRICES

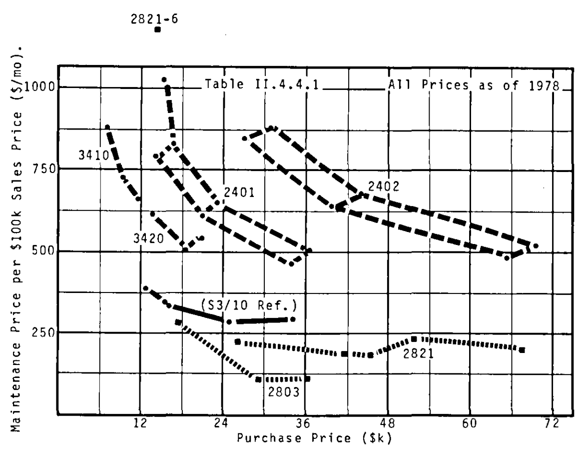



FIGURE 4.4.12a IBM MAINTENANCE PRICES VII
MAINTENANCE VS. PURCHASE PRICE FOR PERIPHERALS

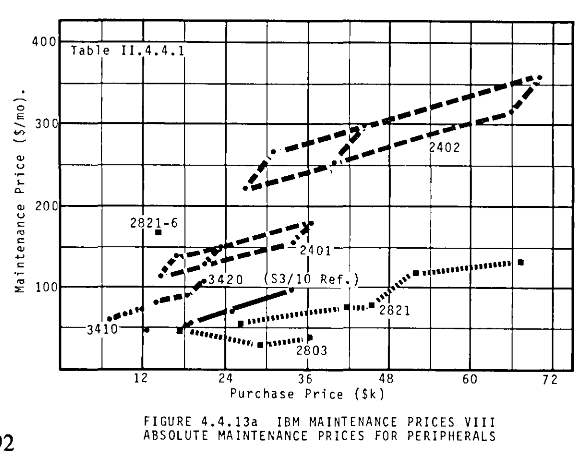



FIGURE 4.4.13a IBM MAINTENANCE PRICES VIII
ABSOLUTE MAINTENANCE PRICES FOR PERIPHERALS

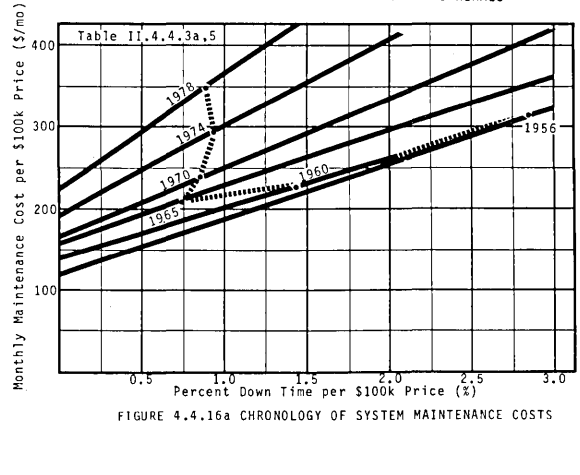



FIGURE 4.4.16a CHRONOLOGY OF SYSTEM MAINTENANCE COSTS

# Supplement

## Part II

## Introduction to Part II.

Generally speaking, this portion of the Supplement updates the tables in DPT&E. Updated tables are marked with a ● opposite the table heading in DPT&E, and have identical numbers here, except for the addition of an "a". Line numbers in updated tables correspond to numbers in the original tables. Thus line 25 in Table II.1.22.1a estimates the number of tape units in use on IBM GP systems, just as does line 25 of Table II.1.22.1. The notes to the tables in DPT&E (pp. 239-512) thus generally apply to the tables here in the Supplement, *and the reader will find notes here only when there have been major revisions or additions to the table.* If there are no notes, one may assume that the sources, definitions, and calculations in the supplementary table are the same as for the original table.

In many cases I have concluded, on the basis of new evidence, that DPT&E estimates could be improved. In each such case, the Supplement table covers a period longer than the 5 years 1974-1978, and should be used *in place of* the DPT&E table for the overlapped period.

### NOTES TO THE TABLES

**TABLE II.1.1.3a Semiconductor Sales**. Source: EIAYrbk.

**TABLE II.1.20a Data Processing Industry–Summary.** 4-4d. This data is from IDC1932.78, for the years 1970-1978. Plug-compatible peripherals (line 4a) is from the *EDP/IR* Annual Review. Since my estimates for line 4 in DPT&E were so low for the period 1970-1974, I revised them upwards for earlier years.

**TABLE II.1.21a Computer System Shipments and Installations.** This is a major revision to Table II.1.21, taking into account: a. A new definition for minisystems, and new categories called Small Business Computers and "Other" systems–see Section 1.21a for definitions and discussion; b. IDC revisions in the number and value of systems in use, including a major revision in GP systems for the years 1967-1972, which reduced the estimated number and value of IBM systems while holding non-IBM systems fixed.

IDC, in the *EDP/IR* Annual Review and Forecast, has provided data on GP, Mini (new definition), SBC and "Other" systems for the period 1973-1978. Earlier figures are my own estimates, based in part on an analysis of earlier *EDP/IR* censuses.

Since some minicomputers are included in SBC products (lines 125m-125x), there is an overlap in those two categories. The overlap is removed in the totals (lines 126-137), which are computed by adding GP, mini, SBC, and "Other" systems, and then subtracting "Minis in SBC's".

**TABLE II.1.22.1a System Components. Magnetic Tape Units.** Recent studies by IDC indicate that about 85% of 360/370 systems had an average 4.7 tape units in 1975-1976 (IDC1740.76). Thus my assumption, in DPT&E, that the fraction of systems having tape was decreasing, is wrong, and this table corrects my error. I have revised the "totals" figures (lines 25, 31-36) to reflect changes in the estimated populations of IBM systems in use–see comment above, in connection with Table II.1.21a.

**Moving Head Files.** Estimates of the 2311, 2314/19, 3330, and 3340 populations for the years 1970-1974 are from a Department of Justice Exhibit in the IBM anti-trust suit. Spindles per system for those years were computed by dividing disk populations by the number of 370 systems in use. The "percent having" and "spindles on these having" figures are my own estimates, and are in part based on data from IDC1728.76. Spindle populations for other years are extrapolations based in part on IDC1728.76 and IDC1740.76. The 3330 and 3350 populations for 1976 and 1978 come from IDCBrief77 and '79. My estimate that non-IBM spindles per system has increased faster than IBM spindles per system is based on a fragment of data in IDC1940.76. Total value in use was computed using the following figures for (value per spindle, value per controller): Second generation ($40k, $32k); 2311 ($25.5k $26k); 3330 SD ($26k, $85k); 3330 DD ($36k, $85k); 3340 ($15k, $10k); 3344/50 ($25k, $65k); 5445 ($15k, $18k).

**Other Equipment.** The card equipment and head-per-track estimates assume no change in units per system. The line printer figures are based on IDC1824.77. From it one can infer that the distribution of line printers on GP systems in Dec. 1976 was roughly: 21% at 100-600 lpm and $17.7k average price; 36% at 600-1000 lpm, $25k price; 41.5% at 1000-3000 lpm, $60k price; and 1.5% over 3000 lpm at $100k price. The COM estimate is based on IDCBrief78.

**Internal Memory.** Average memory sizes were based on data from IDC1675.76. Average prices are incremental prices, computed from data in the *IBM Consultants Manual.*

**Peripherals for Mini- and SBC Systems.** The estimates of moving-head files, magnetic tape units and line printers shown on lines 194-222 are based on very fragmentary data. The only sources worth mentioning are IDC reports (IDC1671.70, 1811.77), but the data they contain is largely based on small samples. I based my estimates on an a analysis of those samples, and on some reasonable-seeming extrapolations.

**TABLE II.1.23a Data Entry Equipment.** IDC has for some years published an annual review and analysis of their statistics on data entry and communications equipment (including terminals), and I adopted their estimates in most cases here, from IDC1905.78 and earlier editions.

**TABLE II.1.24a Communications and Terminals.** The data in the 1977 column for Data Sets is from a Frost & Sullivan Corp. report, as quoted in an article "Datacom Update for 1978", in *Communications News,* December, 1977. Other figures are extrapolations. In the annual IDCBrief, IDC estimates user budgets for communications. Their definition for this item has changed from time to time, but for the past few years, it has included carriage of data only. The data on terminals is based on IDC1905.78.

**TABLE II.1.25a Software and TABLE II.1.26a Service Industries.** IDC has in recent years improved its coverage of the software and service industries, which are periodically reviewed in *EDP/IR*, and are annually covered in IDCBrief. After reviewing a number of reports (IDC1781.77, INPUT-Serv78, IDC1968.79, IDC1980.79), I concluded that my DPT&E estimates needed revision. These tables are the result. They lean heavily on the latter two IDC reports.

**TABLE II.1.27a Supplies. Continuous Forms.** CenCenMan77 for business forms had not been released at the time we went to press, so line 1 is an estimate from ComIndOut. Line 3 assumes line 2 increased slightly since 1972. The distribution of costs between GP systems and mini/SBC systems is based on the number of line printers in each category, from Table II.1.22.1a, and on the unsubstantiated assumption that an average GP printer required ten times as much paper as an average mini/SBC printer.

**Tabulating Cards.** I discovered I had overlooked the Department of Commerce's analysis of Tab card shipments, which appears every five years in CenCenMan under SIC 2645, Die-Cut Paper and Board (specifically, under 26451, 53-59). The 1977 report gives value and tonnage shipped, as shown on lines 11a and 11d. Line 11b here is the same as line 7 of Table II.1.27, and 11c is the sum of 11a and 11b. Card cost on line 6 is computed from lines 11a and 11d for the Census years (1977, 1972, etc.) and is interpolated in between.

**Magnetic Tape.** I have re-estimated magnetic tape sales and prices (line 15, 20-21a) to agree with a recent and authoritative report from ICI (BroeC78). Line 17 is based on the assumptions there were an average of 250 reels per tape unit on GP systems in 1973 (from IDC1554.75), and that between 1/5 and 1/6 of tapes in use are replaced each year. IDC1554.75 also provided data which helped me estimate tape usage on SBC and mini systems.

**Disk Packs.** The principal sources for this data were IDC1740.76, and some private reports. The sources did not agree very well. Generally, IDC tends to show that domestic shipments of a pack cease when the spindle population starts to decline—which seems reasonable. The other sources show a continuing sale of new-production packs. I have resolved the difference (which I cannot satisfactorily explain) in a way which gives results between those of the two sources. The margin of error is large: the sources typically differ by more than a factor of two. The estimates of cartridge sales for mini/SBC systems comes from some private reports, and is also based on the estimates of spindle populations from Table II.1.22.1a.

**Print Ribbons.** A private report more recent than, and I believe, more reliable than the one used in DPT&E estimated that $65M was spent on print ribbons for GP computers in 1974. I adopted that figure, assumed minis and SBC's added another 10% and that ribbon costs per printer are in each year proportional to paper costs.

**TABLE II.1.30a Data Processing Industry Revenues.** Lines 11-44 are from AR. Lines 49-97 were derived from various IDCBrief, especially IDCBrief79, p. B-19. Lines 150-156 come from Table II.1.31.3a.

**TABLE II.1.31.1a System Manufacturers.** The method used in deriving these populations is basically that given on page 296, in the notes to Table II.1.31.1: I derived percentage distributions from *EDP/IR* and *C&A* censuses, and applied those percentages to the revised total populations from Figure II.1.21a. (To conserve space, the percentage figures themselves were omitted from the Supplement.) In computing the percentages, I made use of the adjustment shown on line 43a, which was stated by IDC to be a reduction in the number of systems in use, as shown in the census, *due entirely to a reduction in their estimate of IBM systems in use.* In making this adjustment, I assumed that individual IBM model numbers maintained their relative proportions to the new IBM total.

The SBC and mini populations were similarly calculated, based on an analysis of old GP and mini censuses. However, that census data was incomplete, and I had to extrapolate various populations back to original ship dates.

**TABLE II.1.4.2a Personnel.** 50a-50d. These are the assumptions I used in computing lines 51-56. The systems analysts and programmers per $100k of equipment in use is based on total GP and mini systems (excluding SBC's) in use, and is thus slightly lower in 1974, than the value used in DPT&E. I assumed this ratio has fallen off somewhat during the period 1974-1978, as it fell from 1969 to 1973 (see Table II.1.4.1, line 25 in DPT&E, p. 320). However, this estimate must be regarded with a great deal of suspicion. Between 1974 and 1978 the number of GP systems in use hardly changed, but the average value of a system increased by over 70%. Meanwhile, the number of minis in use almost tripled. We don't have good data, to my knowledge, on the effect an increase in installation size has on programmer staff, nor do we know the average number of programmers per minicomputer. However, the user budget data we do have (see Section II.3.25) suggests that personnel costs have been an increasing proportion of total costs during the years when average GP system size has increased.

The number of computer operators per $100k value in use I held fixed despite the fact that that ratio had been increasing for GP systems (Table II.1.4.1 line 26, p. 320). It would appear that an increase in system size—in peripherals, for example—would require more operators. But on the other hand, minisystems probably make little use of "computer operators"—the systems often are operated by factory personnel or by individuals with other responsibilities.

50e-50h. Dolotta et al estimated the U.S. programmer population at 220,000 in 1975 and predicted it would be only 275,000 in 1980, basing their estimates on 75,000 GP Systems in use in 1975 and 125,000 in 1980 (DoloT76,p.173). Using their ratios of programmers to computers (lines 50e and 50f) and the actual number of computers in use, we see they would predict (line 50g or 50h) a much lower population than the one I have estimated.

**TABLE 2.11.1a System Characteristics.** 3. Word length is bits per access to the highest-speed internal memory. 5-6a. Logic operation is the average time of a branch command. Speeds generally come from AuerCTR or DProEDP. For some systems (DEC PDP-11, IBM Systems/32 and /34), I estimated programmed multiplication times. For some machines, where the manufacturer has not provided data, I estimated speeds—they are marked with an e.

14. I computed Knight's commercial index using the algorithm of Figure II.2.11, pp 358-359, with the following amendments: for total memory words, I used the average of lines 72 and 74; for I/O time I used 50% of CPU time for most computers (for the slower machines I computed I/O time based on what seemed a reasonable assumption about I/O devices).

18a. The memory bit rate is based on the data of lines 3 and 4, rather than 70 and 76. It is this factor which is plotted Figure 2.11.5a.

42a.-42f. Performance is estimated as the product of the ratio, and of the performance of the indicated computer. The ratios come from various sources, including the manufacturers, AuerCTR, DProEDP, IDC (see Table II.2.11.6a), and BellG79.

**TABLE II.2.11.6a Processor Performance Ratios.** The column labeled IDC (Rel) is a set of relative speed ratios published in various issues of International Data Corp.'s *EDP/IR* and *Computerworld.* The first column of Knight indexes was computed by Knight; the second, labeled M.P., was computed by the author (see notes to line 14 of Table

II.2.11.1a). The numbers in the "weighted speed" column were computed from lines 4 and 5 of Table II.2.11.1a, assuming 95% additions and 5% multiplications. For the computers for which add and multiply times are unknown (the entries in parentheses), I computed weighted speed from the IDC factor, using the relationship in Figure 2.11.8b.

**TABLE II.2.14a Data Communications.** The data in these tables was collected in conversations with representatives of AT&T, Pacific Telephone, and Tymnet, Inc. I also made use of Data Pro's Communication Handbooks.

**TABLE II.2.23.3a System Utilization and Response Time.** The entries in this table were derived from the equations of Figure II.2.23a. Here is an example of their use:

Suppose we have a system whose CPU operates at 5M operations per second, and which contains four I/O channels each operating at 200 kbytes/sec. suppose our average job requires the processing of 100,000 bytes, and that k = 1.2. Then

$$s_c = kC'/D' = 1.2\times 5\times 10^6/(800\times 10^3) = 7.5 \text{ operations per byte}$$

$$Y_2 = kD/D' = 1.2\times 10^5/(800\times 10^3) = 0.15 \text{ seconds per job}$$

Now suppose we expect a workload having an average s of 15 operations per byte, and want to know throughput and turnaround time for five levels of multiprogramming. In Table II.2.23.3a, we look for I = 4, J = 5, and $s/s_c = 15/7.5 = 2$, and find

$$W/(1/Y_2) = .427, \text{ and } R/Y_2 = 11.72$$

and therefore W = .427/.15 = 2.8 jobs/sec., and R = 11.72 (.15) = 1.8 sec.

**TABLE 2.23.5a CPU and I/O Activity of Various Systems.** Sources: For 370/155 and "Time-Sharing Systems", *ACM Computing Surveys*, Sept. 1978, pp. 263-279 and 333-342. For MVS, *IBM Systems Journal, 17,* 3, 1978, 290-313. For 370/125 and 370/158, *IBM Systems Journal, 17,* 4, 409-462. For CDC6600, BricR78.

**TABLE 3.0.7a An Estimate of Business Record Activity.** 1-5. The data in lines 1-4 is from CenStatAbs. For 1950 and 1955 I estimated total revenue from corporate revenues only—proprietorship and partnership receipts were not available for those years (corporate receipts were 77.5% of total receipts in 1960.) Line 5 is the quotient of line 4 and line 1, times one million.

6-8. I assume clerical speed has remained constant at about one operation per second. Table II.3.24.1 (p. 462) provides some justification for this figure—most of the "manual operation" coefficients are near unity. The increased use of calculators in recent years has undoubtedly increased that figure somewhat, but more clerical time is spent with files than with calculations. And incremental filing operations like opening drawers and flicking through folders and pulling files are also measured in seconds. I also assume a clerk works 40 hours per week, 50 weeks per year, and actually spends only 25% of his time in clerical duties. Line 6 is thus clerical operations per second times number of clerks times seconds per year clerking. Line 7 is an assumption based on the idea that an office maintained two file drawers per clerical person in 1965, and that the ratio had increased uniformly by a factor of three between 1950 and 1974. Line 8 is computed from lines 7, 6, and 1, assuming each file cabinet held one quarter its maximum capacity of 48 Mbytes (Table II.3.22.2, p. 459).

9-11. Line 9, assumed clerical operations per character, is based on a review of manual operations times in DPT&E. For example, Figure 3.24.5 shows it takes about 10 seconds per card to sort a batch of 1000 cards. If a card is half full of data, it contains 250 bytes (Table II.3.22.1), so the operations per byte are 10/250 = 0.04. Figure 3.22.6 shows it would take about a minute to file or retrieve a letter from a four-drawer file containing 16000 sheets. If the letter contained 1000 bytes, the operations per byte would be 60/1000 = 0.06. Filing-type operations thus require less than 0.25 operations per byte. Calculations, on the other hand, require more. Figures 3.24.1 and 3.24.2 show that the addition and multiplication of two 12-digit numbers take 26 and 446 seconds, respectively. The operands and results contain 36 and 48 bytes, so the operations per byte are 0.72 and 9.3 for addition and multiplication. Line 10 is derived from lines 6 (fDs), line 8 (D) and line 9 (s)—line 6 divided by the product of lines 8 and 9. Line 11 is the product of lines 8 and 10.

12-19. Line 12 is from DPT&E, Table II.2.10, line 101. Line 13 is from Table II.4.4.5, line 6. Line 14 is computed in the obvious way from lines 12 and 13. Line 15 is the sum of lines 22 and 73 of Table II.1.27, and line 16 is derived from lines 15 and 1. Line 17 is an assumption on my part—see discussion in connection with Figure 2.21.7, p. 95. Line 18 is line 14 (fsD) divided by line 16 (D) and then by line 17 (s). Line 19 is the product of lines 16 and 18.

20-24. Line 20 is the sum of lines 6 and 14, and line 21 the sum of lines 8 and 16. Line 22 is the sum of lines 11 and 19. Line 23 is the quotient of lines 22 and 21, and line 24 the quotient of 20 and 22.

**TABLES II.3.11.3a,b. Proprietorships, Partnerships, & Corporations.** Sources: CenStatAb; Bureau of the Census, *County Business Patterns*; Internal Revenue Service, *Tax Returns, Sole Partnerships & Proprietorships*, and *Corporation Income Tax Returns.*

**TABLE II.4.12.2a Characteristics of 54/74 TTL Integrated Circuits.** Data in this table comes from the sources listed in the right-hand column. ISSCC7X is the *Proc. of the 197X IEEE International Solid-State Circuits Conference*; IEEE JSSC is the *IEEE Journal of Solid-State Circuits*; EN is Electronic News. The 6 IC's identified by dates were manufactured by Fairchild, and the data is from private correspondence with Bill Hearndon of that organization.

Bit area is the silicon area occupied by the memory array proper, excluding drivers, amplifiers, registers, etc. In most papers, area per bit was given, and total bit area is the product of the area per bit and number of bits. Devices include transistors, diodes, resistors, and capacitors. S.F. is the *memory* stacking factor, defined as the area of the memory array divided by chip area. The remaining chip area contains supporting circuits, connection pads, interconnecting lines and empty space.

**TABLE II.4.12.4a Components in a Chip of Fixed Cost.** Chip area was computed to hold constant the "Processing Cost" of Figure 4.12.9. The constant cost chosen was the 1971 cost of a chip whose area is 20,150 mils$^2$. The fourth through tenth columns for each year are found by multiplying the area by the stacking factor, and then dividing by the appropriate component or bit areas.

Continued on page 643.

## TABLE II.1.1.1a BACKGROUND DATA, 1900-1974

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **U.S. GNP Current Prices** | 1.1.1 | $B | 1307 | 1397 | 1529 | 1707 | 1890 | 2107 |
| 2. | Deflator | 1.1.1 | | 154.6 | 170.2 | 185.8 | 195.6 | 206.4 | 222 |
| 3. | 1958 Prices | 1.1.1 | $B | 845 | 821 | 823 | 873 | 916 | 951 |
| 4. | 1958 Prices | | $B | 853 | 838 | 831 | 883 | | |
| | **Foreign GNP, 1958 Prices** | | | | | | | | |
| 5. | United Kingdom | 1.1.2 | $B | 103 | 103 | 101 | 102 | | |
| 6. | France | 1.1.2 | $B | 111 | 115 | 114 | 121 | | |
| 7. | West Germany | 1.1.2 | $B | 114 | 115 | 112 | 118 | | |
| 8. | Japan | 1.1.2 | $B | 157 | 156 | 160 | 170 | | |
| 9. | **US Nat'l Income, Curr.Pr.** | | $B | | 1152 | 1247 | 1399 | 1545 | |
| 10. | Manufacturing | 1.1.4 | % | | 25.8 | 25.0 | 26.1 | 26.3 | |
| 11. | Trade | 1.1.4 | % | | 15.2 | 15.7 | 15.8 | 15.2 | |
| 12. | Government | 1.1.4 | % | | 15.7 | 16.0 | 15.4 | 15.0 | |
| 13. | Services | 1.1.4 | % | | 13.0 | 13.5 | 13.5 | 13.7 | |
| 14. | Finance | 1.1.4 | % | | 11.1 | 11.5 | 11.5 | 11.4 | |
| 15. | Agriculture | 1.1.4 | % | | 4.0 | 3.4 | 2.9 | 2.9 | |
| | **Industry Data** | | | | | | | | |
| 16. | Automobile Sales | 1.1.5 | $B | | 21.8 | 23.4 | | | |
| 17. | Electronic Sales | 1.1.5 | $B | 37.46 | 40.36 | 40.58 | 45.07 | 50.81 | |
| 18. | Telephone Revenues | 1.1.5 | $B | | 31.5 | 34.9 | 39.6 | 44.1 | |
| 19. | T.V. Sales | | $B | | 3.201 | 2.492 | 3.388 | 3.811 | |
| 20. | D.P. Equipment Shipments | | $B | 10.172 | 11.990 | 12.235 | 13.264 | 15.986 | 18.820 |
| 21. | U.S. Population | | M | 210.4 | 211.9 | 213.5 | 215.1 | 216.8 | 218.5 |
| | **Per Capita, 1958 Dollars** | | | | | | | | |
| 22. | Automobile Sales | 1.1.6 | $ | | 60.45 | 58.99 | | | |
| 23. | Electronic Sales | 1.1.6 | $ | 115.2 | 111.9 | 102.3 | 107.1 | 113.5 | |
| 24. | Telephone Revenues | 1.1.6 | $ | | 87.34 | 87.98 | 94.12 | 98.55 | |
| | **Percent GNP** | | | | | | | | |
| 25. | Automobile Sales | 1.20.1 | % | | 1.56 | 1.53 | | | |
| 26. | Telephone Revenues | 1.20.1 | % | | 2.25 | 2.28 | 2.32 | 2.33 | |
| 27. | TV Sales | 1.20.1 | % | | .23 | .16 | .20 | .20 | |
| 28. | D.P. Equip. Shipments | 1.20.1 | % | 0.78 | 0.86 | 0.80 | 0.78 | 0.85 | 0.89 |

## TABLE II.1.1.2a BACKGROUND DATA, II.

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | **Foreign GNP, Curr. Pr.** | | | | | | | | |
| 1. | France | 1.1.2 | $B | 250 | 265 | 336 | 347 | 382 | 433 |
| 2. | West Germany | 1.1.2 | $B | 347 | 380 | 419 | 446 | 542 | 672 |
| 3. | Japan | 1.1.2 | $B | 408 | 455 | 491 | 555 | 659 | |
| 4. | United Kingdom | 1.1.2 | $B | 176 | 191 | 229 | 220 | 256 | |
| 4a. | World | | $B | 3850 | 4436 | 4945 | | | |
| | **GNP Per Capita, Curr. Pr.** | | | | | | | | |
| 5. | United States | 1.1.3 | $K | 6.15 | 6.59 | 7.16 | 7.94 | 8.71 | 9.64 |
| 6. | France | 1.1.3 | $K | 4.79 | 5.05 | 6.36 | 6.55 | 7.20 | |
| 7. | West Germany | 1.1.3 | $K | 5.60 | 6.14 | 6.77 | 7.25 | 8.83 | |
| 8. | Japan | 1.1.3 | $K | 3.75 | 4.13 | 4.40 | 4.94 | 5.79 | |
| 9. | United Kingdom | 1.1.3 | $K | 3.15 | 3.41 | 4.09 | 3.94 | 4.58 | |
| 10. | **Electronics Industry Sales** | 1.1.5 | $B | 37.46 | 40.36 | 40.58 | 45.07 | 50.81 | |
| 11. | Consumer Products | | $B | 6.93 | 6.27 | 4.96 | 6.92 | 8.12 | |
| 11a. | Percent | 1.1.7 | % | 18.5 | 15.5 | 12.2 | 15.4 | 16.0 | |
| 12. | Commun./Industrial Prod. | | $B | 18.81 | 22.08 | 22.74 | 24.72 | 28.20 | |
| 12a. | Percent | 1.1.7 | % | 50.2 | 54.7 | 56.0 | 54.8 | 55.5 | |
| 13. | Government Products | | $B | 10.80 | 11.05 | 12.09 | 12.45 | 13.40 | |
| 13a. | Percent | 1.1.7 | % | 28.8 | 27.4 | 29.8 | 27.6 | 26.4 | |
| 14. | Replacement Components | | $B | .92 | .96 | .79 | .98 | 1.09 | |
| 14a. | Percent | 1.1.7 | % | 2.5 | 2.4 | 2.0 | 2.2 | 2.1 | |
| 15. | **Component Sales—Total** | 1.1.8 | $B | 7.803 | 7.852 | 6.482 | 8.302 | 9.307 | |
| 16. | Vacuum Tubes | 1.1.8 | % | 17 | 15 | 17 | 15 | 14 | |
| 17. | Semiconductors | 1.1.8 | % | 18 | 13 | 19 | 17 | 15 | |
| 18. | Monolithic IC's | 1.1.8 | % | 22 | 27 | 23 | 30 | 30 | |
| 19. | Passive Components | 1.1.8 | % | 19 | 20 | 20 | 18 | 19 | |
| 20. | Other Components | 1.1.8 | % | 24 | 24 | 21 | 21 | 23 | |
| | **Solid State Shipments** | | | | | | | | |
| 21. | U.S. Dept. Comm.—Total | | $M | 3125 | 3646 | 3002 | 3843 | | |
| 22. | Transistors | | $M | 557 | 543 | 405 | 420 | | |
| 23. | Diodes/Rectifiers | | $M | | 509 | 431 | 431 | | |
| 24. | Other | | $M | 844 | 472 | 454 | 527 | | |
| 25. | IC's | | $M | 1724 | 2122 | 1712 | 2464 | | |
| 26. | Digital Bipolar | | $M | 828 | 993 | 577 | 835 | | |
| 27. | Digital MOS | | $M | 415 | 487 | 652 | 979 | | |
| 28. | Linear | | $M | 226 | 264 | 234 | 346 | | |
| 29. | Hybrid | | $M | 255 | 378 | 249 | 305 | | |
| 30. | Av. Price—DTL | | $ | 0.504 | 0.545 | 0.874 | 0.886 | | |
| 31. | TTL | | $ | 0.718 | 0.726 | 0.643 | 0.636 | | |
| 32. | CML/ECL | | $ | 2.067 | 2.150 | 2.003 | 2.810 | | |
| 33. | MOS | | $ | 1.26 | | | | | |
| 34. | Linear | | $ | 0.958 | 0.850 | 0.888 | 0.856 | | |
| 35. | SIA—Total | | $M | 2756 | 3204 | 2612 | 3434 | 3857 | |
| 36. | Transistors | | $M | 634 | 668 | 522 | 621 | 631 | |
| 37. | Diodes/Rectifiers | | $M | 391 | 438 | 329 | 390 | 394 | |
| 38. | Other | | $M | 311 | 331 | 303 | 390 | 369 | |
| 39. | IC's | | $M | 1421 | 1767 | 1458 | 2032 | 2464 | |
| 40. | Digital Bipolar | | $M | 689 | 767 | 515 | 661 | 766 | |
| 41. | Digital MOS | | $M | 437 | 645 | 643 | 941 | 1136 | |
| 42. | Linear | | $M | 294 | 356 | 300 | 431 | 561 | |

## TABLE II.1.1.3a SEMICONDUCTOR SALES

| Item | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Total Sales | $M | 408 | 560 | 570 | 593 | 603 | 699 | 840 | 1079 | 1038 | 1112 | 1327 | 1215 | 1083 | 1369 | 2756 | 3204 | 2612 | 3434 | 3857 | |
| 2. Transistors | $M | 222 | 301 | 300 | 291 | 305 | 336 | 404 | 476 | 403 | 379 | 419.6 | 352.2 | 303.2 | 358.5 | 634 | 668 | 522 | 621 | 631 | |
| 3. Diodes/Rect | $M | 172 | 231 | 219 | 234 | 232 | 281 | 338 | 428 | 384 | 383 | 438.1 | 377.7 | 278.6 | 314.3 | 391 | 438 | 329 | 390 | 395 | |
| 4. Other | $M | 14 | 28 | 46 | 58 | 46 | 41 | 19 | 27 | 23 | 38 | 47 | 39 | 41 | 76 | 311 | 331 | 303 | 390 | 369 | |
| 5. IC's—Total | $M | | | 5 | 10 | 20 | 41 | 79 | 148 | 228 | 312 | 422.3 | 446.5 | 459.9 | 620.2 | 1421 | 1767 | 1458 | 2032 | 2464 | |
| 6. Digital—Total | $M | | | | | | 35 | 65 | 118 | 182 | 252 | 346.5 | 362.1 | 363.7 | 487.2 | 1126 | 1412 | 1158 | 1602 | 1902 | |
| 7. Bipolar | $M | | | | | | | | | | | | 299.4 | 257.5 | 324.6 | 689 | 767 | 515 | 661 | 766 | |
| 8. MOS | $M | | | | | | | | | | | | 62.7 | 106.2 | 162.6 | 437 | 645 | 643 | 941 | 1136 | |
| 9. Linear | $M | | | | | | 6 | 14 | 31 | 46 | 60 | 75.8 | 84.4 | 96.2 | 133.0 | 294 | 356 | 300 | 431 | 561 | |
| Percent Distribution | | | | | | | | | | | | | | | | | | | | | |
| 10. Transistors | % | 54.4 | 53.8 | 52.6 | 49.1 | 50.6 | 48.1 | 48.1 | 44.1 | 38.8 | 34.1 | 31.7 | 29.0 | 28.0 | 26.2 | 23.0 | 20.8 | 20.0 | 18.1 | 16.4 | |
| 11. Diodes/Rect | % | 42.2 | 41.3 | 38.4 | 39.5 | 38.5 | 40.2 | 40.2 | 39.7 | 37.0 | 34.4 | 33.0 | 31.1 | 25.8 | 22.9 | 14.2 | 13.7 | 12.6 | 11.4 | 10.2 | |
| 12. Other | % | 3.4 | 4.0 | 8.1 | 9.8 | 7.6 | 5.9 | 2.3 | 2.5 | 2.2 | 3.4 | 3.5 | 3.2 | 3.8 | 5.6 | 11.3 | 10.3 | 11.6 | 11.4 | 9.6 | |
| 13. Total IC | % | | | 0.9 | 1.7 | 3.3 | 5.9 | 9.4 | 13.7 | 22.0 | 28.1 | 31.8 | 36.7 | 42.5 | 45.3 | 51.6 | 55.1 | 55.8 | 59.2 | 63.9 | |
| 14. Digital IC | % | | | | | | 5.0 | 7.7 | 10.9 | 17.5 | 22.7 | 26.1 | 29.8 | 33.5 | 35.6 | 40.9 | 44.1 | 44.3 | 46.7 | 49.3 | |
| 15. Bipolar | % | | | | | | | | | | | | 24.6 | 23.8 | 23.7 | 25.0 | 23.9 | 19.7 | 19.2 | 19.9 | |
| 16. MOS | % | | | | | | | | | | | | 5.2 | 9.8 | 11.9 | 15.9 | 20.1 | 24.6 | 27.4 | 29.5 | |
| 17. Linear IC | % | | | | | | 0.9 | 1.7 | 2.9 | 4.4 | 5.4 | 5.7 | 6.9 | 8.9 | 9.7 | 10.7 | 11.1 | 11.5 | 12.6 | 14.5 | |

## TABLE II.1.20a DATA PROCESSING INDUSTRY—SUMMARY

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Domestic Rev. & Shipments** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | Shipments, GP, U.S. | | $B | .475 | .560 | .850 | 1.060 | 1.220 | 1.570 | 1.910 | 2.600 | 3.600 | 4.150 | 4.150 | 3.600 | 3.910 | 5.000 | 5.400 | 6.200 | 5.610 | 5.530 | 6.600 | 7.400 |
| 2. | Mini, U.S. | | $B | | | | | | | .015 | .030 | .050 | .063 | .151 | .172 | .176 | .323 | .370 | .630 | .735 | 1.025 | 1.550 | 1.990 |
| 2a. | SBC, U.S. | | $B | | | | | | | | | | | | .003 | .008 | .024 | .045 | .150 | .300 | .580 | .840 | 1.105 |
| 2b. | Other, U.S. | | $B | .020 | .030 | .030 | .030 | .080 | .100 | .135 | .100 | .080 | .122 | .126 | .109 | .123 | .120 | .160 | .140 | .085 | .059 | .020 | 0 |
| 2c. | Minis in SBC, U.S. | | $B | | | | | | | | | | | | | | .007 | .015 | .039 | .067 | .115 | .097 | .182 |
| 3. | Total Systems, U.S. | 1.20.3 | $B | .495 | .590 | .880 | 1.090 | 1.300 | 1.670 | 2.060 | 2.730 | 3.730 | 4.335 | 4.430 | 3.880 | 4.217 | 5.460 | 5.960 | 7.100 | 6.663 | 7.079 | 8.913 | 10.313 |
| 4. | Independent Peripherals—Tot. | | $B | .075 | .115 | .132 | .170 | .205 | .265 | .300 | .330 | .425 | .605 | .760 | 1.046 | 1.383 | 1.809 | 2.466 | 3.184 | 3.335 | 4.010 | 4.580 | 5.615 |
| 4a. | Plug-Compatible | | $B | | | | | | | | .015 | .025 | .050 | .110 | .280 | .370 | .410 | .574 | .735 | .500 | .650 | .525 | .700 |
| 4b. | Other Peripherals | | $B | .075 | .115 | .132 | .170 | .205 | .265 | .300 | .315 | .400 | .555 | .650 | .766 | 1.013 | 1.399 | 1.892 | 2.449 | 2.835 | 3.360 | 4.055 | 4.915 |
| 4c. | OEM Revenues | | $B | | | | | | | | | | | | .563 | .655 | .725 | 1.003 | 1.298 | 1.451 | 1.720 | 2.075 | 2.470 |
| 4d. | End User Revenues | | $B | | | | | | | | | | | | .203 | .358 | .674 | .889 | 1.151 | 1.384 | 1.640 | 1.980 | 2.445 |
| 5. | Total Hardware, U.S. | | $B | .570 | .705 | 1.012 | 1.260 | 1.505 | 1.935 | 2.360 | 3.060 | 4.155 | 4.940 | 5.190 | 4.926 | 5.600 | 7.269 | 8.426 | 10.284 | 9.998 | 11.089 | 13.493 | 15.928 |
| 6. | Services—Batch, On-Line, etc. | | $B | .090 | .125 | .180 | .220 | .265 | .297 | .360 | .440 | .560 | .770 | 1.030 | 1.385 | 1.670 | 2.010 | 2.495 | 3.020 | 3.530 | 4.080 | 4.760 | 5.575 |
| 7. | Software | | $B | | | | | .005 | .020 | .050 | .100 | .175 | .270 | .340 | .375 | .415 | .470 | .605 | .830 | 1.090 | 1.375 | 1.730 | 2.110 |
| 8. | Total Services | | $B | .090 | .125 | .180 | .220 | .270 | .317 | .410 | .540 | .735 | 1.040 | 1.370 | 1.760 | 2.085 | 2.480 | 3.100 | 3.850 | 4.620 | 5.455 | 6.490 | 7.685 |
| 9. | Data Communications | | $B | | .001 | .005 | .012 | .018 | .029 | .046 | .069 | .111 | .175 | .261 | .369 | .531 | .668 | .804 | .931 | 1.048 | 1.190 | 1.424 | 1.675 |
| 10. | Supplies | | $B | .067 | .109 | .163 | .213 | .300 | .373 | .457 | .530 | .638 | .707 | .822 | .872 | .888 | .980 | 1.170 | 1.470 | 1.536 | 1.589 | 1.782 | 1.970 |
| 11. | Grand Total | 1.20.2 | $B | .727 | .940 | 1.360 | 1.705 | 2.093 | 2.654 | 3.273 | 4.199 | 5.639 | 6.862 | 7.643 | 7.927 | 9.104 | 11.397 | 13.500 | 16.535 | 17.202 | 19.323 | 23.189 | 27.258 |
| | Percent Of Total Shipments | | | | | | | | | | | | | | | | | | | | | | |
| 12. | GP Systems | 1.20.5 | % | 65.3 | 59.6 | 62.5 | 62.2 | 58.3 | 59.2 | 58.4 | 61.9 | 63.8 | 60.5 | 54.3 | 45.4 | 42.9 | 43.9 | 40.0 | 37.5 | 32.6 | 28.6 | 28.5 | 27.1 |
| 13. | Minisystems | 1.20.5 | % | | | | | | | 0.5 | 0.7 | 0.9 | 0.9 | 2.0 | 2.2 | 1.9 | 2.8 | 2.6 | 3.6 | 3.9 | 4.7 | 6.3 | 6.6 |
| 13a. | SBC's | | % | | | | | | | | | | | | 0.0 | 0.1 | 0.2 | 0.3 | 0.9 | 1.7 | 3.0 | 3.6 | 4.1 |
| 13b. | Other | | % | 2.8 | 3.2 | 2.2 | 1.8 | 3.8 | 3.8 | 4.1 | 2.4 | 1.4 | 1.8 | 1.6 | 1.4 | 1.4 | 1.1 | 1.2 | 0.8 | 0.5 | 0.3 | 0.1 | 0.0 |
| 14. | Systems | | % | 68.1 | 62.8 | 64.7 | 63.9 | 62.1 | 62.9 | 62.9 | 65.0 | 66.1 | 63.2 | 58.0 | 48.9 | 46.3 | 47.9 | 44.1 | 42.9 | 38.7 | 36.6 | 38.4 | 37.8 |
| 15. | Independent Peripherals | 1.20.5 | % | 10.3 | 12.2 | 9.7 | 10.0 | 9.8 | 10.0 | 9.2 | 7.9 | 7.5 | 8.8 | 9.9 | 13.2 | 15.2 | 15.9 | 18.3 | 19.3 | 19.4 | 20.8 | 19.8 | 20.6 |
| 15a. | Plug-Compatible | 1.20.5 | % | | | | | | | | 0.4 | 0.4 | 0.7 | 1.4 | 3.5 | 4.1 | 3.6 | 4.3 | 4.4 | 2.9 | 3.4 | 2.3 | 2.6 |

## TABLE II.1.20a DATA PROCESSING INDUSTRY SUMMARY

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15b. | Other Peripherals | | % | 10.3 | 12.2 | 9.7 | 10.0 | 9.8 | 10.0 | 9.2 | 7.5 | 7.1 | 8.1 | 8.5 | 9.7 | 11.1 | 12.3 | 14.0 | 14.8 | 16.5 | 17.4 | 17.5 | 18.0 |
| 16. | All Hardware | 1.20.4 | % | 78.4 | 75.0 | 74.4 | 73.9 | 71.9 | 72.9 | 72.1 | 72.9 | 73.7 | 72.0 | 67.9 | 62.1 | 61.5 | 63.8 | 62.4 | 62.2 | 58.1 | 57.4 | 58.2 | 58.4 |
| 17. | Services–Batch, On-Line | 1.20.6 | % | 12.4 | 13.3 | 13.2 | 12.9 | 12.7 | 11.2 | 11.0 | 10.5 | 9.9 | 11.2 | 13.5 | 17.5 | 18.3 | 17.6 | 18.5 | 18.3 | 20.5 | 21.1 | 20.5 | 20.5 |
| 18. | Software | 1.20.6 | % | | | | | 0.2 | 0.8 | 1.5 | 2.4 | 3.1 | 3.9 | 4.4 | 4.7 | 4.6 | 4.1 | 4.5 | 5.0 | 6.3 | 7.1 | 7.5 | 7.7 |
| 19. | Total Services | 1.20.4 | % | 12.4 | 13.3 | 13.2 | 12.9 | 12.9 | 11.9 | 12.5 | 12.9 | 13.0 | 15.2 | 17.9 | 22.2 | 22.9 | 21.8 | 23.0 | 23.3 | 26.9 | 28.2 | 28.0 | 28.2 |
| 20. | Data Communications | 1.20.4 | % | | 0.1 | 0.4 | 0.7 | 0.9 | 1.1 | 1.4 | 1.6 | 2.0 | 2.6 | 3.4 | 4.7 | 5.8 | 5.9 | 6.0 | 5.6 | 6.1 | 6.2 | 6.1 | 6.1 |
| 21. | Supplies | 1.20.4 | % | 9.2 | 11.6 | 12.0 | 12.5 | 14.3 | 14.1 | 14.0 | 12.6 | 11.3 | 10.3 | 10.8 | 11.0 | 9.8 | 8.6 | 8.7 | 8.9 | 8.9 | 8.2 | 7.7 | 7.2 |
| | **WW Business by US Firms** | | | | | | | | | | | | | | | | | | | | | | |
| 22. | Shipments, GP, WW | | $B | .580 | .690 | 1.050 | 1.370 | 1.710 | 2.320 | 3.070 | 3.700 | 5.200 | 6.250 | 6.650 | 6.800 | 7.210 | 8.500 | 9.350 | 10.700 | 10.610 | 10.830 | 12.500 | 14.300 |
| 23. | Mini, WW | | $B | | | | | | | .015 | .032 | .056 | .075 | .170 | .209 | .214 | .419 | .570 | .940 | 1.185 | 1.600 | 2.315 | 3.065 |
| 23a. | SBC, WW | | $B | | | | | | | | | | | | .004 | .009 | .028 | .059 | .200 | .400 | .880 | 1.280 | 1.725 |
| 23b. | Other, WW | | $B | .020 | .030 | .030 | .038 | .092 | .127 | .165 | .130 | .120 | .167 | .187 | .160 | .182 | .166 | .213 | .203 | .131 | .109 | .040 | 0 |
| 23c. | Minis in SBC, WW | | $B | | | | | | | | | | | | | | .007 | .020 | .053 | .091 | .155 | .149 | .270 |
| 24. | Total Systems, WW | 1.20.3 | $B | .600 | .720 | 1.080 | 1.408 | 1.802 | 2.447 | 3.250 | 3.862 | 5.376 | 6.492 | 7.007 | 7.173 | 7.615 | 9.106 | 10.172 | 11.990 | 12.235 | 13.264 | 15.986 | 18.820 |
| 25. | Other Peripherals | | $B | .075 | .115 | .132 | .170 | ..205 | .265 | .300 | .330 | .425 | .605 | .760 | 1.046 | 1 383 | 1.809 | 2.466 | 3.184 | 3.335 | 4.010 | 4.580 | 5.615 |
| 26. | Total Hardware, WW | | $B | .675 | .835 | 1.212 | 1.578 | 2.007 | 2.712 | 3.550 | 4.192 | 5.801 | 7.097 | 7.767 | 8.219 | .998 | 10.915 | 12.638 | 15.174 | 15.570 | 17.274 | 20.566 | 24.435 |
| 27. | Total Services (U.S.) | | $B | .090 | .125 | .180 | .220 | .270 | .317 | .410 | .540 | .735 | 1.040 | 1.370 | 1.760 | 2.085 | 2.480 | 3.100 | 3.850 | 4.620 | 5.455 | 6.490 | 7.685 |
| 28. | Data Communications (U.S.) | | $B | | .001 | .005 | .012 | .018 | .029 | .046 | .069 | .111 | .175 | .261 | .369 | .531 | .668 | .804 | .931 | 1.048 | 1.190 | 1.424 | 1.675 |
| 29. | Supplies–WW | | $B | .067 | .109 | .163 | .214 | .301 | .374 | .458 | .533 | .645 | .727 | .850 | .916 | .936 | 1.019 | 1.213 | 1.526 | 1.645 | 1.727 | 1.938 | 2.125 |
| 30. | Grand Total | 1.20.2 | $B | .832 | 1.070 | 1.560 | 2.024 | 2.596 | 3.432 | 4.464 | 5.334 | 7.292 | 9.039 | 10.248 | 11.264 | 12.550 | 15.082 | 17.755 | 21.481 | 22.883 | 25.646 | 30.418 | 35.920 |
| 31. | U.S. Syst. Shipped, % WW | 1.20.3 | % | 82.5 | 81.9 | 81.5 | 77.4 | 72.1 | 68.2 | 63.4 | 70.7 | 69.4 | 66.8 | 63.2 | 54.9 | 55.4 | 60.0 | 58.6 | 59.2 | 54.5 | 53.4 | 55.8 | 54.8 |
| | **Equipment Val. in Use (US)** | | | | | | | | | | | | | | | | | | | | | | |
| 32. | GP Systems | | $B | 1.340 | 1.865 | 2.605 | 3.485 | 4.550 | 6.000 | 7.800 | 9.400 | 12.400 | 15.700 | 19.100 | 21.400 | 23.300 | 24.700 | 27.300 | 30.200 | 33.800 | 37.900 | 42.900 | 48.700 |
| 33. | Peripherals & Controllers | 1.22.1 | $B | .532 | .835 | 1.163 | 1.482 | 2.060 | 3.079 | 4.140 | 5.435 | 6.376 | 7.572 | 8.663 | 9.607 | 10.739 | 12.052 | 13.914 | 15.007 | 15.370 | 15.839 | 16.471 | 17.741 |
| 34. | Internal Memory | 1.22.1 | $B | .259 | .400 | .548 | .626 | 1.018 | 1.450 | 1.749 | 2.074 | 2.748 | 3.657 | 4.130 | 4.719 | 5.137 | 5.741 | 5.832 | 5.805 | 5.960 | 6.623 | 6.666 | 7.185 |
| 35. | Terminals | 1.22.1 | $B | | | | .040 | .055 | .080 | .140 | .230 | .410 | .630 | .900 | 1.220 | 1.400 | 1.760 | 2.500 | 3.335 | 4.600 | 5.750 | 7.600 | 9.150 |
| 36. | OCR/MICR Equipment | | $B | | | .010 | .030 | .050 | .070 | .110 | .150 | .215 | .308 | .410 | .490 | .570 | 0.650 | 0.720 | 0.825 | 0.868 | 0.895 | 1.050 | 1.325 |
| 37. | Processors | 1.22.1 | $B | .549 | .630 | .884 | 1.307 | 1.367 | 1.321 | 1.661 | 1.511 | 2.651 | 3.533 | 4.997 | 5.364 | 5.454 | 4.497 | 4.334 | 5.228 | 7.002 | 8.793 | 11.113 | 13.299 |
| 38. | Minisystems | | $B | | | | | | | .015 | .045 | .095 | .158 | .309 | .481 | .654 | .970 | 1.325 | 1.900 | 2.535 | 3.410 | 4.770 | 6.515 |
| 38a. | SBC Systems | | $B | | | | | | | | | | | | .003 | .011 | .035 | .080 | .230 | .530 | 1.110 | 1.950 | 2.990 |
| 38b. | Other Systems | | $B | .045 | .075 | .105 | .135 | .210 | .298 | .412 | .510 | .587 | .707 | .775 | .800 | .850 | .880 | .937 | 1.037 | 1.072 | 1.074 | 1.024 | .943 |
| 38c. | Minis in SBC | | $B | | | | | | | | | | | | | | .007 | .022 | .061 | .128 | .243 | .340 | .522 |
| 38d. | Terminals on Mini/SBC | | $B | | | | | | | | | | | | | .150 | .180 | .300 | .430 | .525 | .841 | .941 | 1.678 |
| 39. | Data Entry Keyboard Systems | | $B | .067 | .095 | .136 | .179 | .258 | .374 | .483 | .637 | .811 | .975 | 1.193 | 1.445 | 1.775 | 2.045 | 2.365 | 2.489 | 2.461 | 2.515 | 2.515 | 2.454 |
| 40. | Total Hardware in Use | 1.20.8 | $B | 1.452 | 2.035 | 2.846 | 3.799 | 5.018 | 6.672 | 8.710 | 10.592 | 13.893 | 17.540 | 21.377 | 24.129 | 26.590 | 28.623 | 31.985 | 35.795 | 40.270 | 45.766 | 52.819 | 61.080 |
| | Percent of GP Systems | | | | | | | | | | | | | | | | | | | | | | |
| 41. | Processors | 1.22.2 | % | 41.0 | 33.8 | 33.9 | 37.5 | 30.0 | 22.0 | 21.3 | 16.1 | 21.4 | 22.5 | 26.2 | 25.1 | 23.4 | 18.2 | 15.9 | 17.3 | 20.7 | 23.2 | 25.9 | 27.3 |
| 42. | Internal Memory | 1.22.2 | % | 19.3 | 21.4 | 21.0 | 18.0 | 22.4 | 24.2 | 22.4 | 22.1 | 22.2 | 23.3 | 21.6 | 22.1 | 22.0 | 23.2 | 21.4 | 19.2 | 17.6 | 17.5 | 15.5 | 14.8 |
| 43. | Peripherals & Controllers | 1.22.2 | % | 39.7 | 44.8 | 44.6 | 42.5 | 45.3 | 51.3 | 53.1 | 57.8 | 51.4 | 48.2 | 45.4 | 44.9 | 46.1 | 48.8 | 51.0 | 49.7 | 45.5 | 41.8 | 38.4 | 36.4 |
| 44. | Terminals | 1.22.2 | % | | | | 1.1 | 1.2 | 1.3 | 1.8 | 2.4 | 3.3 | 4.0 | 4.7 | 5.7 | 6.0 | 7.1 | 9.2 | 11.0 | 13.6 | 15.2 | 17.7 | 18.8 |
| 45. | OCR/MICR Equipment | | % | | | 0.4 | 0.9 | 1.1 | 1.2 | 1.4 | 1.6 | 1.7 | 2.0 | 2.1 | 2.3 | 2.4 | 2.6 | 2.6 | 2.7 | 2.6 | 2.4 | 2.4 | 2.7 |
| | Percent of Total Hardware | | | | | | | | | | | | | | | | | | | | | | |
| 46. | GP Systems | 1.20.8 | % | 92.3 | 91.6 | 91.5 | 91.7 | 90.7 | 89.9 | 89.6 | 88.7 | 89.3 | 89.5 | 89.3 | 88.7 | 87.6 | 86.3 | 85.4 | 84.4 | 83.9 | 82.8 | 81.2 | 79.7 |
| 47. | Mini Systems | 1.20.8 | % | | | | | | | 0.2 | 0.4 | 0.7 | 0.9 | 1.4 | 2.0 | 2.5 | 3.4 | 4.1 | 5.1 | 6.0 | 6.9 | 8.4 | 9.8 |
| 47a. | SBC System | | % | | | | | | | | | | | | 0.0 | 0.0 | 0.1 | 0.3 | 0.6 | 1.3 | 2.4 | 3.7 | 4.9 |
| 47b. | Other System | | % | 3.1 | 3.7 | 3.7 | 3.6 | 4.2 | 4.5 | 4.7 | 4.8 | 4.2 | 4.0 | 3.6 | 3.3 | 3.2 | 3.1 | 2.9 | 2.9 | 2.7 | 2.3 | 1.9 | 1.5 |
| 48. | Data Entry–Total | | % | 4.6 | 4.7 | 5.2 | 5.5 | 6.1 | 6.6 | 6.8 | 7.4 | 7.3 | 7.4 | 7.5 | 8.0 | 8.8 | 9.4 | 9.7 | 9.3 | 8.3 | 7.5 | 6.8 | 6.2 |
| 49. | Keyboard Systems | 1.20.8 | % | 4.6 | 4.7 | 4.8 | 4.7 | 5.1 | 5.6 | 5.5 | 6.0 | 5.8 | 5.6 | 5.6 | 6.0 | 6.7 | 7.1 | 7.4 | 7.0 | 6.1 | 5.5 | 4.8 | 4.0 |
| 50. | OCR/MICR Equipment | | % | | | 0.4 | 0.8 | 1.0 | 1.0 | 1.3 | 1.4 | 1.5 | 1.8 | 1.9 | 2.0 | 2.1 | 2.3 | 2.3 | 2.3 | 2.2 | 2.0 | 2.0 | 2.2 |
| | Percent of GP Systems in Use | | | | | | | | | | | | | | | | | | | | | | |
| 51. | Services–Batch, On-Line | 1.20.7 | % | 6.7 | 6.7 | 6.9 | 6.3 | 5.8 | 5.0 | 4.6 | 4.7 | 4.5 | 4.9 | 5.4 | 6.5 | 7.2 | 8.1 | 9.1 | 10.0 | 10.4 | 10.8 | 11.1 | 11.4 |

## TABLE II.1.20a DATA PROCESSING INDUSTRY SUMMARY

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52. | Software | 1.20.7 | % | | | | | 0.1 | 0.3 | 0.6 | 1.1 | 1.4 | 1.7 | 1.8 | 1.8 | 1.8 | 1.9 | 2.2 | 2.7 | 3.2 | 3.6 | 4.0 | 4.3 |
| 53. | Total Services | | % | 6.7 | 6.7 | 6.9 | 6.3 | 5.9 | 5.3 | 5.3 | 5.7 | 5.9 | 6.6 | 7.2 | 8.2 | 8.9 | 10.0 | 11.4 | 12.7 | 13.7 | 14.4 | 15.1 | 15.8 |
| 54. | Data Communications | 1.20.7 | % | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.9 | 1.1 | 1.4 | 1.7 | 2.3 | 2.7 | 2.9 | 3.1 | 3.1 | 3.1 | 3.3 | 3.4 |
| 55. | Supplies | 1.20.7 | % | 5.0 | 5.8 | 6.3 | 6.1 | 6.6 | 6.2 | 5.9 | 5.6 | 5.1 | 4.5 | 4.3 | 4.1 | 3.8 | 4.0 | 4.3 | 4.9 | 4.1 | 4.2 | 4.2 | 4.0 |

## TABLE II.1.21a COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Data Base** | | | | | | | | | | | | | | | | | | | | | | |
| 102. | GP–WW–No. Shipped | | k | 1.455 | 1.910 | 2.920 | 4.020 | 5.200 | 7.200 | 8.500 | 10.200 | 15.700 | 13.000 | 11.000 | 12.000 | 14.300 | 18.300 | 21.900 | 16.000 | 13.800 | 14.800 | 17.800 | 10.600 |
| 103. | GP–WW–No. in Use | | k | 3.800 | 5.500 | 7.750 | 10.500 | 15.200 | 21.900 | 29.600 | 39.100 | 48.000 | 59.000 | 66.800 | 74.700 | 84.200 | 94.200 | 106.00 | 111.30 | 115.40 | 112.50 | 112.80 | 113.20 |
| 104. | GP–WW–Value Shipped | | $B | .580 | .690 | 1.050 | 1.370 | 1.710 | 2.320 | 3.070 | 3.700 | 5.200 | 6.250 | 6.650 | 6.800 | 7.210 | 8.500 | 9.350 | 10.700 | 10.610 | 10.830 | 12.500 | 14.300 |
| 105. | GP–WW–Value in Use | | $B | 1.550 | 2.195 | 3.105 | 4.255 | 5.730 | 7.800 | 10.650 | 13.100 | 17.600 | 22.600 | 29.200 | 34.600 | 39.500 | 43.500 | 48.700 | 54.200 | 61.300 | 68.600 | 77.800 | 88.900 |
| 106. | GP–US–No. Shipped | 1.21.3 | k | 1.150 | 1.500 | 2.300 | 3.100 | 3.800 | 5.100 | 5.300 | 6.000 | 10.000 | 7.400 | 6.000 | 5.700 | 7.600 | 10.700 | 13.900 | 8.600 | 6.700 | 7.200 | 8.900 | 4.600 |
| 107. | GP–US–No. in Use | 1.21.1 | k | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 27.100 | 31.000 | 37.000 | 40.000 | 41.900 | 45.000 | 50.200 | 58.300 | 61.500 | 62.100 | 59.600 | 58.200 | 58.000 |
| 108. | GP–US–Value Shipped | 1.21.4 | $B | .475 | .560 | .850 | 1.060 | 1.220 | 1.570 | 1.910 | 2.600 | 3.600 | 4.150 | 4.150 | 3.600 | 3.910 | 5.000 | 5.400 | 6.200 | 5.610 | 5.530 | 6.600 | 7.400 |
| 109. | GP–US–Value in Use | 1.21.2 | $B | 1.340 | 1.865 | 2.605 | 3.485 | 4.550 | 6.000 | 7.800 | 9.400 | 12.400 | 15.700 | 19.100 | 21.400 | 23.300 | 24.700 | 27.300 | 30.200 | 33.800 | 37.900 | 42.900 | 48.700 |
| 110. | GP–Int'l.–No. Shipped | | k | .305 | .410 | .620 | .920 | 1.400 | 2.100 | 3.200 | 4.200 | 5.700 | 5.600 | 5.000 | 6.300 | 6.700 | 7.600 | 8.000 | 7.400 | 7.100 | 7.600 | 8.900 | 6.000 |
| 111. | GP–Int'l.–No. in Use | | k | .690 | 1.100 | 1.600 | 2.400 | 3.500 | 5.200 | 8.000 | 12.000 | 17.000 | 22.000 | 26.800 | 32.800 | 39.200 | 44.000 | 47.700 | 49.800 | 53.300 | 52.900 | 54.600 | 55.200 |
| 112. | GP–Int'l.–Value Shipped | | $B | .105 | .130 | .200 | .310 | .490 | .750 | 1.160 | 1.500 | 2.000 | 2.100 | 2.500 | 3.200 | 3.300 | 3.500 | 3.950 | 4.500 | 5.000 | 5.300 | 5.900 | 6.900 |
| 113. | GP–Int'l.–Value in Use | | $B | .210 | .330 | .500 | .770 | 1.180 | 1.800 | 2.850 | 4.100 | 6.000 | 7.700 | 10.100 | 13.200 | 16.200 | 18.800 | 21.400 | 24.000 | 27.500 | 30.700 | 34.900 | 40.200 |
| 113a. | Others WW No. Shipped | | k | .250 | .300 | .400 | .450 | .500 | .750 | .900 | .800 | .900 | 1.050 | 1.100 | 1.200 | 1.600 | 2.100 | 3.350 | 2.900 | 2.000 | 1.700 | .600 | 0 |
| 113b. | Others WW No. in Use | | k | .700 | 1.000 | 1.400 | 1.850 | 2.250 | 2.900 | 3.600 | 4.350 | 5.205 | 6.200 | 7.000 | 7.300 | 7.800 | 9.400 | 12.240 | 14.590 | 15.940 | 16.890 | 16.550 | 15.300 |
| 113c. | Others WW Value Shipped | | $B | .020 | .030 | .030 | .038 | .092 | .127 | .165 | .130 | .120 | .167 | .187 | .160 | .182 | .166 | .213 | .203 | .131 | .109 | .040 | 0 |
| 113d. | Others WW Value in Use | | $B | .045 | .075 | .105 | .143 | .230 | .345 | .489 | .605 | .712 | .872 | .970 | 1.015 | 1.095 | 1.150 | 1.241 | 1.389 | 1.455 | 1.493 | 1.444 | 1.331 |
| 113e. | Others U.S. No. Shipped | | k | .250 | .300 | .400 | .400 | .400 | .500 | .600 | .500 | .450 | .550 | .700 | .900 | 1.200 | 1.700 | 2.900 | 2.000 | 1.300 | .900 | .300 | 0 |
| 113f. | Others U.S. No. in Use | | k | .700 | 1.000 | 1.400 | 1.800 | 2.100 | 2.500 | 2.900 | 3.370 | 3.790 | 4.300 | 4.900 | 5.100 | 5.400 | 6.800 | 9.440 | 11.040 | 11.840 | 12.140 | 11.700 | 10.800 |
| 113g. | Others U.S. Value Ship. | | $B | .020 | .030 | .030 | .030 | .080 | .100 | .135 | .100 | .080 | .122 | .126 | .109 | .123 | .120 | .160 | .140 | .085 | .059 | .020 | 0 |
| 113h. | Others U.S. Value in Use | | $B | .045 | .075 | .105 | .135 | .210 | .298 | .412 | .510 | .587 | .707 | .775 | .800 | .850 | .880 | .937 | 1.037 | 1.072 | 1.074 | 1.024 | .943 |
| 113i. | Others Int.l No. Ship. | | k | | | | .050 | .100 | .250 | .300 | .300 | .450 | .500 | .400 | .300 | .400 | .400 | .450 | .900 | .700 | .800 | .300 | 0 |
| 113j. | Others Int.l No. in Use | | k | | | | .050 | .150 | .400 | .700 | .980 | 1.415 | 1.900 | 2.100 | 2.200 | 2.400 | 2.600 | 2.800 | 3.550 | 4.100 | 4.750 | 4.850 | 4.500 |
| 113k. | Others Int.l Value Ship. | | $B | | | | .008 | .012 | .027 | .030 | .030 | .040 | .045 | .061 | .051 | .059 | .046 | .053 | .063 | .046 | .050 | .020 | 0 |
| 113l. | Others Int.l Value in Use | | $B | | | | .008 | .020 | .047 | .077 | .095 | .125 | .165 | .195 | .215 | .245 | .270 | .304 | .352 | .383 | .419 | .420 | .388 |
| 114. | Mini–WW–No. Shipped | | k | | | | | | | .200 | 1.200 | 2.100 | 2.700 | 7.300 | 10.800 | 11.200 | 23.000 | 31.100 | 46.600 | 48.600 | 58.400 | 82.000 | 100.00 |
| 115. | Mini–WW–No. in Use | | k | | | | | | | .200 | 1.400 | 3.500 | 6.200 | 13.500 | 24.300 | 35.500 | 58.500 | 89.600 | 135.30 | 181.40 | 235.30 | 311.20 | 402.30 |
| 116. | Mini–WW–Value Shipped | | $B | | | | | | | .015 | .032 | .056 | .075 | .170 | .209 | .214 | .419 | .570 | .940 | 1.185 | 1.600 | 2.315 | 3.065 |
| 117. | Mini–WW–Value in Use | | $B | | | | | | | .015 | .047 | .103 | .178 | .348 | .557 | .771 | 1.190 | 1.760 | 2.670 | 3.775 | 5.235 | 7.360 | 10.175 |
| 118. | Mini–US–No. Shipped | 1.21.3 | k | | | | | | | .200 | 1.000 | 1.800 | 2.200 | 6.300 | 8.600 | 8.800 | 17.000 | 21.100 | 33.900 | 34.500 | 42.000 | 60.000 | 71.000 |
| 119. | Mini–US–No. in Use | 1.21.1 | k | | | | | | | .200 | 1.200 | 3.000 | 5.200 | 11.500 | 20.000 | 28.500 | 45.000 | 65.100 | 96.100 | 126.30 | 162.30 | 214.50 | 275.30 |
| 120. | Mini–US–Value Shipped | 1.21.4 | $B | | | | | | | .015 | .030 | .050 | .063 | .151 | .172 | .176 | .323 | .370 | .630 | .735 | 1.025 | 1.550 | 1.990 |
| 121. | Mini–US–Value in Use | 1.21.2 | $B | | | | | | | .015 | .045 | .095 | .158 | .309 | .481 | .654 | .970 | 1.325 | 1.900 | 2.535 | 3.410 | 4.770 | 6.515 |
| 122. | Mini–Int'l.–No. Shipped | | k | | | | | | | | .200 | .300 | .500 | 1.000 | 2.200 | 2.400 | 6.000 | 10.000 | 12.700 | 14.100 | 16.400 | 22.000 | 29.000 |
| 123. | Mini–Int'l.–No. in Use | | k | | | | | | | | .200 | .500 | 1.000 | 2.000 | 4.300 | 7.000 | 13.500 | 24.500 | 39.200 | 55.100 | 73.000 | 96.700 | 127.00 |
| 124. | Mini–Int'l.–Value Shipped | | $B | | | | | | | | .002 | .006 | .012 | .019 | .037 | .038 | .096 | .200 | .310 | .450 | .575 | .765 | 1.075 |
| 125. | Mini–Int'l.–Value in Use | | $B | | | | | | | | .002 | .008 | .020 | .039 | .076 | .117 | .220 | .435 | .770 | 1.240 | 1.825 | 2.590 | 3.660 |
| 125a. | SBC WW No. Shipped | | k | | | | | | | | | | | | .100 | .230 | .600 | 1.120 | 4.150 | 10.600 | 22.400 | 32.500 | 40.100 |
| 125b. | SBC WW No. In Use | | k | | | | | | | | | | | | .100 | .330 | .930 | 2.050 | 6.200 | 16.800 | 39.200 | 71.700 | 110.30 |
| 125c. | SBC WW Value Shipped | | $B | | | | | | | | | | | | .004 | .009 | .028 | .059 | .200 | .400 | .880 | 1.280 | 1.725 |
| 125d. | SBC WW Value in Use | | $B | | | | | | | | | | | | .004 | .013 | .041 | .100 | .300 | .700 | 1.580 | 2.860 | 4.520 |

## TABLE II.1.21a COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125e. | SBC U.S. No. Shipped | | k | | | | | | | | | | | | .080 | .180 | .470 | .770 | 3.000 | 7.900 | 14.800 | 21.600 | 25.500 |
| 125f. | SBC U.S. No. in Use | | k | | | | | | | | | | | | .080 | .260 | .730 | 1.500 | 4.500 | 12.400 | 27.200 | 48.800 | 72.800 |
| 125g. | SBC U.S. Value Shipped | | $B | | | | | | | | | | | | .003 | .008 | .024 | .045 | .150 | .300 | .580 | .840 | 1.105 |
| 125h. | SBC U.S. Value in Use | | $B | | | | | | | | | | | | .003 | .011 | .035 | .080 | .230 | .530 | 1.110 | 1.950 | 2.990 |
| 125i. | SBC Intl. No. Shipped | | k | | | | | | | | | | | | .020 | .050 | .130 | .350 | 1.150 | 2.700 | 7.600 | 10.900 | 14.600 |
| 125j. | SBC Intl. No. in Use | | k | | | | | | | | | | | | .020 | .070 | .200 | .550 | 1.700 | 4.400 | 12.000 | 22.900 | 37.500 |
| 125k. | SBC Intl. Value Shipped | | $B | | | | | | | | | | | | .001 | .001 | .004 | .014 | .050 | .100 | .300 | .440 | .620 |
| 125l. | SBC Intl. Value in Use | | $B | | | | | | | | | | | | .001 | .002 | .006 | .020 | .070 | .170 | .470 | .910 | 1.530 |
| 125m. | Minis in SBC WW No. Ship. | | k | | | | | | | | | | | | | | .200 | .700 | 1.800 | 3.100 | 5.260 | 4.430 | 6.290 |
| 125n. | Minis in SBC WW No. in Use | | k | | | | | | | | | | | | | | .200 | .900 | 2.700 | 5.800 | 11.060 | 15.490 | 21.780 |
| 125o. | Minis in SBC WW Value Ship. | | $B | | | | | | | | | | | | | | .007 | .020 | .053 | .091 | .155 | .149 | .270 |
| 125p. | Minis in SBC WW Value in Use. | | $B | | | | | | | | | | | | | | .007 | .027 | .080 | .171 | .326 | .475 | .745 |
| 125q. | Minis in SBC U.S. No. Ship. | | k | | | | | | | | | | | | | | .200 | .500 | 1.200 | 2.100 | 3.660 | 3.220 | 4.560 |
| 125r. | Minis in SBC U.S. No. in Use | | k | | | | | | | | | | | | | | .200 | .700 | 1.900 | 4.000 | 7.660 | 10.880 | 15.440 |
| 125s. | Minis in SBC U.S. Value Shp. | | $B | | | | | | | | | | | | | | .007 | .015 | .039 | .067 | .115 | .097 | .182 |
| 125t. | Minis in SBC U.S.Value in Use | | $B | | | | | | | | | | | | | | .007 | .022 | .061 | .128 | .243 | .340 | .522 |
| 125u. | Minis in SBC Intl. No. Ship. | | k | | | | | | | | | | | | | | | .200 | .600 | 1.000 | 1.600 | 1.210 | 1.730 |
| 125v. | Minis in SBC Intl. No. in Use | | k | | | | | | | | | | | | | | | .200 | .800 | 1.800 | 3.400 | 4.610 | 6.340 |
| 125w. | Minis in SBC Intl.Value Ship. | | $B | | | | | | | | | | | | | | | .005 | .014 | .024 | .040 | .052 | .088 |
| 125x. | Minis in SBC Intl. Val. in Use | | $B | | | | | | | | | | | | | | | .005 | .019 | .043 | .083 | .135 | .223 |
| 126. | Total–US–No. Shipped | 1.21.3 | k | 1.400 | 1.800 | 2.700 | 3.500 | 4.200 | 5.600 | 6.100 | 7.500 | 12.250 | 10.150 | 13.000 | 15.280 | 17.780 | 29.670 | 38.170 | 46.300 | 48.300 | 61.240 | 87.580 | 96.540 |
| 127. | Total–US–No. in Use | 1.21.1 | k | 3.810 | 5.400 | 7.550 | 9.900 | 13.800 | 19.200 | 24.700 | 31.670 | 37.790 | 46.500 | 56.400 | 67.080 | 79.160 | 102.53 | 133.64 | 171.24 | 208.64 | 253.58 | 322.32 | 401.46 |
| 128. | Total–US–Value Shipped | 1.21.4 | $B | .495 | .590 | .880 | 1.090 | 1.300 | 1.670 | 2.060 | 2.730 | 3.730 | 4.335 | 4.430 | 3.880 | 4.217 | 5.460 | 5.960 | 7.100 | 6.663 | 7.079 | 8.913 | 10.313 |
| 129. | Total–US–Value in Use | 1.21.2 | $B | 1.385 | 1.940 | 2.710 | 3.620 | 4.760 | 6.298 | 8.227 | 9.955 | 13.082 | 16.565 | 20.184 | 22.684 | 24.815 | 26.578 | 29.620 | 33.306 | 37.809 | 43.251 | 50.304 | 58.626 |
| 130. | Total–Int'l.–No. Shipped | | k | .305 | .410 | .620 | .970 | 1.500 | 2.350 | 3.500 | 4.709 | 6.450 | 6.600 | 6.400 | 8.820 | 9.550 | 14.130 | 18.600 | 21.550 | 23.600 | 30.800 | 40.890 | 47.870 |
| 131. | Total–Int'l.–No. in Use | | k | .690 | 1.100 | 1.600 | 2.450 | 3.650 | 5.600 | 8.700 | 13.180 | 18.915 | 24.900 | 30.900 | 39.320 | 48.670 | 60.300 | 75.350 | 93.450 | 115.10 | 139.25 | 174.44 | 217.86 |
| 132. | Total–Int'l.–Value Shipped | | $B | .150 | .130 | .200 | .318 | .502 | .780 | 1.190 | 1.132 | 2.046 | 2.157 | 2.577 | 3.289 | 3.398 | 3.646 | 4.212 | 4.900 | 5.572 | 6.185 | 7.073 | 8.507 |
| 133. | Total–Int'l.–Value in Use | | $B | .210 | .330 | .500 | .778 | 1.200 | 1.847 | 2.927 | 4.197 | 6.133 | 7.885 | 10.334 | 13.491 | 16.564 | 19.296 | 22.154 | 25.173 | 29.250 | 33.720 | 38.700 | 45.555 |
| 134. | Total–WW–No. Shipped | | k | 1.705 | 2.210 | 3.320 | 4.470 | 5.700 | 7.950 | 9.600 | 12.209 | 18.700 | 16.750 | 19.400 | 24.100 | 27.330 | 44.000 | 57.470 | 67.850 | 71.900 | 92.040 | 128.47 | 144.41 |
| 135. | Total–WW–No. in Use | | k | 4.500 | 6.500 | 9.150 | 12.350 | 17.450 | 24.800 | 33.400 | 44.850 | 56.705 | 71.400 | 87.300 | 106.40 | 127.83 | 163.03 | 208.99 | 264.69 | 323.74 | 392.83 | 496.76 | 619.32 |
| 136. | Total–WW–Value Shipped | | $B | .600 | .720 | 1.080 | 1.408 | 1.802 | 2.447 | 3.250 | 3.862 | 5.376 | 6.492 | 7.007 | 7.169 | 7.606 | 9.085 | 10.133 | 12.000 | 12.250 | 13.300 | 16.000 | 18.800 |
| 137. | Total–WW–Value in Use | | $B | 1.595 | 2.270 | 3.210 | 4.398 | 5.960 | 8.145 | 11.154 | 13.752 | 18.415 | 23.650 | 30.518 | 36.172 | 41.366 | 45.840 | 51.774 | 58.479 | 67.059 | 76.582 | 88.989 | 104.18 |
| | **Averages** | | | | | | | | | | | | | | | | | | | | | | |
| 138. | GP–US–Av. Val. Shipped | 1.21.5 | $k | 413.0 | 373.3 | 369.6 | 341.9 | 321.1 | 307.8 | 360.4 | 433.3 | 360.0 | 560.8 | 691.7 | 631.6 | 514.5 | 467.2 | 388.5 | 720.9 | 837.3 | 768.1 | 741.6 | 1609 |
| 139. | GP–US–Av. Val. in Use | 1.21.5 | $k | 430.8 | 423.9 | 423.6 | 430.2 | 388.9 | 359.3 | 361.1 | 346.9 | 400.0 | 424.3 | 477.5 | 510.7 | 517.8 | 492.0 | 468.3 | 491.0 | 544.3 | 635.9 | 737.1 | 839.7 |
| 140. | Mini–US–Av. Val. Shipped | 1.21.5 | $k | | | | | | | | 30.0 | 27.8 | 28.6 | 24.0 | 20.0 | 20.0 | 19.0 | 17.5 | 18.6 | 21.3 | 24.4 | 25.8 | 28.0 |
| 141. | Mini–US–Av. Val. in Use | 1.21.5 | $k | | | | | | | | 37.5 | 31.7 | 30.4 | 26.9 | 24.1 | 22.9 | 21.6 | 20.4 | 19.8 | 20.1 | 21.0 | 22.2 | 23.7 |
| 142. | GP–Int'l.–Av. Value Shipped | | $k | 344.3 | 317.1 | 322.6 | 337.0 | 350.0 | 357.1 | 362.5 | 357.1 | 350.9 | 357.1 | 500.0 | 507.9 | 492.5 | 460.5 | 493.8 | 608.1 | 704.2 | 697.4 | 662.9 | 1150.0 |
| 143. | GP–Int'l.–Av. Val. in Use | | $k | 304.3 | 300.0 | 312.5 | 320.8 | 337.1 | 346.2 | 356.3 | 341.7 | 352.9 | 350.0 | 376.9 | 479.3 | 413.3 | 427.3 | 448.6 | 481.9 | 515.9 | 580.3 | 639.2 | 736.3 |
| 144. | Mini–Int'l–Av. Value Shipped | | $k | | | | | | | | | | 24.0 | 19.0 | 16.8 | 15.8 | 16.0 | 20.0 | 24.4 | 31.9 | 35.1 | 34.8 | 37.0 |
| 145. | Mini–Int'l–Av. Val. in Use | | $k | | | | | | | | | | 20.0 | 19.6 | 17.7 | 16.7 | 16.3 | 17.8 | 19.6 | 22.5 | 25.0 | 26.8 | 28.8 |
| 145a. | SBC–U.S.–Av. Val. Shipped | | $k | | | | | | | | | | | | | 44.4 | 51.1 | 58.4 | 50.0 | 38.0 | 39.2 | 38.9 | 43.3 |
| 145b. | SBC–U.S.–Av. Val. in Use | | $k | | | | | | | | | | | | | 42.3 | 47.9 | 53.3 | 51.1 | 42.7 | 40.8 | 40.0 | 41.1 |
| 145c. | SBC Intl–Av. Val. Shipped | | $k | | | | | | | | | | | | | | 30.8 | 40.0 | 43.4 | 37.0 | 39.5 | 40.4 | 42.5 |
| 145d. | SBC Intl–Av. Val. In Use | | $k | | | | | | | | | | | | | | 30.0 | 36.4 | 41.2 | 38.6 | 39.2 | 39.7 | 40.8 |
| 146. | GP–US–Rtrns, of Ship'ts. | 1.21.7 | % | 7.4 | 6.3 | 12.9 | 17.0 | 12.7 | 7.6 | 5.8 | 38.5 | 16.7 | 20.5 | 18.1 | 36.1 | 51.4 | 72.0 | 51.9 | 53.2 | 35.8 | 25.9 | 24.2 | 21.6 |
| | **GP System Life, U.S.** | | | | | | | | | | | | | | | | | | | | | | |
| 233. | Tot. Value Shipped to Date | | $B | 1.431 | 1.991 | 2.841 | 3.901 | 5.121 | 6.691 | 8.601 | 11.201 | 14.801 | 18.951 | 23.101 | 26.701 | 30.611 | 35.611 | 41.011 | 47.211 | 52.821 | 58.351 | 64.951 | 72.351 |
| 233a. | Tot. Value in Use to Date | | $B | 3.520 | 5.385 | 7.990 | 11.475 | 16.025 | 22.025 | 29.825 | 39.225 | 51.625 | 67.325 | 86.425 | 107.83 | 131.13 | 155.83 | 183.13 | 213.33 | 247.13 | 285.03 | 327.93 | 376.63 |
| 234. | Tot. Retirements to Date | | $B | .091 | .126 | .236 | .416 | .571 | .691 | .801 | 1.801 | 2.401 | 3.251 | 4.001 | 5.301 | 7.311 | 10.911 | 13.711 | 17.011 | 19.021 | 20.451 | 22.051 | 23.651 |
| | Average Life | | | | | | | | | | | | | | | | | | | | | | |

## TABLE II.1.21a COMPUTER SYSTEM SHIPMENTS AND INSTALLATIONS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 235. | Syst. Shipped to Date | 1.21.7 | yrs. | 2.46 | 2.70 | 2.81 | 2.94 | 3.13 | 3.29 | 3.47 | 3.50 | 3.49 | 3.55 | 3.74 | 4.04 | 4.28 | 4.38 | 4.47 | 4.52 | 4.68 | 4.88 | 5.05 | 5.21 |
| 236. | Syst. Retired This Year | 1.21.7 | yrs. | 5.6 | 6.0 | 5.7 | 5.7 | 6.0 | 6.7 | 7.4 | 6.3 | 6.5 | 6.6 | 6.9 | 6.9 | 6.7 | 6.1 | 6.3 | 6.5 | 7.0 | 7.6 | 8.3 | 8.8 |
| | **Commerical CPU Models** | | | | | | | | | | | | | | | | | | | | | | |
| 237. | GP Comp.–Intro. This Yr. | 1.21.8 | | 9 | 13 | 14 | 10 | 12 | 20 | 18 | 14 | 14 | 9 | 16 | 12 | 25 | 18 | 12 | 19 | 12 | 15 | 17 | 19 |
| 238. | Cumulative Total Introd. | | | 9 | 22 | 36 | 46 | 58 | 78 | 96 | 110 | 124 | 133 | 149 | 161 | 186 | 204 | 216 | 235 | 247 | 262 | 279 | 298 |
| 239. | Minis–Intro. This Yr. | 1.21.8 | | | | | | | 2 | 4 | 8 | 3 | 6 | 18 | 29 | 15 | 18 | 10 | 12 | 15 | 29 | 14 | |
| 240. | Cumulative Total Introduced | | | | | | | | 2 | 6 | 14 | 17 | 23 | 41 | 70 | 85 | 103 | 113 | 125 | 140 | 169 | 183 | |
| 240a | SBC–Intro. This Yr. | | | | 3 | 6 | 10 | 8 | 11 | 26 | 43 | 39 | | | 3 | 6 | 10 | 8 | 11 | 26 | 43 | 39 | |
| 240b. | Cumulative Total Introd. | | | | 3 | 9 | 19 | 27 | 38 | 64 | 107 | 146 | | | 3 | 9 | 19 | 27 | 38 | 64 | 107 | 146 | |
| 241. | Total–Intro. This Year | 1.21.8 | | 9 | 13 | 14 | 10 | 12 | 22 | 22 | 22 | 17 | 15 | 34 | 44 | 46 | 46 | 30 | 42 | 53 | 87 | 70 | |
| 242. | Cumulative Tot. Introduced | | | 9 | 22 | 36 | 46 | 58 | 80 | 102 | 124 | 141 | 156 | 190 | 234 | 280 | 326 | 356 | 398 | 451 | 538 | 608 | |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GP Systems in Use–US** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | IBM–Total | | k | 2.545 | 3.520 | 4.860 | 6.545 | 8.890 | 11.690 | 14.170 | 18.031 | 19.930 | 22.900 | 25.317 | 26.771 | 28.479 | 32.305 | 38.333 | 40.490 | 41.133 | 40.107 | 39.882 | 38.808 |
| 3. | Second Generation | | k | .003 | .880 | 2.510 | 4.725 | 7.720 | 10.940 | 13.090 | 13.330 | 9.977 | 6.896 | 4.646 | 3.297 | 2.916 | 2.384 | 2.079 | 1.676 | 1.397 | 1.107 | .894 | .829 |
| 4. | 360/370 | | k | | | | | | | .625 | 3.881 | 8.125 | 13.110 | 17.687 | 19.412 | 18.335 | 17.831 | 16.362 | 16.500 | 15.785 | 14.965 | 15.568 | 16.539 |
| 5. | System 3 & 1130 | | k | | | | | | | | .517 | 1.625 | 2.724 | 2.935 | 4.035 | 7.214 | 12.084 | 19.887 | 22.310 | 23.948 | 24.036 | 23.420 | 21.990 |
| 6. | Non-IBM | | k | .565 | .880 | 1.290 | 1.555 | 2.810 | 5.010 | 7.430 | 9.069 | 11.070 | 14.100 | 14.683 | 15.129 | 16.521 | 17.895 | 19.967 | 21.010 | 20.967 | 19.493 | 18.318 | 19.152 |
| 7. | Total | | k | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 27.100 | 31.000 | 37.000 | 40.000 | 41.900 | 45.000 | 50.200 | 58.300 | 61.500 | 62.100 | 59.600 | 58.200 | 57.960 |
| | **Magnetic Tape Units (MTU)** | | | | | | | | | | | | | | | | | | | | | | |
| 9. | IBM 2nd Gen.–% Having Tapes | | % | | | | | | | | | | | | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 10. | Tapes on Those Having | | | | | | | | | | | | | | 4.7 | 4.6 | 4.6 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| 11. | No. Per System | | | | | | | | | | | | | | 1.88 | 1.84 | 1.84 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 |
| 12. | 360/370–% Having Tapes | | % | | | | | | | | | | | | 60 | 67 | 73 | 78 | 82 | 85 | 87 | 88 | 89 |
| 13. | Tapes on Those Having | | | | | | | | | | | | | | 4.4 | 4.4 | 4.5 | 4.6 | 4.6 | 4.7 | 4.7 | 4.7 | 4.8 |
| 14. | No. Per System | | | | | | | | | | | | | | 2.64 | 2.95 | 3.29 | 3.59 | 3.77 | 4.00 | 4.09 | 4.14 | 4.27 |
| 15. | S3 & 1130–No. Per System | | | | | | | | | | | | | | | | .05 | .09 | .10 | .11 | .11 | .12 | .12 |
| 16. | Non-IBM–% Having Tapes | | % | | | | | | | | | | | | 52 | 55 | 60 | 64 | 67 | 69 | 70 | 71 | 71 |
| 17. | Tapes on Those Having | | | | | | | | | | | | | | 4.6 | 4.5 | 4.5 | 4.4 | 4.3 | 4.2 | 4.2 | 4.2 | 4.2 |
| 18. | No. Per System | | | | | | | | | | | | | | 2.39 | 2.48 | 2.70 | 2.82 | 2.88 | 2.90 | 2.94 | 2.98 | 2.98 |
| | Magnetic Tape Units in Use | | | | | | | | | | | | | | | | | | | | | | |
| 20. | IBM–2nd Generation | | k | | | | | | | | | | | | 6.198 | 5.365 | 4.387 | 3.742 | 3.016 | 2.520 | 1.993 | 1.610 | 1.492 |
| 21. | 360/70 | | k | | | | | | | | | | | | 51.248 | 54.052 | 58.575 | 58.707 | 62.238 | 63.100 | 61.200 | 64.400 | 70.656 |
| 22. | System 3 & 1130 | | k | | | | | | | | | | | | | | .604 | 1.800 | 2.231 | 2.600 | 2.640 | 2.810 | 2.639 |
| 23. | Total IBM | | k | | | | | | | | | | | | 57.446 | 59.417 | 63.566 | 64.320 | 67.480 | 68.210 | 65.830 | 68.800 | 74.786 |
| 24. | Non-IBM | | k | | | | | | | | | | | | 36.189 | 40.889 | 48.317 | 56.227 | 60.530 | 60.760 | 57.300 | 54.600 | 57.111 |
| 25. | Grand Total | 1.22.9 | k | 2.900 | 6.200 | 11.400 | 17.200 | 25.400 | 37.200 | 49.700 | 63.776 | 73.930 | 85.100 | 90.000 | 93.635 | 100.31 | 111.88 | 120.50 | 128.10 | 129.00 | 123.10 | 123.43 | 131.90 |
| | MTU Controllers in Use | | | | | | | | | | | | | | | | | | | | | | |
| 27. | IBM–2nd Generation | | k | | | | | | | | | | | | 1.319 | 1.166 | .954 | .832 | .670 | .559 | .443 | .357 | 0.332 |
| 28. | 360/370 | | k | | | | | | | | | | | | 11.647 | 12.284 | 13.016 | 12.700 | 13.530 | 13.420 | 13.000 | 13.700 | 14.720 |
| 29. | System 3 & 1130 | | k | | | | | | | | | | | | | | .240 | .716 | .892 | 1.054 | 1.058 | 1.124 | 1.056 |
| 30. | Non-IBM | | k | | | | | | | | | | | | 7.867 | 9.086 | 10.737 | 12.800 | 14.077 | 14.470 | 13.650 | 13.000 | 13.598 |
| | Tape System Value in Use | | | | | | | | | | | | | | | | | | | | | | |
| 31. | Magnetic Tape Units | | $B | .054 | .138 | .278 | .444 | .666 | .995 | 1.336 | 1.705 | 1.942 | 2.227 | 2.340 | 2.443 | 2.525 | 2.591 | 2.538 | 2.442 | 2.329 | 2.330 | 2.440 | 2.739 |
| 32. | MTU Controllers | | $B | .021 | .042 | .071 | .105 | .153 | .222 | .295 | .380 | .441 | .532 | .598 | .604 | .653 | .716 | .761 | .815 | .844 | .810 | .831 | .881 |
| 33. | Total Tape System Value | 1.22.3 | $B | .075 | .180 | .349 | .549 | .819 | 1.217 | 1.631 | 2.085 | 2.383 | 2.759 | 2.938 | 3.047 | 3.179 | 3.310 | 3.299 | 3.259 | 3.170 | 3.130 | 3.274 | 3.620 |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MTU Storage Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 34. | Capacity Per Tape Reel | | M ch | 5.0 | 8.7 | 10.6 | 11.8 | 12.4 | 12.7 | 13.3 | 14.4 | 15.6 | 16.5 | 17.0 | 17.46 | 18.46 | 18.59 | 19.59 | 20.64 | 21.66 | 23.67 | 25.70 | 27.70 |
| 34a. | Total On-Line Capacity | 1.22.9 | B ch | 15 | 54 | 122 | 204 | 315 | 473 | 659 | 918 | 1151 | 1404 | 1530 | 1635 | 1851 | 2079 | 2360 | 2643 | 2795 | 2914 | 3172 | 3654 |
| | Averages | | | | | | | | | | | | | | | | | | | | | | |
| 35. | MTU Per System | 1.22.10 | | .90 | 1.40 | 1.90 | 2.10 | 2.20 | 2.20 | 2.30 | 2.35 | 2.38 | 2.30 | 2.25 | 2.23 | 2.23 | 2.23 | 2.10 | 2.08 | 2.08 | 2.07 | 2.12 | 2.28 |
| 36. | Price Per MTU | 1.22.10 | $K | 18 | 22 | 24 | 26 | 26 | 27 | 27 | 27 | 26 | 26 | 26 | 26.1 | 25.2 | 23.2 | 21.1 | 19.1 | 18.1 | 18.9 | 19.8 | 20.8 |
| 36a. | Price per Kbyte | 2.12.10 | $/Kby | 3.60 | 2.50 | 2.30 | 2.20 | 2.10 | 2.10 | 2.02 | 1.86 | 1.68 | 1.59 | 1.53 | 1.49 | 1.36 | 1.25 | 1.08 | .93 | .83 | .80 | .77 | .75 |
| | **Moving-Head Files (MHF)** | | | | | | | | | | | | | | | | | | | | | | |
| 37. | IBM–1st Gen.–No. Per System | | | .7 | .9 | .9 | .9 | 1.0 | 1.3 | 1.8 | 1.7 | 1.5 | 1.5 | | | | | | | | | | |
| 40. | 2nd Generation–No. per System | | | | .2 | .2 | .4 | .6 | .8 | 1.0 | 1.2 | 1.37 | 1.32 | 1.29 | 1.27 | 1.25 | 1.25 | 1.25 | 1.3 | 1.5 | 1.8 | 2.1 | 2.2 |
| 43. | 360/370-2311's/System | | | | | | | | | 1.92 | 1.78 | 1.76 | 1.41 | 1.27 | 1.11 | 0.99 | 0.90 | 0.83 | 0.72 | 0.6 | 0.5 | 0.4 | 0.3 |
| 46. | 360/370-2314/9's/System | | | | | | | | | | | .62 | 1.17 | 1.73 | 2.56 | 3.34 | 3.25 | 3.73 | 2.95 | 2.12 | 1.87 | 1.54 | 1.33 |
| 47. | 370–% Having 3330 | | % | | | | | | | | | | | | | 43 | 49 | 50 | 53 | 58 | 63 | 50 | 42 |
| 48. | Spindles on Those Having | | | | | | | | | | | | | | | 8 | 9 | 10 | 11 | 11 | 11 | 11 | 11 |
| 49. | No. Per System | | | | | | | | | | | | | | | 3.47 | 4.41 | 5.01 | 5.78 | 6.43 | 6.95 | 5.50 | 4.58 |
| 49a. | 370–% Having 3340 | | % | | | | | | | | | | | | | | | | | 41 | 46 | 50 | 52 |
| 49b. | Spindles on Those Having | | | | | | | | | | | | | | | | | | | 4.7 | 4.8 | 4.9 | 5.0 |
| 49c. | No. per System | | | | | | | | | | | | | | | | | | | 1.93 | 2.21 | 2.45 | 2.60 |
| 49d. | 370–% Having 3344/50 | | % | | | | | | | | | | | | | | | | | | 6 | 17 | 40 |
| 49e. | Spindles on Those Having | | | | | | | | | | | | | | | | | | | | 8.0 | 8.0 | 8.0 |
| 49f. | No. per System | | | | | | | | | | | | | | | | | | | | .44 | 1.34 | 3.17 |
| 50a. | System 3–5445's/Syst. | | | | | | | | | | | | | | .20 | .22 | .24 | .26 | .30 | .30 | .29 | .27 | .24 |
| 50b. | 3340's per System | | | | | | | | | | | | | | | | | | | .18 | .50 | .75 | 1.00 |
| 50c. | 1130–No. per System | | | | | | | | | | | | | .5 | .5 | .5 | .5 | .5 | .5 | .5 | .5 | .5 | .5 |
| 51. | Non-IBM–% Having MHF | | % | | | | | | | | 10 | 15 | 25 | 40 | 45 | 50 | 55 | 58 | 60 | 60 | 60 | 60 | 60 |
| 52. | Spindles on Those Having | | | | | | | | | | 1 | 1.2 | 1.4 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.5 | 3.9 | 4.3 | 4.7 | 5.0 |
| 53. | No. Per System | | | | | | | | | | .1 | .18 | .35 | .64 | .90 | 1.20 | 1.54 | 1.86 | 2.10 | 2.34 | 2.58 | 2.82 | 3.00 |
| | Moving-Head Files in Use | | | | | | | | | | | | | | | | | | | | | | |
| 54. | IBM–1st Generation | | k | 1.8 | 2.4 | 2.1 | 1.6 | 1.2 | 1.0 | .8 | .5 | .3 | .3 | | | | | | | | | | |
| 55. | 2nd Generation | | k | | .2 | .5 | 1.9 | 4.6 | 8.8 | 13.1 | 16.0 | 13.7 | 9.1 | 6.0 | 4.2 | 3.6 | 3.0 | 2.6 | 2.2 | 2.1 | 2.0 | 1.9 | 1.8 |
| 56. | 360/70–Total | | k | | | | | | | 1.2 | 6.9 | 19.3 | 33.9 | 53.1 | 71.2 | 82.2 | 86.9 | 104.3 | 113.4 | 121.0 | 122.4 | 127.3 | 144.5 |
| 57. | 2311's | | k | | | | | | | 1.2 | 6.9 | 14.3 | 18.5 | 22.5 | 21.6 | 18.1 | 16.1 | 13.6 | 11.9 | 9.5 | 7.5 | 6.2 | 5.0 |
| 58. | 2314/19's | | k | | | | | | | | | 5.0 | 15.4 | 30.6 | 49.6 | 61.3 | 57.9 | 61.1 | 48.6 | 33.5 | 28.0 | 24.0 | 22.0 |
| 59. | 3330's | | k | | | | | | | | | | | | | 2.8 | 12.9 | 29.5 | 48.8 | 60.0 | 62.9 | 57.5 | 52.0 |
| 59a. | Single Density | | k | | | | | | | | | | | | | 2.8 | 12.9 | 29.5 | 43.1 | 50.0 | 39.0 | 30.8 | 26.0 |
| 59b. | Double Density | | k | | | | | | | | | | | | | | | | 5.7 | 10.0 | 23.9 | 26.7 | 26.0 |
| 59c. | 3340's | | k | | | | | | | | | | | | | | | 0.1 | 4.1 | 18.0 | 20.0 | 25.6 | 29.5 |
| 59d. | 3344/50's | | k | | | | | | | | | | | | | | | | | | 4.0 | 14.0 | 36.0 |
| 60a. | System 3–Total | | k | | | | | | | | | | | | .3 | .9 | 2.1 | 4.5 | 6.0 | 10.6 | 17.7 | 22.5 | 25.7 |
| 60b. | 5445 | | k | | | | | | | | | | | | .3 | .9 | 2.1 | 4.5 | 6.0 | 6.6 | 6.5 | 6.0 | 5.0 |
| 60c. | 3340 | | k | | | | | | | | | | | | | | | | | 4.0 | 11.2 | 16.5 | 20.7 |
| 60d. | 1130–Total | | k | | | | | | | | .3 | .8 | 1.4 | 1.5 | 1.4 | 1.6 | 1.6 | 1.3 | 1.2 | .9 | .8 | .7 | .6 |
| 61. | Total IBM | | k | 1.8 | 2.6 | 2.6 | 3.5 | 5.8 | 9.8 | 15.1 | 23.7 | 34.1 | 44.7 | 60.6 | 77.1 | 88.3 | 93.6 | 112.7 | 122.8 | 134.6 | 142.9 | 152.4 | 172.6 |
| 62. | Non-IBM Spindles | | k | | | | | | | | .9 | 2.0 | 4.9 | 9.4 | 13.6 | 19.8 | 27.6 | 37.1 | 44.1 | 49.1 | 56.9 | 67.1 | 76.9 |
| 63. | Grand Total Spindles | 1.22.11 | k | 1.8 | 2.6 | 2.6 | 3.5 | 5.8 | 9.8 | 15.1 | 24.6 | 36.1 | 49.6 | 70.0 | 90.7 | 108.1 | 121.2 | 149.8 | 166.9 | 183.7 | 199.8 | 219.5 | 249.5 |
| 63a. | 2311-Type | | k | | | | | 1.0 | 4.5 | 9.2 | 17.8 | 23.2 | 23.2 | 23.4 | 23.5 | 23.7 | 25.3 | 23.4 | 23.7 | 20.5 | 16.8 | 13.8 | 11.0 |
| 63b. | 2314/5445-Type | | k | | | | | | | | | 5.0 | 15.4 | 30.6 | 52.4 | 69.2 | 73.4 | 83.7 | 73.5 | 59.8 | 53.1 | 47.0 | 42.0 |
| 63c. | 3330-Type | | k | | | | | | | | | | | | | 2.8 | 12.9 | 30.1 | 51.6 | 66.8 | 76.9 | 80.0 | 80.9 |
| 63d. | 3340-Type | | k | | | | | | | | | | | | | | | .1 | 4.1 | 22.0 | 31.2 | 42.1 | 50.2 |
| 63e. | 3344/50 | | k | | | | | | | | | | | | | | | | | | 4.0 | 14.0 | 36.0 |
| 63f. | Other | | k | 1.8 | 2.6 | 2.6 | 3.5 | 4.8 | 5.3 | 5.9 | 6.8 | 7.9 | 11.0 | 16.0 | 14.8 | 12.4 | 9.7 | 12.5 | 14.0 | 14.6 | 17.8 | 22.6 | 29.4 |
| | MHF Controllers in Use | | | | | | | | | | | | | | | | | | | | | | |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64. | 2nd Gen. | | k | | .1 | .3 | .9 | 2.3 | 4.4 | 6.5 | 8.0 | 6.5 | 4.1 | 2.6 | 1.7 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 |
| 65. | 2311's | | k | | | | | | | .4 | 2.3 | 4.5 | 6.6 | 9.4 | 9.3 | 8.0 | 7.3 | 6.3 | 5.7 | 4.8 | 3.8 | 3.1 | 2.5 |
| 66. | 3330's | | k | | | | | | | | | | | | | .3 | 1.4 | 2.9 | 4.5 | 5.4 | 5.7 | 5.2 | 4.8 |
| 66a. | 3340 | | k | | | | | | | | | | | | | | | | | 3.8 | 4.2 | 5.2 | 5.9 |
| 66b. | 3350 | | k | | | | | | | | | | | | | | | | | | .5 | 1.8 | 4.5 |
| 66c. | System 3–5445 | | k | | | | | | | | | | | | .1 | .4 | 1.0 | 2.2 | 3.0 | 3.3 | 3.2 | 3.0 | 2.5 |
| 67. | Non-IBM | | k | | | | | | | | .9 | 1.7 | 3.5 | 5.9 | 6.8 | 8.3 | 9.8 | 11.6 | 12.6 | 12.6 | 13.2 | 14.3 | 15.4 |
| | MHF Value in Use | | | | | | | | | | | | | | | | | | | | | | |
| 68. | Moving Head Files | | $B | .090 | .128 | .125 | .156 | .244 | .402 | .595 | .876 | 1.153 | 1.481 | 2.035 | 2.648 | 3.157 | 3.470 | 4.207 | 4.571 | 4.703 | 5.136 | 5.482 | 6.097 |
| 69. | MHF Controllers | | $B | | .003 | .010 | .029 | .074 | .141 | .219 | .345 | .378 | .405 | .488 | .480 | .530 | .722 | .961 | 1.117 | 1.149 | 1.224 | 1.295 | 1.501 |
| 70. | Total MHF System Val. | 1.22.3 | $B | .090 | .131 | .135 | .185 | .318 | .543 | .814 | 1.221 | 1.531 | 1.886 | 2.523 | 3.128 | 3.687 | 4.192 | 5.168 | 5.688 | 5.852 | 6.360 | 6.777 | 7.598 |
| | **Spindle Capacity** | | | | | | | | | | | | | | | | | | | | | | |
| 70a. | 1st Generation at 6 MBy | | kBBy | .011 | .014 | .013 | .010 | .007 | .006 | .005 | .003 | .001 | .001 | | | | | | | | | | |
| 70b. | 2nd Generation at 10 MBy | | kBBy | | .002 | .005 | .019 | .046 | .088 | .131 | .160 | .137 | .091 | .060 | .042 | .036 | .030 | .026 | .022 | .021 | .020 | .019 | .018 |
| 70c. | 2311 at 7.5 MBy | | kBBy | | | | | | | .009 | .052 | .107 | .139 | .169 | .162 | .136 | .121 | .102 | .089 | .071 | .056 | .047 | .038 |
| 70d. | 2314/19 at 29 MBy | | kBBy | | | | | | | | | .145 | .447 | 887 | 1.438 | 1.778 | 1.679 | 1.772 | 1.409 | .972 | .812 | .696 | .638 |
| 70e. | 3330 SD at 100 MBy | | kBBy | | | | | | | | | | | | | .280 | 1.290 | 2.950 | 4.310 | 5.000 | 3.900 | 3.080 | 2.600 |
| 70f. | 3330 DD at 200 MBy | | kBBy | | | | | | | | | | | | | | | | 1.140 | 2.000 | 4.780 | 5.340 | 5.200 |
| 70g. | 3340 at 70 MBy | | kBBy | | | | | | | | | | | | | | | .007 | .287 | 1.260 | 1.400 | 1.792 | 2.065 |
| 70h. | 3350 at 300 MBy | | kBBy | | | | | | | | | | | | | | | | | | 1.200 | 4.200 | 10.800 |
| 70i. | 5445 at 3 MBy | | kBBy | | | | | | | | | | | | .001 | .003 | .006 | .014 | .018 | .020 | .020 | .018 | .015 |
| 70j. | 3340 on S/3 at 70 MBy | | kBBy | | | | | | | | | | | | | | | | | .280 | .784 | 1.155 | 1.449 |
| 70k. | 2310 at 1 MBy | | kBBy | | | | | | | | | | .001 | .002 | .002 | .002 | .002 | .001 | .001 | .001 | .001 | .001 | .001 |
| | Total IBM Capacity | | | .011 | .016 | .018 | .029 | .053 | .094 | .145 | .215 | .390 | .679 | 1.118 | 1.645 | 2.235 | 3.128 | 4.872 | 7.276 | 9.625 | 12.973 | 16.348 | 22.824 |
| 70l. | 1st Generation | | % | 100.0 | 87.5 | 72.2 | 34.5 | 13.2 | 6.4 | 3.4 | 1.4 | 0.3 | 0.1 | | | | | | | | | | |
| 70m. | 2nd Generation | | % | | 12.5 | 27.8 | 65.5 | 86.8 | 93.6 | 90.3 | 94.4 | 35.1 | 13.4 | 5.4 | 2.6 | 1.6 | 1.0 | 0.5 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |
| 70n. | 2314/19 | | % | | | | | | | | | | | 79.3 | 87.4 | 79.6 | 53.7 | 36.4 | 19.4 | 10.1 | 6.3 | 4.3 | 2.8 |
| 70o. | All 3330's | | % | | | | | | | | | | | | | 12.5 | 41.2 | 60.6 | 74.9 | 72.7 | 66.9 | 51.5 | 34.2 |
| 70p. | All 3340's | | % | | | | | | | | | | | | | | | 0.1 | 3.9 | 16.0 | 16.8 | 18.1 | 15.3 |
| 70q. | 3350 | | % | | | | | | | | | | | | | | | | | | 9.2 | 25.7 | 47.3 |
| | MHF Storage Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 71. | Total On-Line Capacity | 1.22.11 | B By | 11 | 16 | 18 | 29 | 53 | 94 | 145 | 223 | 413 | 753 | 1291 | 1935 | 2736 | 4050 | 6476 | 9889 | 13136 | 18142 | 23552 | 32993 |
| | Averages | | | | | | | | | | | | | | | | | | | | | | |
| 72. | MHF Spindles per System | 1.22.12 | | .58 | .59 | .42 | .43 | .50 | .59 | .70 | .91 | 1.16 | 1.34 | 1.75 | 2.16 | 2.40 | 2.41 | 2.57 | 2.71 | 2.96 | 3.35 | 3.77 | 4.30 |
| 73. | Price per Spindle | 1.22.12 | $k | 50.0 | 49.2 | 48.1 | 44.6 | 42.1 | 41.0 | 39.4 | 35.6 | 31.9 | 29.9 | 29.1 | 29.2 | 29.2 | 28.6 | 28.1 | 27.4 | 25.6 | 25.7 | 25.0 | 24.4 |
| 73a. | Capacity Per Spindle | | M By | 6.0 | 6.2 | 6.9 | 8.3 | 9.1 | 9.6 | 9.6 | 9.1 | 11.4 | 15.2 | 18.4 | 21.3 | 25.3 | 33.4 | 43.2 | 59.3 | 71.5 | 90.8 | 107.3 | 132.2 |
| 73b. | Price per Kbyte | 2.12.1 | $/Kby | 8.3 | 8.0 | 6.9 | 5.4 | 4.6 | 4.3 | 4.10 | 3.93 | 2.79 | 1.97 | 1.58 | 1.37 | 1.15 | .857 | .650 | .462 | .358 | .284 | .233 | .185 |
| | **Punched Card Equipment** | | | | | | | | | | | | | | | | | | | | | | |
| 74. | No. Per System | 1.22.15 | | .69 | .73 | .77 | .80 | .82 | .84 | .85 | .86 | .87 | .86 | .86 | .85 | .84 | .83 | .82 | .81 | .80 | .80 | .80 | .80 |
| 75. | Total Units | 1.22.14 | k | 2.140 | 3.210 | 4.730 | 6.480 | 9.590 | 14.030 | 18.360 | 23.305 | 26.970 | 31.820 | 34.400 | 35.615 | 37.800 | 41.666 | 47.806 | 49.815 | 49.680 | 47.680 | 46.560 | 46.368 |
| 76. | Average Price | 1.22.15 | $k | 40 | 38 | 36 | 33 | 31 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 29 | 28 | 26 | 24 | 23 | 22 | 22 | 22 |
| 77. | Total Value in Use | 1.22.4 | $B | .086 | .122 | .170 | .214 | .297 | .421 | .551 | .699 | .809 | .955 | 1.032 | 1.068 | 1.095 | 1.167 | 1.243 | 1.196 | 1.143 | 1.049 | 1.024 | 1.020 |
| | **Line Printers** | | | | | | | | | | | | | | | | | | | | | | |
| 80. | Percent Having Printers | | % | 69 | 73 | 77 | 80 | 82 | 84 | 85 | 87 | 89 | 91 | 93 | 92 | 90 | 87 | 84 | 83 | 82 | 82 | 82 | 81 |
| 81. | No. on Those Having | | | 1.02 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.04 | 1.04 | 1.05 | 1.07 | 1.11 | 1.20 | 1.32 | 1.45 | 1.58 | 1.68 | 1.72 | 1.75 | 1.77 | 1.80 |
| 82. | No. Per System | 1.22.16 | | .70 | .75 | .79 | .82 | .84 | .87 | .88 | .90 | .93 | .97 | 1.03 | 1.10 | 1.19 | 1.26 | 1.33 | 1.39 | 1.41 | 1.44 | 1.45 | 1.46 |
| 83. | Total Printers | 1.22.14 | k | 2.180 | 3.300 | 4.860 | 6.640 | 9.830 | 14.530 | 19.094 | 24.520 | 28.970 | 36.027 | 41.292 | 46.258 | 53.460 | 63.327 | 77.376 | 85.756 | 87.586 | 85.526 | 84.471 | 84.506 |
| 84. | Total Controllers | | k | 2.140 | 3.210 | 4.730 | 6.480 | 9.590 | 14.030 | 18.360 | 23.577 | 27.590 | 33.670 | 37.200 | 38.548 | 40.500 | 43.674 | 48.972 | 51.045 | 50.922 | 48.872 | 47.724 | 46.948 |
| 85. | Average Printer Price | 1.22.16 | $k | 71 | 70 | 60 | 46 | 36 | 35 | 35 | 34 | 34 | 32 | 29 | 27 | 28 | 30 | 32 | 35 | 37 | 39 | 40 | 41 |
| 86. | Average Controller Price | | $k | 43 | 42 | 38 | 30 | 25 | 25 | 24 | 23 | 21 | 19 | 17 | 16 | 17 | 18 | 19 | 20 | 21 | 21 | 22 | 22 |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 87. | Printer Value in Use | | $B | .155 | .231 | .292 | .305 | .354 | .509 | .665 | .834 | .985 | 1.152 | 1.197 | 1.249 | 1.500 | 1.900 | 2.476 | 3.001 | 3.241 | 3.336 | 3.379 | 3.465 |
| 88. | Controller Value in Use | | $B | .092 | .135 | .180 | .194 | .240 | .351 | .441 | .542 | .579 | .640 | .632 | .617 | .689 | .786 | .930 | 1.021 | 1.069 | 1.026 | 1.050 | 1.033 |
| 89. | Total Value in Use | 1.22.4 | $B | .247 | .366 | .472 | .499 | .594 | .860 | 1.106 | 1.376 | 1.564 | 1.792 | 1.829 | 1.866 | 2.189 | 2.686 | 3.406 | 4.022 | 4.310 | 4.362 | 4.429 | 4.498 |
| | **Other Memories** | | | | | | | | | | | | | | | | | | | | | | |
| | Head-Per-Track Devices | | | | | | | | | | | | | | | | | | | | | | |
| 90. | No. Per System | | | .20 | .15 | .11 | .08 | .05 | .04 | .03 | .03 | .04 | .06 | .09 | .12 | .14 | .15 | .15 | .15 | .15 | .15 | .15 | .15 |
| 91. | Total Units | 1.22.13 | k | .620 | .660 | .680 | .650 | .590 | .670 | .648 | .813 | 1.240 | 2.220 | 3.600 | 5.028 | 6.300 | 7.530 | 8.745 | 9.225 | 9.315 | 8.940 | 8.730 | 8.694 |
| 92. | Average Price | | $k | 55 | 55 | 54 | 54 | 55 | 56 | 58 | 67 | 72 | 78 | 78 | 78 | 75 | 74 | 72 | 70 | 70 | 70 | 70 | 70 |
| 93. | Total Value in Use | 1.22.3 | $B | .034 | .036 | .037 | .035 | .032 | .038 | .038 | .054 | .089 | .173 | .281 | .392 | .473 | .557 | .630 | .646 | .652 | .626 | .611 | .609 |
| | **Other Peripherals** | | | | | | | | | | | | | | | | | | | | | | |
| | Computer Output Microfilm | | | | | | | | | | | | | | | | | | | | | | |
| 97. | No. in Use | | k | | | | | | | | | | .05 | .43 | .76 | .83 | 1.00 | 1.20 | 1.40 | 1.80 | 2.40 | 2.85 | 3.30 |
| 98. | Total Value in Use at $140k | | $B | | | | | | | | | | .007 | .060 | .106 | .116 | .140 | .168 | .196 | .243 | .312 | .356 | .396 |
| | **Summary—Peripherals** | | | | | | | | | | | | | | | | | | | | | | |
| 103. | Total Value in Use | 1.22.1 | $B | .532 | .835 | 1.163 | 1.482 | 2.06 | 3.079 | 4.140 | 5.435 | 6.376 | 7.572 | 8.663 | 9.607 | 10.739 | 12.052 | 13.914 | 15.007 | 15.37 | 15.839 | 16.471 | 17.741 |
| 104. | Subtotal Memory | 1.22.4 | $B | .199 | .347 | .521 | .769 | 1.169 | 1.798 | 2.483 | 3.360 | 4.003 | 4.818 | 5.742 | 6.567 | 7.339 | 8.059 | 9.097 | 9.593 | 9.674 | 10.116 | 10.662 | 11.827 |
| | Percent of Peripheral Value | | | | | | | | | | | | | | | | | | | | | | |
| 105. | Tape Systems | 1.22.5 | % | 14.1 | 21.6 | 30.0 | 37.0 | 39.8 | 39.5 | 39.4 | 38.4 | 37.4 | 36.4 | 33.9 | 31.7 | 29.6 | 27.5 | 23.7 | 21.7 | 20.6 | 19.8 | 19.9 | 20.4 |
| 106. | Moving-Head-Files | 1.22.5 | % | 16.9 | 15.7 | 11.6 | 12.5 | 15.4 | 17.6 | 19.7 | 22.5 | 24.0 | 24.9 | 29.1 | 32.6 | 34.3 | 34.8 | 37.1 | 37.9 | 38.1 | 40.2 | 41.1 | 42.8 |
| 107. | Head-Per-Track Systems | 1.22.5 | % | 6.4 | 4.3 | 3.2 | 2.4 | 1.6 | 1.2 | 0.9 | 1.0 | 1.4 | 2.3 | 3.2 | 4.1 | 4.4 | 4.6 | 4.5 | 4.3 | 4.2 | 4.0 | 3.7 | 3.4 |
| 109. | Subtotal Memory | 1.22.6 | % | 37.4 | 41.6 | 44.8 | 51.9 | 56.7 | 58.4 | 60.0 | 61.8 | 62.8 | 63.6 | 66.3 | 68.4 | 68.3 | 66.9 | 65.4 | 63.9 | 62.9 | 63.9 | 64.7 | 66.7 |
| 110. | Punched Card Equip. | 1.22.6 | % | 16.2 | 14.6 | 14.6 | 14.4 | 14.4 | 13.7 | 13.3 | 12.9 | 12.7 | 12.6 | 11.9 | 11.1 | 10.2 | 9.7 | 8.9 | 8.0 | 7.4 | 6.6 | 6.2 | 5.7 |
| 111. | Line Printers | 1.22.6 | % | 46.4 | 43.8 | 40.6 | 33.7 | 28.8 | 27.9 | 26.7 | 25.3 | 24.5 | 23.7 | 21.1 | 19.4 | 20.4 | 22.3 | 24.5 | 26.8 | 28.0 | 27.5 | 26.9 | 25.4 |
| 112. | COM | | % | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.7 | 1.1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.6 | 2.0 | 2.2 | 2.2 |
| | Percent of GP System Value | | | | | | | | | | | | | | | | | | | | | | |
| 114. | Tape Systems | 1.22.7 | % | 5.6 | 9.7 | 13.4 | 15.8 | 18.0 | 20.3 | 20.9 | 22.2 | 19.2 | 17.6 | 15.4 | 14.2 | 13.6 | 13.4 | 12.1 | 10.8 | 9.4 | 8.3 | 7.6 | 7.4 |
| 115. | Moving-Head-Files | 1.22.7 | % | 6.7 | 7.0 | 5.2 | 5.3 | 7.0 | 9.1 | 10.4 | 13.0 | 12.3 | 12.0 | 13.2 | 14.6 | 15.8 | 17.0 | 18.9 | 18.8 | 17.3 | 16.8 | 15.8 | 15.6 |
| 116. | Head-Per-Track Systems | 1.22.7 | % | 2.5 | 1.9 | 1.4 | 1.0 | 0.7 | 0.6 | 0.5 | 0.6 | 0.7 | 1.1 | 1.5 | 1.8 | 2.0 | 2.3 | 2.3 | 2.1 | 1.9 | 1.7 | 1.4 | 1.3 |
| 118. | Subtotal Memory | 1.22.8 | % | 14.9 | 18.6 | 20.0 | 22.1 | 25.7 | 30.0 | 31.8 | 35.7 | 32.3 | 30.7 | 30.1 | 30.7 | 31.5 | 32.6 | 33.3 | 31.8 | 28.6 | 26.7 | 24.9 | 24.3 |
| 119. | Punched Card Equipment | 1.22.8 | % | 6.4 | 6.5 | 6.5 | 6.1 | 6.5 | 7.0 | 7.1 | 7.4 | 6.5 | 6.1 | 5.4 | 5.0 | 4.7 | 4.7 | 4.6 | 4.0 | 3.4 | 2.8 | 2.4 | 2.1 |
| 120. | Line Printers | 1.22.8 | % | 18.4 | 19.6 | 18.1 | 14.3 | 13.1 | 14.3 | 14.2 | 14.6 | 12.6 | 11.4 | 9.6 | 8.7 | 9.4 | 10.9 | 12.5 | 13.3 | 12.8 | 11.5 | 10.3 | 9.2 |
| 121. | COM | | % | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.8 | 0.8 | 0.8 |
| 123. | All Peripherals | 1.22.2 | % | 39.7 | 44.8 | 44.6 | 42.5 | 45.3 | 51.3 | 53.1 | 57.8 | 51.4 | 48.2 | 45.4 | 44.9 | 46.1 | 48.8 | 51.0 | 49.7 | 45.5 | 41.8 | 38.4 | 36.4 |
| | **Internal Memory** | | | | | | | | | | | | | | | | | | | | | | |
| | IBM Systems | | | | | | | | | | | | | | | | | | | | | | |
| 124. | 1st Gen.—Av. Size | | M By | .017 | .017 | .017 | .018 | .021 | .024 | .027 | .029 | .031 | .032 | | | | | | | | | | |
| 125. | Total Bytes in Use | 1.22.19 | B By | .043 | .045 | .040 | .033 | .025 | .018 | .012 | .009 | .006 | .005 | | | | | | | | | | |
| 126. | Av. Price Per Byte | | $/By | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | | | | | | | | | |
| 127. | Value in Use | 1.22.20 | $B | .216 | .224 | .200 | .164 | .123 | .090 | .061 | .044 | .031 | .027 | .010 | | | | | | | | | |
| 128. | 2nd Gen.—Av. Size | | M By | | .020 | .017 | .015 | .016 | .015 | .014 | .014 | .016 | .018 | .020 | .023 | .024 | .023 | .023 | .023 | .023 | .023 | .023 | .023 |
| 129. | Total Bytes in Use | 1.22.19 | B By | | .018 | .043 | .071 | .124 | .164 | .183 | .187 | .160 | .124 | .093 | .076 | .070 | .055 | .048 | .039 | .032 | .025 | .021 | .019 |
| 130. | Av. Price Per Byte | | $/By | | 6.0 | 5.7 | 4.8 | 5.3 | 5.7 | 5.5 | 5.4 | 5.3 | 5.2 | 5.2 | 5.3 | 5.2 | 5.1 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| 131. | Value in Use | 1.22.20 | $B | | .106 | .243 | .340 | .655 | .935 | 1.008 | 1.008 | .846 | .645 | .484 | .403 | .364 | .281 | .240 | .195 | .160 | .125 | .105 | .095 |
| | 3rd Generation | | | | | | | | | | | | | | | | | | | | | | |
| 132. | No. in Use—All 360's | | k | | | | | | | .625 | 3.881 | 8.125 | 13.110 | 17.687 | 19.412 | 17.529 | 14.909 | 10.475 | 8.060 | 6.450 | 5.919 | 5.118 | 4.641 |
| 145. | Total 360 Memory in Use | 1.22.19 | B By | | | | | | | .030 | .182 | .528 | .996 | 1.380 | 1.786 | 1.770 | 1.655 | 1.309 | 1.088 | 1.032 | 1.154 | 1.152 | 1.160 |
| 152. | Average 360 Memory | | M By | | | | | | | .048 | .047 | .065 | .076 | .078 | .092 | .101 | .111 | .125 | .135 | .160 | .195 | .225 | .250 |
| 159. | Total 360 Memory Value | 1.22.20 | $B | | | | | | | .051 | .310 | .850 | 1.514 | 2.042 | 2.483 | 2.372 | 2.185 | 1.518 | 1.229 | 1.146 | 1.258 | 1.233 | 1.218 |
| 166. | Average Value Per Byte | | $/By | | | | | | | 1.70 | 1.70 | 1.61 | 1.52 | 1.48 | 1.39 | 1.34 | 1.32 | 1.16 | 1.13 | 1.11 | 1.09 | 1.07 | 1.05 |
| 167. | 370 Family—No. in Use | | k | | | | | | | | | | | | | .806 | 2.922 | 5.887 | 8.440 | 9.335 | 9.046 | 10.450 | 11.348 |
| 167a. | 370/115 | | k | | | | | | | | | | | | | | | | .805 | 1.375 | 1.287 | 1.152 | 1.040 |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 167b. | 370/125 | | k | | | | | | | | | | | | | | | .721 | 1.654 | 1.911 | 1.257 | 1.102 | .980 |
| 167c. | 370/135 | | k | | | | | | | | | | | | | | .814 | 2.060 | 2.600 | 2.522 | 2.399 | 1.823 | 1.290 |
| 167d. | 370/145 | | k | | | | | | | | | | | | | .353 | 1.066 | 1.592 | 1.820 | 1.784 | 1.774 | 1.603 | 1.210 |
| 167e. | 370/155 | | k | | | | | | | | | | | | | .384 | .878 | 1.114 | .657 | .498 | .517 | .476 | .440 |
| 167f. | 370/158 | | k | | | | | | | | | | | | | | | .138 | .600 | .864 | 1.247 | 1.503 | 1.550 |
| 167g. | 370/165 | | k | | | | | | | | | | | | | .069 | .164 | .197 | .142 | .108 | .117 | .120 | .115 |
| 167h. | 370/168 | | k | | | | | | | | | | | | | | | .047 | .143 | .258 | .405 | .526 | .650 |
| 167i. | 370/195 | | k | | | | | | | | | | | | | | | .018 | .019 | .015 | .014 | .012 | .013 |
| 167j. | 370/138 | | k | | | | | | | | | | | | | | | | | | .029 | 1.272 | 1.910 |
| 167k. | 370/148 | | k | | | | | | | | | | | | | | | | | | | .861 | 1.600 |
| 167l. | 303x | | k | | | | | | | | | | | | | | | | | | | | .550 |
| 168a | Average Mem. 370/115 | | MBy | | | | | | | | | | | | | | | | .120 | .125 | .135 | .145 | .155 |
| 168b. | 370/125 | | MBy | | | | | | | | | | | | | | | .125 | .145 | .165 | .180 | .195 | .210 |
| 168c. | 370/135 | | MBy | | | | | | | | | | | | | | .150 | .170 | .185 | .220 | .240 | .260 | .280 |
| 168d. | 370/145 | | MBy | | | | | | | | | | | | | .260 | .310 | .375 | .450 | .520 | .570 | .620 | .670 |
| 168e. | 370/155 | | MBy | | | | | | | | | | | | | .870 | .950 | 1.050 | 1.175 | 1.325 | 1.375 | 1.425 | 1.475 |
| 168f. | 370/158 | | MBy | | | | | | | | | | | | | | | 1.360 | 1.520 | 1.600 | 1.775 | 1.950 | 2.100 |
| 168g. | 370/165 | | MBy | | | | | | | | | | | | | 1.450 | 1.675 | 1.925 | 2.180 | 2.400 | 2.500 | 2.600 | 2.700 |
| 168h. | 370/168 | | MBy | | | | | | | | | | | | | | | 2.600 | 2.900 | 3.000 | 3.250 | 3.500 | 3.700 |
| 168i. | 370/195 | | MBy | | | | | | | | | | | | | | | 2.600 | 2.900 | 3.000 | 3.250 | 3.500 | 3.700 |
| 168j. | 370/138 | | MBy | | | | | | | | | | | | | | | | | | .700 | .800 | .900 |
| 168k. | 370/148 | | MBy | | | | | | | | | | | | | | | | | | | 1.300 | 1.400 |
| 168l. | 303x | | MBy | | | | | | | | | | | | | | | | | | | | 4.000 |
| 169. | Total 370 Bytes in Use | 1.22.19 | BBy | | | | | | | | | | | | | .526 | 1.561 | 2.943 | 4.100 | 5.090 | 6.586 | 9.791 | 14.366 |
| | Av. Price per Byte | | | | | | | | | | | | | | | | | | | | | | |
| 170a. | 370/115 | | $/By | | | | | | | | | | | | | | | | .30 | .30 | .30 | .13 | .10 |
| 170b. | 370/125 | | $/By | | | | | | | | | | | | | | | .30 | .30 | .25 | .25 | .10 | .07 |
| 170c. | 370/135 | | $/By | | | | | | | | | | | | | | .90 | .60 | .60 | .70 | .65 | .45 | .45 |
| 170d. | 370/145 | | $/By | | | | | | | | | | | | | .90 | .48 | .48 | .49 | .55 | .55 | .36 | .36 |
| 170e. | 370/155 | | $/By | | | | | | | | | | | | | .58 | .58 | .58 | .58 | .58 | .58 | .58 | .58 |
| 170f. | 370/158 | | $/By | | | | | | | | | | | | | | | .23 | .24 | .27 | .27 | .11 | .08 |
| 170g. | 370/165 | | $/By | | | | | | | | | | | | | .53 | .53 | .53 | .53 | .53 | .53 | .53 | .53 |
| 170h. | 370/168 | | $/By | | | | | | | | | | | | | | | .23 | .23 | .26 | .26 | .11 | .07 |
| 170i. | 370/195 | | $/By | | | | | | | | | | | | | | | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| 170j. | 370/138 | | $/By | | | | | | | | | | | | | | | | | | .16 | .10 | .07 |
| 170k. | 370/148 | | $/By | | | | | | | | | | | | | | | | | | | .10 | .09 |
| 170l. | 303x | | $/By | | | | | | | | | | | | | | | | | | | | .11 |
| 171. | Total 370 Value in Use | 1.22.20 | $B | | | | | | | | | | | | | .329 | .936 | 1.601 | 1.845 | 2.115 | 2.586 | 2.819 | 3.086 |
| 171a. | Av. Value per Byte | | $B | | | | | | | | | | | | | .626 | .600 | .544 | .450 | .416 | .390 | .288 | .215 |
| 171b. | Av. 370 Memory Size | | $B | | | | | | | | | | | | | .653 | .534 | .500 | .486 | .545 | .728 | .937 | 1.266 |
| 172a. | 1130—No. in Use | | k | | | | | | | | .517 | 1.625 | 2.724 | 2.935 | 2.745 | 3.201 | 3.268 | 2.547 | 2.335 | 1.878 | 1.658 | 1.352 | 1.240 |
| 172b. | System 3—No. in Use | | k | | | | | | | | | | | | 1.290 | 4.013 | 8.816 | 17.340 | 19.975 | 22.070 | 22.378 | 22.068 | 20.750 |
| 172c. | 3/4 | | k | | | | | | | | | | | | | | | | | | .146 | .511 | .580 |
| 172d. | 3/6 | | k | | | | | | | | | | | | .064 | 1.270 | 1.512 | 2.824 | 2.930 | 2.583 | 1.706 | .942 | .740 |
| 172e. | 3/8 | | k | | | | | | | | | | | | | | | | | 1.127 | 3.706 | 5.169 | 4.850 |
| 172f. | 3/10 | | k | | | | | | | | | | | | 1.286 | 2.744 | 7.304 | 14.516 | 15.910 | 15.683 | 11.944 | 8.034 | 6.900 |
| 172g. | 3/12 | | k | | | | | | | | | | | | | | | | | | 2.175 | 4.458 | 4.550 |
| 172h. | 3/15 | | k | | | | | | | | | | | | | | | | 1.135 | 2.677 | 2.701 | 2.955 | 3.130 |
| 173. | Av. Memory Size | | M By | | | | | | | | | | | | | | | | | | | | |
| 173a | Av. Memory Size—1130 | | M By | | | | | | | | .008 | .009 | .011 | .012 | .013 | .014 | .015 | .016 | .016 | .017 | .017 | .018 | .018 |
| 173b | System 3/4 | | MBy | | | | | | | | | | | | | | | | | | .064 | .064 | .064 |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 173c. | System 3/6 | | MBy | | | | | | | | | | | | .011 | .011 | .0115 | .0115 | .012 | .0125 | .013 | .013 | .0135 |
| 173d. | System 3/8 | | MBy | | | | | | | | | | | | | | | | | .025 | .028 | .031 | .034 |
| 173e. | System 3/10 | | MBy | | | | | | | | | | | | .019 | .019 | .019 | .019 | .019 | .019 | .019 | .019 | .019 |
| 173f. | System 3/12 | | MBy | | | | | | | | | | | | | | | | | | .040 | .045 | .050 |
| 173g. | System 3/15 | | MBy | | | | | | | | | | | | | | | | .078 | .087 | .095 | .102 | .108 |
| 174a. | Bytes in Use—1130 | | B By | | | | | | | | .004 | .015 | .030 | .035 | .036 | .045 | .049 | .041 | .037 | .032 | .028 | .024 | .022 |
| 174b. | System 3 | 1.22.19 | BBy | | | | | | | | | | | | .024 | .066 | .156 | .308 | .426 | .591 | .706 | .860 | .909 |
| 175a. | Av. Price per Byte—1130 | | $/By | | | | | | | | 2.0 | 2.1 | 2.2 | 2.3 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 1.6 | 1.4 | 1.2 | 1.2 |
| 175b. | System 3/4 | | $/By | | | | | | | | | | | | | | | | | | .20 | .13 | .13 |
| 175c. | System 3/6 | | $/By | | | | | | | | | | | | 1.05 | .90 | .80 | .80 | .80 | .70 | .60 | .40 | .40 |
| 175d. | System 3/8 | | $/By | | | | | | | | | | | | | | | | | .25 | .16 | .11 | .11 |
| 175e. | System 3/10 | | $/By | | | | | | | | | | | | 1.35 | 1.15 | 1.00 | 1.00 | 1.00 | .90 | .80 | .55 | .55 |
| 175f. | System 3/12 | | $/By | | | | | | | | | | | | | | | | | | .16 | .11 | .11 |
| 175g. | System 3/15 | | $/By | | | | | | | | | | | | | | | | .29 | .29 | .20 | .13 | .13 |
| 176a. | Value in Use—1130 | | | | | | | | | | .008 | .031 | .066 | .081 | .090 | .113 | .123 | .103 | .093 | .051 | .039 | .029 | .026 |
| 176b. | System 3 | | $B | | | | | | | | | | | | .033 | .077 | .167 | .316 | .370 | .412 | .362 | .304 | .289 |
| 176c. | Av. System 3 Val./Byte | | $B | | | | | | | | | | | | 1.349 | 1.171 | 1.068 | 1.025 | .869 | .697 | .513 | .354 | .318 |
| 176d. | Av. System 3 Val./Byte | | $B | | | | | | | | | | | | .019 | .016 | .018 | .018 | .021 | .027 | .032 | .039 | .044 |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| | IBM Memory (GP, U.S.) | | | | | | | | | | | | | | | | | | | | | | |
| 177. | Total Bytes in Use | | B By | .043 | .063 | .083 | .102 | .149 | .182 | .225 | .385 | .708 | 1.157 | 1.508 | 1.922 | 2.477 | 3.476 | 4.649 | 5.690 | 6.777 | 8.499 | 11.848 | 16.476 |
| 178. | Total Value in Use | | $B | .216 | .330 | .443 | .496 | .778 | 1.025 | 1.120 | 1.387 | 1.760 | 2.255 | 2.606 | 3.009 | 3.255 | 3.692 | 3.778 | 3.732 | 3.884 | 4.350 | 4.490 | 4.714 |
| 179. | Av. Bytes Per System | | M By | .017 | .018 | .017 | .016 | .017 | .016 | .016 | .021 | .036 | .051 | .060 | .072 | .087 | .108 | .121 | .141 | .165 | .212 | .297 | .430 |
| 180. | Av. Value Per Byte | | $/By | 5.02 | 5.24 | 5.34 | 4.86 | 5.22 | 5.63 | 4.98 | 3.60 | 2.48 | 1.95 | 1.73 | 1.57 | 1.31 | 1.06 | .80 | .66 | .57 | .51 | .38 | .29 |
| | Non-IBM Memory (GP, U.S.) | | | | | | | | | | | | | | | | | | | | | | |
| 181. | Bytes Per System | | M By | .016 | .016 | .016 | .017 | .017 | .017 | .017 | .021 | .036 | .051 | .060 | .072 | .087 | .108 | .121 | .141 | .165 | .212 | .297 | .430 |
| 182. | Total Bytes in Use | | B By | .009 | .014 | .021 | .026 | .048 | .085 | .126 | .190 | .399 | .719 | .881 | 1.089 | 1.437 | 1.933 | 2.416 | 2.962 | 3.460 | 4.133 | 5.440 | 8.235 |
| 183. | Av. Value Per Byte | | $/By | 4.80 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 4.98 | 3.60 | 2.48 | 1.95 | 1.73 | 1.57 | 1.31 | 1.06 | .85 | .70 | .60 | .55 | .40 | .30 |
| 184. | Total Value in Use | | $B | .043 | .070 | .105 | .130 | .240 | .425 | .629 | .687 | .988 | 1.402 | 1.524 | 1.710 | 1.882 | 2.049 | 2.054 | 2.073 | 2.076 | 2.273 | 2.176 | 2.471 |
| | Total U.S. GP Memory | | | | | | | | | | | | | | | | | | | | | | |
| 185. | Bytes in Use | 1.22.17 | B By | .052 | .077 | .104 | .128 | .197 | .267 | .351 | .575 | 1.107 | 1.876 | 2.389 | 3.011 | 3.914 | 5.409 | 7.065 | 8.652 | 10.237 | 12.632 | 17.288 | 24.711 |
| 186. | Value in Use | 1.22.17 | $B | .259 | .400 | .548 | .626 | 1.018 | 1.450 | 1.749 | 2.074 | 2.748 | 3.657 | 4.130 | 4.719 | 5.137 | 5.741 | 5.832 | 5.805 | 5.960 | 6.623 | 6.666 | 7.185 |
| 187. | Average U.S. Bytes/Syst. | 1.22.18 | M By | .017 | .017 | .017 | .017 | .017 | .017 | .016 | .021 | .036 | .051 | .060 | .072 | .087 | .108 | .121 | .141 | .165 | .212 | .297 | .426 |
| 188. | Price/Byte | 1.22.18 | $/By | 4.98 | 5.19 | 5.27 | 4.89 | 5.17 | 5.43 | 4.98 | 3.61 | 2.48 | 1.95 | 1.73 | 1.57 | 1.31 | 1.06 | .83 | .67 | .58 | .52 | .39 | .29 |
| 193. | Int. Mem.—% of GP Value | | % | 19.3 | 21.4 | 21.0 | 18.0 | 22.4 | 24.2 | 22.2 | 22.1 | 22.2 | 23.3 | 21.6 | 22.1 | 22.0 | 23.2 | 21.4 | 19.2 | 17.6 | 17.5 | 15.5 | 14.8 |
| | **Minisystem Peripherals** | | | | | | | | | | | | | | | | | | | | | | |
| 194. | Minis Shipped, U.S. | | k | | | | | | | .2 | 1.0 | 1.8 | 2.2 | 6.3 | 8.6 | 8.8 | 17.0 | 21.1 | 33.9 | 34.5 | 42.0 | 60.0 | 71.0 |
| 195. | In Use, U.S. | | k | | | | | | | .2 | 1.2 | 3.0 | 5.2 | 11.5 | 20.0 | 28.5 | 45.0 | 65.1 | 96.1 | 126.3 | 162.3 | 214.5 | 275.3 |
| | Moving Head Files | | | | | | | | | | | | | | | | | | | | | | |
| 196. | Shipped/System Shipped | | | | | | | | | | | | | 0 | .2 | .6 | .9 | 1 | 1 | 1 | 1 | 1 | 1 |
| 197. | Total Shipped | | k | | | | | | | | | | | | 1.7 | 5.3 | 15.3 | 21.1 | 33.9 | 34.5 | 42.0 | 60.0 | 71.0 |
| 198. | Total in Use | 1.22.11 | k | | | | | | | | | | | | 1.7 | 7.0 | 22.3 | 43.4 | 78.3 | 112.8 | 154.8 | 214.8 | 285.8 |
| | Magnetic Tape Units | | | | | | | | | | | | | | | | | | | | | | |
| 199. | In Use/System in Use | | | | | | | | | .6 | .62 | .64 | .66 | .68 | .70 | .72 | .75 | .74 | .72 | .70 | .677 | .65 | .60 |
| 200. | Total Shipped | | k | | | | | | | .1 | .6 | 1.2 | 1.5 | 4.4 | 6.3 | 6.8 | 13.6 | 15.1 | 23.0 | 22.0 | 25.2 | 34.0 | 30.1 |
| 201. | Total in Use | 1.22.9 | k | | | | | | | .1 | .7 | 1.9 | 3.4 | 7.8 | 14.0 | 20.5 | 33.8 | 48.2 | 69.2 | 88.4 | 110.0 | 139.4 | 165.2 |
| | Line Printers | | | | | | | | | | | | | | | | | | | | | | |
| 202. | In Use/System in Use | | | | | | | | | .3 | .3 | .3 | .3 | .3 | .3 | .3 | .3 | .3 | .30 | .31 | .322 | .313 | .32 |
| 203. | Total Shipped | | k | | | | | | | .1 | .3 | .5 | .7 | 1.9 | 2.6 | 2.6 | 5.1 | 6.3 | 10.2 | 11.8 | 15.3 | 17.1 | 18.1 |
| 204. | Total in Use | 1.22.14 | k | | | | | | | .1 | .4 | .9 | 1.6 | 3.5 | 6.0 | 8.6 | 13.5 | 19.5 | 28.8 | 39.2 | 52.2 | 67.1 | 82.6 |
| | Character Printers | | | | | | | | | | | | | | | | | | | | | | |

## TABLE II.1.22.1a SYSTEM COMPONENTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 205. | In Use/System in Use | | | | | | | | | .25 | .25 | .25 | .25 | .25 | .25 | .245 | .24 | .235 | .23 | .22 | .214 | .200 | .19 |
| 206. | Total Shipped | | k | | | | | | | | .2 | .5 | .6 | 1.6 | 2.2 | 2.1 | 3.9 | 4.7 | 7.4 | 6.5 | 8.1 | 9.4 | 11.0 |
| 207. | Total in Use | | k | | | | | | | .1 | .3 | .8 | 1.3 | 2.9 | 5.0 | 7.0 | 10.8 | 15.3 | 22.1 | 27.8 | 34.8 | 42.9 | 52.3 |
| | **SBC Peripherals** | | | | | | | | | | | | | | | | | | | | | | |
| 208. | SBC's Shipped, U.S. | | k | | | | | | | | | | | | .08 | .18 | .47 | .77 | 3.0 | 7.9 | 14.8 | 21.6 | 25.5 |
| 209. | In Use, U.S. | | k | | | | | | | | | | | | .08 | .26 | .73 | 1.50 | 4.5 | 12.4 | 27.2 | 48.8 | 72.8 |
| | Moving-Head Files | | | | | | | | | | | | | | | | | | | | | | |
| 210. | In Use/System in Use | | | | | | | | | | | | | | 2 | 2 | 2 | 1.9 | 1.75 | 1.5 | 1.25 | 1.25 | 1.25 |
| 211. | Total Shipped | | k | | | | | | | | | | | | 0.2 | 0.4 | 0.9 | 1.4 | 5.0 | 10.7 | 15.4 | 27.0 | 31.9 |
| 212. | Total in Use | 1.22.11 | k | | | | | | | | | | | | 0.2 | 0.6 | 1.5 | 2.9 | 7.9 | 18.6 | 34.0 | 61.0 | 91.0 |
| | Magnetic Tape Units | | | | | | | | | | | | | | | | | | | | | | |
| 213. | In Use/System in Use | | | | | | | | | | | | | | .35 | .35 | .35 | .3 | .25 | .2 | .15 | .15 | .15 |
| 214. | Total Shipped | | k | | | | | | | | | | | | | 0.1 | 0.1 | 0.2 | 0.6 | 1.4 | 1.6 | 3.2 | 3.8 |
| 215. | Total in Use | 1.22.9 | k | | | | | | | | | | | | 0.1 | 0.2 | 0.3 | 0.5 | 1.1 | 2.5 | 4.1 | 7.3 | 10.9 |
| | Line Printers | | | | | | | | | | | | | | | | | | | | | | |
| 216. | In Use at .75/System | | k | | | | | | | | | | | | 0.1 | 0.2 | 0.5 | 1.1 | 3.4 | 9.3 | 20.4 | 36.6 | 54.6 |
| | Character Printers | | | | | | | | | | | | | | | | | | | | | | |
| 217. | In Use at .25/System | | k | | | | | | | | | | | | | 0.1 | 0.2 | .4 | 1.1 | 3.1 | 6.8 | 12.2 | 18.2 |
| | **Summary–Mini/SBC** | | | | | | | | | | | | | | | | | | | | | | |
| 218. | Total MHF–Shipped | | k | | | | | | | | | | | | 1.9 | 5.7 | 16.2 | 22.5 | 38.9 | 45.2 | 57.4 | 87.0 | 102.9 |
| 219. | In Use | | k | | | | | | | | | | | | 1.9 | 7.6 | 23.8 | 46.3 | 86.2 | 131.4 | 188.8 | 275.8 | 376.8 |
| 220. | Total MTU–Shipped | | k | | | | | | | .1 | .6 | 1.2 | 1.5 | 4.4 | 6.3 | 6.9 | 13.7 | 15.3 | 23.6 | 23.4 | 26.8 | 37.2 | 33.9 |
| 221. | In Use | | k | | | | | | | .1 | .7 | 1.9 | 3.4 | 7.8 | 14.1 | 20.7 | 34.1 | 48.7 | 70.3 | 90.9 | 114.1 | 146.7 | 176.1 |
| 222. | Total Line Printers in Use | | k | | | | | | | .1 | .4 | .9 | 1.6 | 3.5 | 6.1 | 8.8 | 14.0 | 20.6 | 32.2 | 48.5 | 72.6 | 103.7 | 137.2 |

## TABLE II.1.23a DATA ENTRY EQUIPMENT

| Line | Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Keypunches–Total in Use | k | 255 | 266 | 268 | 260 | 250 | 235 | 215 |
| 2. | Verifiers–Total in Use | k | 85 | 70 | 55 | 40 | 30 | 25 | 20 |
| 3. | Keyp. & Ver.–Total in Use | k | 340 | 336 | 323 | 300 | 280 | 260 | 235 |
| 5. | Keyp. & Ver. with Comp. | k | 323 | 326 | 323 | 300 | 280 | 260 | 235 |
| 6. | Key-to-Tape Kbds. in Use | k | 60.5 | 52.3 | 46.0 | 32.5 | 30.0 | 27.5 | 25.0 |
| 7. | Key-to-Disk Kbds. in Use | k | 17.5 | 44.0 | 60.0 | 68.5 | 77.0 | 82.0 | 84.0 |
| 7a. | Key-to-Diskette Kbds. in Use | | | | 20.0 | 51.4 | 76.5 | 95.0 | 110.0 |
| 8. | Total Keyboards in Use | k | 401.0 | 422.3 | 449.0 | 452.4 | 463.5 | 464.5 | 454.0 |
| 12. | Keyp. & Ver.–Value in Use | $B | 1.421 | 1.630 | 1.615 | 1.500 | 1.400 | 1.300 | 1.175 |
| 13. | Key-to-Tape–Value in Use | $B | .484 | .471 | .414 | .293 | .270 | .248 | .225 |
| 14. | Key-to-Disk–Value in Use | $B | .140 | .264 | .360 | .411 | .462 | .492 | .504 |
| 14a. | Key-to-Diskette–Value in Use | | | | .100 | .257 | .383 | .475 | .550 |
| 15. | Tot. Kbd. Val. in Use | $B | 2.045 | 2.365 | 2.489 | 2.461 | 2.515 | 2.515 | 2.454 |

| Line | Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| 16. | OCR Systems–No. in Use | k | 2.2 | 2.6 | 3.2 | 3.5 | 3.8 | 5.1 | 7.4 |
| 17. | Value in Use | $B | .330 | .390 | .480 | .525 | .545 | .700 | .975 |
| 18. | MICR Systems–No. in Use | k | 4.4 | 4.6 | 4.8 | 4.9 | 5.0 | 5.0 | 5.0 |
| 19. | Value in Use | $B | .320 | .330 | .345 | .343 | .350 | .350 | .350 |
| 20. | Grand Tot. Val. in Use | $B | 2.695 | 3.085 | 3.314 | 3.329 | 3.410 | 3.565 | 3.779 |
| | % of Tot. Keyboard Value | | | | | | | | |
| 21. | Keyp. & Ver. | % | 69.5 | 68.9 | 64.9 | 61.0 | 55.7 | 51.7 | 47.9 |
| 22. | Key-to-Tape Keyboards | % | 23.7 | 19.9 | 16.6 | 11.9 | 10.7 | 9.9 | 9.2 |
| 23. | Key-to-Disk Keyboards | % | 6.8 | 11.2 | 14.5 | 16.7 | 14.4 | 19.6 | 20.5 |
| 23a. | Key-to-Diskette Kbds. | | | | 4.0 | 10.4 | 15.2 | 18.9 | 22.4 |
| | % of Tot. Data Entry Value | | | | | | | | |
| 24. | Keyboards | % | 75.9 | 76.7 | 75.1 | 73.9 | 73.8 | 70.5 | 64.9 |
| 25. | OCR | % | 12.2 | 12.6 | 14.5 | 15.8 | 16.0 | 19.6 | 25.8 |
| 26. | MICR | % | 11.9 | 10.7 | 10.4 | 10.3 | 10.3 | 9.8 | 9.3 |

# TABLE II.1.24a COMMUNICATIONS AND TERMINALS

| Line | Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | **Communications** | | | | | | | | |
| | Data Sets in Use | | | | | | | | |
| 1a. | Low Speed, Asynch | k | | | | | | 555 | |
| 1b. | Medium Speed, Asynch | k | | | | | | 230 | |
| 4a. | Medium Speed, Synch | k | | | | | | 80 | |
| 7a. | High Speed, Synch | k | | | | | | 32 | |
| 7b. | Wideband | k | | | | | | 5.7 | |
| 16. | Grand Total Data Sets | k | 400 | 510 | 610 | 710 | 810 | 902.7 | 1000 |
| 34. | Total D.S. Lease Rev. | $B/yr | .168 | .214 | .256 | .298 | .340 | .379 | .420 |
| | Carriage of Data Per Year | | | | | | | | |
| 35. | Total Carriage of Data | $B/yr | .500 | .590 | .675 | .750 | .850 | 1.045 | 1.255 |
| 36. | Carriage of Data per D.S. | $k/yr | 1.25 | 1.16 | 1.11 | 1.06 | 1.05 | 1.15 | 1.26 |
| | **Terminals** | | | | | | | | |
| 43a. | General Purpose, in Use | k | 305. | 416. | 570. | 771.1 | 1028.0 | 1381.3 | 1785.0 |
| 43b. | Value | $B | .530 | | 1.215 | 1.526 | 1.899 | 2.316 | 2.754 |
| 44. | Keyboard-Printers–No. | k | 215. | 285. | 375. | 494.0 | 584.7 | 713.3 | 861.5 |
| 45. | Value at $4k | $B | .860 | 1.081 | 1.528 | 2.237 | 2.835 | 3.679 | 4.718 |
| 45a. | Conversational–No. | k | | 245. | 303.5 | 362.0 | 400.4 | 457.8 | 515.0 |
| 45b. | Value | $B | | .711 | .850 | .977 | 1.080 | 1.235 | 1.390 |
| 45c. | Editing–No. | k | | 10.0 | 12.5 | 20.0 | 29.3 | 37.0 | 45.7 |
| 45d. | Value | $B | | .070 | .088 | .140 | .205 | .259 | .320 |
| 45e. | Processing–No. | k | | 30.0 | 59.0 | 112.0 | 155.0 | 218.5 | 300.8 |
| 45f. | Value | $B | | .300 | .590 | 1.120 | 1.550 | 2.185 | 3.008 |
| 46. | Cathode-Ray-Tube–No. | k | 90 | 131.0 | 195.0 | 277.1 | 443.3 | 668.0 | 923.5 |
| 47. | Value at $4k | $B | .360 | .490 | .709 | .965 | 1.422 | 2.110 | 2.901 |
| 47a. | Conversational–No. | k | | 17.0 | 27.0 | 47.0 | 98.9 | 162.2 | 229.0 |
| 47b. | Value | $B | | .034 | .054 | .090 | .178 | .292 | .412 |
| 47c. | Editing–No. | k | | 114.0 | 168.0 | 230.1 | 344.4 | 505.8 | 694.5 |
| 47d. | Value | $B | | .456 | .655 | .875 | 1.244 | 1.818 | 2.489 |
| | Application-Oriented–In Use | | | | | | | | |
| 47e. | Total | k | 145. | | 334.5 | 408.3 | 525.0 | 652.0 | 780.4 |
| 47f. | Value | $B | .530 | | 1.215 | 1.526 | 1.899 | 2.316 | 2.754 |
| 50. | Banking–No. | k | 20. | | 54. | 75.3 | 112.0 | 150.9 | 189.8 |
| 51. | Value at $8k | $B | .160 | | .405 | .551 | .721 | .900 | 1.078 |
| 51a. | Teller Terminals–No. | k | | | 47.5 | 63.0 | 90.7 | 119.5 | 147.3 |
| 51b. | Value | $B | | | .322 | .406 | .530 | .658 | .783 |
| 51c. | ATM–No. | k | | | 2.5 | 4.3 | 5.3 | 6.4 | 7.5 |
| 51d. | Value | $B | | | .075 | .129 | .159 | .192 | .225 |
| 51e. | FTT–No. | k | | | 4.0 | 8.0 | 16.0 | 25.0 | 35.0 |
| 51f. | Value | $B | | | .008 | .016 | .032 | .050 | .070 |
| 52. | Point-of-Sale–No. | k | 15. | | 108.0 | 148.5 | 191.0 | 241.1 | 293.6 |
| 53. | Value | $B | .060 | | .387 | .543 | .695 | .874 | 1.060 |
| 53a. | General Merchandise–No. | k | | | 98.0 | 126.5 | 152.0 | 179.1 | 198.6 |
| 53b. | Value | $B | | | .353 | .468 | .562 | .663 | .737 |
| 53c. | Supermarket–No. | k | | | 10.0 | 22.0 | 39.0 | 62.0 | 95.0 |
| 53d. | Value | $B | | | .034 | .075 | .133 | .211 | .323 |
| 54. | Stock Quotation–No. | k | 40. | | 48.5 | 47.0 | 46.0 | 45.0 | 45.0 |
| 55. | Value at $4k | $B | .160 | | .194 | .188 | .184 | .180 | .180 |
| 56. | Credit Authorization–No. | k | 30. | | 55.0 | 65.0 | 78.0 | 86.0 | 84.0 |
| 57. | Value | $B | .030 | | .033 | .039 | .047 | .052 | .050 |
| 58. | Data Collection–No. | k | 40. | | 67.0 | 68.5 | 90.0 | 116.0 | 148.0 |
| 59. | Value | $B | .120 | | .188 | .189 | .220 | .258 | .306 |
| 59a. | Other–No. | k | | | 2.0 | 4.0 | 8.0 | 13.0 | 20.0 |
| 59b. | Value | $B | | | .008 | .016 | .032 | .052 | .080 |
| | Machine-to-Machine–In Use | | | | | | | | |
| 60. | Remote Batch | k | 11. | | 18.4 | 20.5 | 21.2 | 20.4 | 20.3 |
| 61. | Value at $16k-$25k | $B | .190 | | .313 | .397 | .435 | .436 | .455 |
| 62. | Total Terminals in Use | k | 461. | | 922.9 | 1199.9 | 1574.2 | 2053.7 | 2585.7 |
| 63. | Total Value in Use | $B | 1.940 | 2.800 | 3.765 | 5.125 | 6.591 | 8.541 | 10.828 |
| 64. | Average Value in Use | $k | 4.21 | | 4.08 | 4.27 | 4.19 | 4.16 | 4.19 |
| | **Summary** | | | | | | | | |
| 65. | GP. Systs. Having Comm. | k | 13.0 | | 13.4 | | 13.8 | | 14.0 |
| 65a. | Minisystems Having Comm. | k | 2.7 | | 7.7 | | 16.2 | | 33.0 |
| 65b. | Tot. U.S.–Syst. Having Comm. | k | 15.7 | | 21.1 | | 30.0 | | 47.0 |
| 65c. | GP Systems Having Terminals | k | 14.0 | | 17.0 | | 18.0 | | 19.0 |
| 65d. | Minisystems Having Term. | k | 7.2 | | 17.3 | | 32.5 | | 63.3 |
| 65e. | SBC's Having Terminals | k | .1 | | .5 | | 2.7 | | 7.3 |
| 65f. | Tot. U.S. Syst Having Term. | k | 21.3 | | 34.8 | | 53.2 | | 89.6 |
| 67. | Data Sets Per System | | 25.5 | | 28.9 | | 27.0 | | 21.2 |
| 68. | Terminals Per System | | 21.6 | | 26.5 | | 29.6 | | 28.9 |
| 69. | Terminals Per Data Set | | 1.15 | | 1.52 | 1.69 | 1.94 | 2.27 | 2.59 |
| 70. | Cost Per System–Data Sets | $k/yr | 10.7 | | 12.1 | | 11.3 | | 8.9 |
| 71. | Carriage of Data | $k/yr | 31.8 | | 32.0 | | 28.3 | | 26.7 |
| 72. | Terminal Investment | $k | 91 | | 108 | | 124 | | 121 |
| 73. | Total Data Revenues | $B/yr | .668 | .804 | .931 | 1.048 | 1.190 | 1.424 | 1.675 |
| | Terminals | | | | | | | | |
| 75. | Percent of Total No.–GP | % | 66.2 | | 61.8 | 64.3 | 65.3 | 67.3 | 69.0 |
| 76. | Keyboard–Printers | % | 46.6 | | 40.6 | 41.2 | 37.1 | 34.7 | 33.3 |
| 77. | CRT's | % | 19.5 | | 21.1 | 23.1 | 28.2 | 32.5 | 35.7 |
| 78. | Application-Oriented | % | 31.4 | | 36.2 | 34.0 | 33.3 | 31.7 | 30.2 |
| 78a. | Banking | % | 4.3 | | 5.9 | 6.3 | 7.1 | 7.3 | 7.3 |
| 80. | Stock Quotation | % | 8.7 | | 5.3 | 3.9 | 2.9 | 2.2 | 1.7 |
| 81. | Data Collection | % | 8.7 | | 7.3 | 5.7 | 5.7 | 5.6 | 5.7 |
| 81a. | Point-of-Sale | % | 3.3 | | 11.7 | 12.4 | 12.1 | 11.7 | 11.4 |
| 81b. | Credit Authorization | % | 6.5 | | 6.0 | 5.4 | 5.0 | 4.2 | 3.2 |
| 82. | Machine-to-Machine | % | 2.4 | | 2.0 | 1.7 | 1.3 | 1.0 | 0.8 |
| 83. | Percent of Total Value–GP | % | 62.9 | | 59.4 | 62.5 | 64.6 | 67.8 | 70.4 |
| 84. | Keyboard-Printers | % | 44.3 | | 40.6 | 43.6 | 43.0 | 43.1 | 43.6 |
| 85. | CRT's | % | 18.6 | | 18.8 | 18.8 | 21.6 | 24.7 | 26.8 |
| 86. | Application-Oriented | % | 27.3 | | 32.3 | 29.8 | 28.8 | 27.1 | 25.4 |
| 88. | Stock Quotation | % | 8.2 | | 5.2 | 3.7 | 2.8 | 2.1 | 1.7 |
| 89. | Data Collection | % | 6.2 | | 5.0 | 3.7 | 3.3 | 3.0 | 2.8 |
| 89a. | Point-of-Sale | % | 3.1 | | 10.3 | 10.6 | 10.5 | 10.2 | 9.8 |
| 89b. | Banking | % | 8.2 | | 10.8 | 10.8 | 10.9 | 10.5 | 10.0 |
| 89c. | Credit Authorization | % | 1.5 | | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 |
| 90. | Machine-to-Machine | % | 9.8 | | 8.3 | 7.7 | 6.6 | 5.1 | 4.2 |

## TABLE II.1.25a SOFTWARE

| Line | Item | Figure | Units | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **User Costs** | | | | | | | | | | | | |
| 1. | Salaries–System Analysts | 1.25.2 | $B | 1.477 | 1.794 | 1.966 | 2.181 | 2.431 | 2.714 | 3.095 | 3.744 | 4.612 | 5.609 |
| 2. | Programmers | 1.25.2 | $B | 1.535 | 1.862 | 2.102 | 2.348 | 2.527 | 2.839 | 3.402 | 4.147 | 5.009 | 6.088 |
| 3. | Total | | $B | 3.012 | 3.656 | 4.068 | 4.529 | 4.958 | 5.554 | 6.497 | 7.891 | 9.621 | 11.697 |
| 4. | Overhead Ratio | | % | 53 | 54 | 54 | 54 | 55 | 57 | 57 | 58 | 58 | 59 |
| 5. | Total User Software Costs | 1.25.2 | $B | 4.609 | 5.630 | 6.264 | 6.975 | 7.685 | 8.719 | 10.200 | 12.468 | 15.202 | 18.598 |
| 5a. | % of U.S. GP Value in Use | | % | 24.1 | 26.3 | 26.9 | 28.2 | 28.2 | 32.2 | 30.2 | 32.9 | 35.4 | 38.2 |
| | **Software Industry** | | | | | | | | | | | | |
| 6. | Custom Software | 1.25.3 | $B | .290 | .315 | .340 | .360 | .385 | .420 | .455 | .500 | .575 | .630 |
| 7. | Standard Packages–Tot. | 1.25.3 | $B | .050 | .060 | .075 | .110 | .220 | .410 | .635 | .875 | 1.155 | 1.480 |
| 7a. | Independents (WW) | | $M | | | | 65 | 120 | 190 | 275 | 370 | 500 | 670 |
| 7b. | System Mfgrs. | | $M | | | | 45 | 100 | 220 | 360 | 505 | 655 | 810 |
| 8. | Total Revenue | 1.25.3 | $B | .340 | .375 | .415 | .470 | .605 | .830 | 1.090 | 1.375 | 1.730 | 2.110 |
| | **Suppliers' Devel. Costs** | | | | | | | | | | | | |
| 9. | Total Software Dev. Cost | 1.25.4 | $B | .160 | .184 | .208 | .235 | .256 | .302 | .346 | .380 | .424 | .470 |
| 9a. | % of Total Dev. Costs | 1.25.4 | % | 33.1 | 33.9 | 34.4 | 35.1 | 35.2 | 37.1 | 36.8 | 37.1 | 37.0 | 37.2 |
| | **Summary** | | | | | | | | | | | | |
| 10. | Total Software Costs | 1.25.1 | $B | 5.109 | 6.189 | 6.887 | 7.680 | 8.546 | 9.851 | 11.636 | 14.223 | 17.356 | 21.179 |
| 11. | Percent of Tot.–Users | | % | 90.2 | 91.0 | 91.0 | 90.8 | 89.9 | 88.5 | 87.7 | 87.7 | 87.6 | 87.8 |
| 12. | Software Industry | 1.25.1 | % | 6.7 | 6.1 | 6.0 | 6.1 | 7.1 | 8.4 | 9.4 | 9.7 | 10.0 | 10.0 |
| 13. | Suppliers | 1.25.1 | % | 3.1 | 3.0 | 3.0 | 3.1 | 3.0 | 3.1 | 3.0 | 2.7 | 2.4 | 2.2 |

## TABLE II.1.26a SERVICE INDUSTRIES

| Line | Item | Figure | Units | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Total Service Revenue | 1.26.1 | $M | 1370 | 1760 | 2085 | 2480 | 3100 | 3850 | 4620 | 5455 | 6490 | 7685 |
| 2. | Batch Data Processing | 1.26.1 | $M | 740 | 945 | 1075 | 1235 | 1405 | 1580 | 1740 | 1860 | 1935 | 2100 |
| 2a. | Raw Power | | $M | | 100 | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 |
| 2b. | Regular Calculations | | $M | | 825 | 950 | 1110 | 1280 | 1460 | 1625 | 1750 | 1830 | 1995 |
| 2c. | Access Common Files | | $M | | 20 | 30 | 35 | 40 | 40 | 40 | 40 | 40 | 45 |
| 3. | On-Line Proc'sng–Tot. | 1.26.1 | $M | 210 | 330 | 450 | 585 | 835 | 1105 | 1375 | 1725 | 2250 | 2815 |
| 4. | Remote Batch | | $M | 50 | 87 | 115 | 145 | 205 | 280 | 350 | 565 | 840 | 1077 |
| 4a. | Raw Power | | $M | | 80 | 100 | 122 | 165 | 210 | 270 | 325 | 410 | 505 |
| 4b. | Regular Calculations | | $M | | 5 | 10 | 15 | 30 | 55 | 65 | 225 | 415 | 555 |
| 4c. | Access Common Files | | $M | | 2 | 5 | 8 | 10 | 15 | 15 | 15 | 15 | 17 |
| 5. | Interactive | | $M | 160 | 243 | 335 | 440 | 630 | 825 | 1025 | 1160 | 1410 | 1738 |
| 5a. | Raw Power | | $M | | 145 | 185 | 228 | 300 | 370 | 455 | 525 | 635 | 770 |
| 5b. | Regular Calculations | | $M | | 25 | 65 | 110 | 175 | 265 | 350 | 365 | 430 | 530 |
| 5c. | Access Common Files | | $M | | 73 | 85 | 102 | 155 | 190 | 220 | 270 | 345 | 438 |
| 5d. | Sub-total–All DP | | $M | 950 | 1275 | 1525 | 1820 | 2240 | 2685 | 3115 | 3585 | 4185 | 4915 |
| 6. | Software–Total | 1.26.1 | $M | 340 | 375 | 415 | 470 | 605 | 830 | 1090 | 1375 | 1730 | 2110 |
| 7. | Custom W.W. | | $M | 290 | 315 | 340 | 360 | 385 | 420 | 455 | 500 | 575 | 630 |
| 8. | Std. Packages | | $M | 50 | 60 | 75 | 110 | 220 | 410 | 635 | 875 | 1155 | 1480 |
| 9. | Facilities Management | 1.26.1 | $M | 80 | 110 | 145 | 190 | 255 | 335 | 415 | 495 | 575 | 660 |
| | Proportion of Total Revenue | | | | | | | | | | | | |
| 14. | Batch Data Processing | 1.26.2 | % | 54.0 | 53.7 | 51.6 | 49.8 | 45.3 | 41.0 | 37.4 | 34.1 | 29.8 | 27.3 |
| 15. | On-Line Processing–Tot. | | % | 15.3 | 18.8 | 21.6 | 23.6 | 26.9 | 28.7 | 29.9 | 31.6 | 34.7 | 36.6 |
| 16. | Remote Batch | | % | 3.6 | 4.9 | 5.5 | 5.8 | 6.6 | 7.3 | 7.6 | 10.4 | 12.9 | 14.0 |
| 17. | Interactive | | % | 11.7 | 13.8 | 16.1 | 17.7 | 20.3 | 21.4 | 22.3 | 21.3 | 21.7 | 22.6 |
| 18. | Software–Total | 1.26.2 | % | 24.8 | 21.3 | 19.9 | 19.0 | 19.5 | 21.6 | 23.7 | 25.2 | 26.7 | 27.5 |
| 19. | Custom | | % | 21.2 | 17.9 | 16.3 | 14.5 | 12.4 | 10.9 | 9.9 | 9.2 | 8.9 | 8.2 |
| 20. | Std. Packages | | % | 3.6 | 3.4 | 3.6 | 4.4 | 7.1 | 10.6 | 13.8 | 16.0 | 17.8 | 19.3 |
| 21a. | Facilities Mgmt. | 1.26.2 | % | 5.8 | 6.3 | 7.0 | 7.7 | 8.2 | 8.7 | 9.0 | 9.1 | 8.9 | 8.6 |
| 22. | Tot. Rev., Excl. Software | 1.20.5 | $M | 1030 | 1385 | 1670 | 2010 | 2495 | 3020 | 3510 | 4080 | 4760 | 5575 |
| | ADAPSO Reports | | | | | | | | | | | | |
| 23. | Total Service Revenue | | $B | | | | | | | 4.580 | 5.325 | 6.3 | 7.5 |
| 23a. | Processing Revenue | | $B | | | | | | | 3.290 | 3.605 | 4.7 | 5.6 |
| 26. | Software–Total | | $B | | | | | | | 0.922 | 1.225 | 0.6 | 0.76 |
| 29. | Facilities Management | | $B | | | | | | | | .495 | | |
| 29a. | Professional Services | | $B | | | | | | | .368 | | 1.0 | 1.2 |
| | Proportion of All DP Revenue | | | | | | | | | | | | |
| 32. | Batch DP | 1.26.2b | % | 77.9 | 74.1 | 70.5 | 67.9 | 62.7 | 58.8 | 55.9 | 51.9 | 46.2 | 42.7 |
| 33. | Remote Batch | 1.26.2b | % | 5.3 | 6.8 | 7.5 | 8.0 | 9.2 | 10.4 | 11.2 | 15.8 | 20.1 | 21.9 |
| 34. | Raw Power | | % | | 6.3 | 6.6 | 6.7 | 7.4 | 7.8 | 8.7 | 9.1 | 9.8 | 10.3 |
| 35. | Regular Calculations | | % | | 0.4 | 0.7 | 0.8 | 1.3 | 2.0 | 2.1 | 6.3 | 9.9 | 11.3 |
| 36. | Interactive | 1.26.2b | % | 16.8 | 19.1 | 22.0 | 24.2 | 28.1 | 30.7 | 32.9 | 32.4 | 33.7 | 35.4 |
| 37. | Raw Power | 1.26.3a | % | | 11.4 | 12.1 | 12.5 | 13.4 | 13.8 | 14.6 | 14.6 | 15.2 | 15.7 |
| 38. | Regular Calculations | 1.26.3a | % | | 2.0 | 4.3 | 6.0 | 7.8 | 9.9 | 11.2 | 10.2 | 10.3 | 10.8 |
| 39. | Access Common Files | 1.26.3a | % | | 5.7 | 5.6 | 5.6 | 6.9 | 7.1 | 7.1 | 7.5 | 8.2 | 8.9 |
| 40. | Raw Power | | % | | 25.5 | 24.9 | 24.2 | 24.6 | 24.6 | 25.7 | 25.7 | 26.5 | 27.7 |
| 41. | Regular Calculations | | | | 67.1 | 67.2 | 67.9 | 66.3 | 66.3 | 65.5 | 65.3 | 63.9 | 62.7 |
| 42. | Access Common Files | | % | | 7.5 | 7.9 | 8.0 | 9.2 | 9.1 | 8.8 | 9.1 | 9.6 | 10.2 |

## TABLE II.1.27a SUPPLIES

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Continuous Forms** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | US Dept of Comm—Tot Biz Forms | | $M | | | | | 598.4 | 631.9 | 700.2 | 793.7 | 895.8 | 990.6 | 1113.5 | 1199.1 | 1242.3 | 1381.9 | 1648.7 | 2139.2 | 2106.2 | 2226.1 | 2471. | 2768. |
| 2. | Percent Printer Cont. Forms | | % | | | | | 40.1 | | | | 46.0 | | | | | 49.7 | | | | | | |
| 3. | Shipments | | $M | | | | | 239.7 | 262. | 301. | 353. | 412.1 | 475. | 557. | 609. | 625. | 686.5 | 825 | 1080 | 1075 | 1145 | 1285 | 1453 |
| 4. | Cont. Forms for EDP | 1.27.2 | $M | 34 | 50 | 73 | 98 | 144 | 173 | 217 | 268 | 330 | 394 | 490 | 554 | 581 | 652 | 800 | 1050 | 1050 | 1120 | 1280 | 1450 |
| 4a. | For GP Systems | | $M | 34 | 50 | 73 | 98 | 144 | 173 | 217 | 268 | 329 | 392 | 486 | 547 | 572 | 638 | 779 | 1012 | 995 | 1032 | 1140 | 1247 |
| 4b. | For Mini/SBC Systems | | $M | | | | | | | | | 1 | 2 | 4 | 7 | 9 | 14 | 21 | 38 | 55 | 88 | 140 | 203 |
| 5a. | Per GP Printer | 1.27.2 | $k/yr | 15.6 | 15.2 | 15.0 | 14.8 | 14.6 | 11.9 | 11.4 | 10.9 | 11.4 | 10.8 | 11.8 | 11.8 | 10.7 | 10.1 | 10.1 | 11.8 | 11.4 | 12.1 | 13.5 | 14.8 |
| 5b. | Per Mini/SBC Printer | | $k | | | | | | | | | 1.1 | 1.1 | 1.2 | 1.2 | 1.1 | 1.0 | 1.0 | 1.2 | 1.1 | 1.2 | 1.3 | 1.5 |
| | **Tabulating Cards** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Card Cost Per 1000—80 By | 1.27.5a | $/k | 1.11 | 1.06 | 1.03 | .99 | .97 | .93 | .91 | .89 | .88 | .90 | .92 | .95 | .98 | 1.04 | 1.13 | 1.30 | 1.50 | 1.73 | 2.00 | 2.30 |
| 6a. | 96-Byte | | $/k | | | | | | | | | | | | | | .55 | .75 | | | | | 1.35 |
| 6b. | Per Ton | | $ | 365 | 338 | 339 | 355 | 376.1 | 385 | 394 | 405 | 417.3 | 408 | 406 | 403 | 401 | 407.2 | 427 | 478 | 557 | 659 | 780.9 | 942 |
| 9. | No. Cards for EDP Keyp. | | B | 3.5 | 4.9 | 7.0 | 9.1 | 13 | 19 | 25 | 33 | 39 | 44 | 49 | 52 | 56 | 59 | 59 | 59 | 55 | 51 | 47 | 43 |
| 10. | Ship Value of Cards | 1.27.3 | $M | 3.9 | 5.2 | 7.2 | 9.0 | 12.6 | 17.7 | 22.8 | 29.4 | 34.3 | 39.6 | 45.1 | 49.4 | 54.9 | 61.4 | 66.7 | 76.7 | 82.5 | 88.2 | 94.0 | 98.9 |
| 11. | Ship Value of All Cards | 1.27.3 | $M | 27 | 44 | 59 | 73 | 92 | 108 | 130 | 148 | 164 | 166 | 175 | 178 | 179 | 183 | 187 | 191 | 196 | 203 | 208.7 | 215 |
| 11a. | Tab Card Shipments | | $M | 95 | 110 | 120 | 128 | 136.5 | 139 | 142 | 145 | 148.2 | 142 | 139 | 135 | 130 | 128.6 | 128 | 129 | 131 | 135 | 139.7 | 145 |
| 11b. | Tab Card Forms | | $M | 2 | 5 | 8 | 10 | 17.3 | 24 | 39 | 50 | 56.3 | 58 | 60 | 61 | 62 | 64.2 | 6.5 | 66 | 67 | 68 | 69 | 70 |
| 11c. | Total Tab Cards | | $M | 97 | 115 | 128 | 138 | 153.8 | 163 | 181 | 195 | 204.5 | 200 | 199 | 196 | 192 | 192.8 | 193 | 195 | 198 | 203 | 208.7 | 215 |
| 11d. | Tab Card Shipments (wt.) | | Tons | 260 | 325 | 354 | 361 | 362.9 | 361 | 360 | 358 | 355.1 | 348 | 342 | 335 | 324 | 315.8 | 300 | 270 | 235 | 205 | 178.9 | 154 |
| 12. | Ship Value Comp Punched Cards | | $M | 23.1 | 38.8 | 51.8 | 64.0 | 79.4 | 90.3 | 107.2 | 118.6 | 129.7 | 126.4 | 129.9 | 128.6 | 124.1 | 121.6 | 120.3 | 114.3 | 113.5 | 114.8 | 114.7 | 116.1 |
| 13. | Per Card Punch | | $k/yr | 10.8 | 12.1 | 11.0 | 9.9 | 8.3 | 6.4 | 5.8 | 5.1 | 4.8 | 4.0 | 3.8 | 3.6 | 3.3 | 2.9 | 2.5 | 2.3 | 2.3 | 2.4 | 2.5 | 2.5 |
| 14. | No. Cards Per Card Punch | | M | 9.7 | 11.4 | 10.7 | 10.0 | 8.6 | 6.9 | 6.4 | 5.7 | 5.5 | 4.4 | 4.1 | 3.8 | 3.4 | 2.8 | 2.2 | 1.8 | 1.5 | 1.4 | 1.3 | 1.1 |
| | **Magnetic Tape Reels** | | | | | | | | | | | | | | | | | | | | | | |
| 15. | MT Cost Per Reel | 1.27.5b | $ | 50 | 50 | 47 | 44 | 40 | 36 | 32 | 28 | 24 | 15.1 | 13.6 | 13.6 | 13.1 | 10.4 | 8.3 | 10.5 | 9.8 | 9.0 | 9.6 | 9.8 |
| 16. | Tapes Per Drive In Use | | | 50 | 60 | 80 | 100 | 120 | 140 | 160 | 153 | 165 | 176 | 193 | 193 | 183 | 175 | 184 | 183 | 185 | 188 | 180 | 171 |
| 16a. | On GP Systems | 1.27.6a | | 50 | 60 | 80 | 100 | 120 | 140 | 160 | 155 | 169 | 183 | 210 | 220 | 218 | 223 | 250 | 270 | 294 | 331 | 347 | 339 |
| 16b. | On Minis and SBC's | | | | | | | | | | 15 | 15 | 15 | 15 | 15 | 16 | 17 | 20 | 25 | 30 | 35 | 40 | 45 |
| 17. | Total Tapes In Use | 1.27.7 | M | .145 | .372 | .912 | 1.72 | 3.05 | 5.21 | 7.95 | 9.9 | 12.5 | 15.6 | 19.0 | 20.8 | 22.2 | 25.5 | 31.1 | 36.4 | 40.6 | 44.7 | 48.7 | 52.6 |
| 20. | Total Tapes Shipped | | M | .085 | .227 | .544 | .825 | 1.37 | 2.25 | 2.97 | 3.2 | 4.0 | 5.0 | 5.7 | 4.7 | 4.5 | 6.6 | 9.4 | 9.9 | 9.7 | 10.1 | 10.7 | 11.2 |
| 21. | Shipment Value | 1.27.4 | $M | 4.30 | 11.4 | 25.6 | 36.3 | 54.7 | 80.8 | 95.0 | 89.6 | 96.0 | 75.5 | 77.5 | 63.8 | 59.3 | 68.8 | 78.1 | 83.3 | 95.6 | 90.5 | 102.7 | 109.8 |
| 21a. | GP Systems | | $M | 4.30 | 11.4 | 25.6 | 36.3 | 54.7 | 80.8 | 95.0 | 89.4 | 95.4 | 74.5 | 76.1 | 62.1 | 57.4 | 64.8 | 73.6 | 72.2 | 83.0 | 73.7 | 76.4 | 79.1 |
| 21b. | Minis, and SBC's | | $M | | | | | | | | .2 | .6 | 1.0 | 1.4 | 1.7 | 1.9 | 4.0 | 4.5 | 11.1 | 12.6 | 16.8 | 26.3 | 30.7 |
| 21c. | Worldwide | | $M | 4.3 | 12 | 29 | 44 | 68 | 105 | 124 | 116 | 124 | 92.6 | 93.4 | 85.1 | 79.1 | 88.6 | 103.2 | 114.9 | 129.7 | 126.6 | 140.0 | 151.0 |
| 22. | Tot. Tape Capy.—Off-Line | 1.27.8 | MMBy | .725 | 3.24 | 9.67 | 20.3 | 37.8 | 66.1 | 106 | 143 | 195 | 257 | 323 | 363 | 410 | 474 | 609 | 751 | 879 | 1058 | 1252 | 1457 |
| | **Disk Packs,** Domestic | | | | | | | | | | | | | | | | | | | | | | |
| | Packs in Use, Per Spindle | | | | | | | | | | | | | | | | | | | | | | |
| 24. | For 2314/2319 | 1.27.6 | | | | | | | | | | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.4 | | | | | |
| 25. | For 3330 | 1.27.6 | | | | | | | | | | | | | | 2.0 | 2.1 | 2.3 | 2.4 | 2.7 | 3.1 | 3.5 | 4.0 |
| 25a. | For 3340 | 1.27.6a | | | | | | | | | | | | | | | | | 1.8 | 1.9 | 2.1 | 2.3 | 2.5 |
| 28. | For 2311—Tot. Packs in Use | | k | | | | | | | 2 | 20 | 61 | 140 | 222 | 260 | 213 | 207 | 183 | 178 | 153 | 123 | 98 | 77 |
| 29. | Packs Shipped | | k | | | | | | | 2 | 18 | 41 | 79 | 82 | 38 | 20 | 10 | | | | | | |
| 30. | Price Per Pack | 1.27.5a | $ | | | | | | | 490 | 450 | 400 | 350 | 300 | 300 | 300 | 300 | | | | | | |
| 31. | Shipped Value | | $M | | | | | | | 1.0 | 8.1 | 16.4 | 27.7 | 24.6 | 11.4 | 6.0 | 3.0 | | | | | | |
| 32. | 2314—Total Spindles | | | | | | | | | | | 5.0 | 15.4 | 30.6 | 52.4 | 69.2 | 73.4 | 83.7 | 73.5 | 59.8 | 53.1 | 47.0 | 42.0 |
| 33. | For 2314/9—Tot. Packs in Use | | k | | | | | | | | | 17 | 51 | 100 | 173 | 228 | 245 | 285 | 275 | 246 | 236 | 225 | 215 |
| 34. | Packs Shipped | | k | | | | | | | | | 17 | 34 | 49 | 73 | 55 | 17 | 40 | 25 | 22 | 18 | 16 | 14 |
| 35. | Price Per Pack | 1.27.5a | $ | | | | | | | | | 650 | 600 | 500 | 400 | 350 | 300 | 250 | 200 | 150 | 130 | 130 | 130 |
| 36. | Shipped Value | | $M | | | | | | | | | 11.1 | 20.4 | 24.5 | 29.2 | 19.3 | 5.1 | 10.0 | 5.0 | 3.3 | 2.3 | 2.1 | 1.8 |
| 37. | 3330—Total Spindles | | K | | | | | | | | | | | | | 2.8 | 12.9 | 30.1 | 51.6 | 66.8 | 76.9 | 80.0 | 80.9 |
| 38. | For 3330—Tot. Packs in Use | | k | | | | | | | | | | | | | 5.6 | 27 | 68 | 126 | 182 | 236 | 281 | 322 |

## TABLE II.1.27a SUPPLIES

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39. | Packs Shipped | | k | | | | | | | | | | | | | 5.6 | 21 | 41 | 58 | 56 | 54 | 45 | 42 |
| 40. | Price Per Pack | 1.27.5a | $ | | | | | | | | | | | | | 1000 | 1000 | 850 | 700 | 650 | 600 | 550 | 500 |
| 41. | Shipped Value | | $M | | | | | | | | | | | | | 5.6 | 21.0 | 34.9 | 40.6 | 36.4 | 32.4 | 24.8 | 21.0 |
| 41a. | 3340—Total Spindles | | k | | | | | | | | | | | | | | | .1 | 4.1 | 22.0 | 31.2 | 42.1 | 50.2 |
| 41b. | For 3340—Tot. Packs in Use | | k | | | | | | | | | | | | | | | .2 | 7.4 | 41 | 66 | 96 | 126 |
| 41c. | Packs Shipped | | k | | | | | | | | | | | | | | | .2 | 7.2 | 34 | 25 | 30 | 30 |
| 41d. | Price per Pack | 1.27.5a | $ | | | | | | | | | | | | | | | 2500 | 2500 | 2000 | 1800 | 1650 | 1380 |
| 41e. | Shipped Value | | $M | | | | | | | | | | | | | | | .5 | 18.0 | 68.0 | 45.0 | 49.5 | 41.4 |
| | **Mini & SBC Disks** | | | | | | | | | | | | | | | | | | | | | | |
| 41f. | Total Mini & SBC MHF in Use | | k | | | | | | | | | | | | 1.9 | 7.6 | 23.8 | 46.3 | 86.2 | 131.4 | 188.8 | 275.8 | 376.8 |
| 41g. | Less than 12 MBytes | | k | | | | | | | | | | | | 1.9 | 7.6 | 23.8 | 46.3 | 86.2 | 131.4 | 187.8 | 270.8 | 366.8 |
| 41h. | Over 12 MBytes | | k | | | | | | | | | | | | | | | | | | 1.0 | 5.0 | 10.0 |
| | Cartridges | | | | | | | | | | | | | | | | | | | | | | |
| 41i. | Less Than 12 MBytes—Shipped | | k | | | | | | | | | | | | 8 | 25 | 72 | 114 | 206 | 267 | 357 | 520 | 655 |
| 41j. | In Use | | k | | | | | | | | | | | | 8 | 33 | 105 | 219 | 424 | 691 | 1048 | 1568 | 2223 |
| 41k. | Price per Cartridge | 1.27.5b | $ | | | | | | | | | | | | 95 | 92 | 90 | 87 | 85 | 82 | 80 | 77 | 75 |
| 41l. | Shipped Value | | $M | | | | | | | | | | | | 0.76 | 2.30 | 6.48 | 9.92 | 17.5 | 21.9 | 28.6 | 40.0 | 49.1 |
| 41m. | Over 12 MBytes—Shipped | | k | | | | | | | | | | | | | | | | | | 2.5 | 11 | 18 |
| 41n. | In Use | | k | | | | | | | | | | | | | | | | | | 2.5 | 14 | 31 |
| 41o. | Price per Cartridge | 1.27.5b | $ | | | | | | | | | | | | | | | | | | 200 | 180 | 160 |
| 41p. | Shipped Value | | $M | | | | | | | | | | | | | | | | | | .50 | 2.0 | 2.9 |
| 45a. | Floppy Disks Shipped | | M | | | | | | | | | | | | | | | .5 | 1.5 | 3.2 | 7.8 | 12.0 | 14.2 |
| 45b. | Price per Disk | 1.27.5b | $ | | | | | | | | | | | | | | | 8.0 | 7.2 | 5.0 | 3.5 | 3.0 | 2.9 |
| 45c. | Shipped Value | | $M | | | | | | | | | | | | | | | 4.0 | 10.8 | 16.0 | 27.3 | 36.0 | 41.2 |
| | International Business | | | | | | | | | | | | | | | | | | | | | | |
| 49. | 2311 Packs—Shipped Value | | $M | | | | | | | | | 4.9 | 9.0 | 12.0 | 14.0 | 9.0 | 6.0 | | | | | | |
| 53. | 2314 Packs—Shipped Value | | $M | | | | | | | | | | 6.5 | 12.0 | 25.0 | 32.0 | 17.5 | 14.0 | | | | | |
| 55. | For 3330—Packs Shipped | | k | | | | | | | | | | | | | 2.0 | 8.8 | 18.9 | 31.5 | 41.3 | 63.4 | 55.8 | 53.8 |
| 56. | Price Per Pack | | $ | | | | | | | | | | | | | 1000 | 1000 | 850 | 700 | 650 | 600 | 550 | 500 |
| 57. | Shipped Value | | $M | | | | | | | | | | | | | 2.0 | 8.8 | 16.1 | 22.1 | 26.8 | 38.0 | 30.7 | 26.9 |
| 58a. | For 3340—Packs Shipped | | k | | | | | | | | | | | | | | | | 3.9 | 25.0 | 29.4 | 37.2 | 38.4 |
| 58b. | Price per Pack | | $ | | | | | | | | | | | | | | | | 2500 | 2000 | 1800 | 1650 | 1380 |
| 58c. | Shipped Value | | $M | | | | | | | | | | | | | | | | 9.8 | 50.0 | 52.9 | 61.4 | 53.0 |
| 58d. | Cartridges Shipped | | $M | | | | | | | | | | | | .160 | .575 | 1.94 | 3.77 | 7.18 | 9.42 | 13.1 | 18.9 | 24.4 |
| | Summary | | | | | | | | | | | | | | | | | | | | | | |
| | Domestic | | | | | | | | | | | | | | | | | | | | | | |
| 59. | Total Packs in Use | 1.27.6 | k | | | | | | | 2 | 20 | 78 | 191 | 322 | 441 | 480 | 584 | 755 | 1010 | 1313 | 1712 | 2282 | 2994 |
| 59a. | On GP Systems | | k | | | | | | | 2 | 20 | 78 | 191 | 322 | 433 | 447 | 479 | 536 | 586 | 622 | 661 | 700 | 740 |
| 59b. | On Minis & SBC's | | k | | | | | | | | | | | | 8 | 33 | 105 | 219 | 424 | 691 | 1051 | 1582 | 2254 |
| 60. | Total Packs Shipped | | k | | | | | | | 2 | 18 | 58 | 113 | 131 | 119 | 106 | 120 | 195 | 296 | 379 | 457 | 622 | 759 |
| 61. | Total Shipped Value | 1.27.4 | $M | | | | | | | 1.0 | 8.1 | 27.5 | 48.1 | 49.1 | 41.36 | 33.20 | 35.58 | 55.32 | 81.10 | 129.9 | 109.0 | 118.4 | 116.2 |
| 61a. | On GP Systems | | $M | | | | | | | 1.0 | 8.1 | 27.5 | 48.1 | 49.1 | 40.6 | 30.9 | 29.1 | 45.4 | 63.6 | 108 | 79.7 | 76.4 | 64.2 |
| 61b. | On Minis & SBC's | | $M | | | | | | | | | | | | 0.76 | 2.30 | 6.48 | 9.92 | 17.5 | 21.9 | 29.1 | 42.0 | 52.0 |
| | International | | | | | | | | | | | | | | | | | | | | | | |
| 64. | Total Shipped Value | | $M | | | | | | | | | 4.9 | 15.5 | 24.0 | 29.16 | 43.58 | 34.24 | 33.87 | 39.08 | 86.22 | 104.0 | 111.0 | 104.3 |
| | Worldwide | | | | | | | | | | | | | | | | | | | | | | |
| 67. | Total Shipped Value | | $M | | | | | | | 1.0 | 8.1 | 32.4 | 63.6 | 73.1 | 80.52 | 76.78 | 69.82 | 89.19 | 120.2 | 216.1 | 213.0 | 229.4 | 220.5 |
| | Off-Line Disk Pack Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 68. | 2311-Type at 7.5MBy | | MMBy | | | | | | | .015 | .150 | .458 | 1.05 | 1.7 | 2.0 | 1.6 | 1.6 | 1.4 | 1.3 | 1.1 | .92 | .74 | .58 |
| 69. | 2314-Type at 25.5MBy | | MMBy | | | | | | | | | .434 | 1.30 | 2.55 | 4.41 | 5.81 | 6.25 | 7.27 | 7.01 | 6.27 | 6.02 | 5.74 | 5.48 |

## TABLE II.1.27a SUPPLIES

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 69a. | 3330 Av. Capy. per Disk | | MBy | | | | | | | | | | | | | | 100 | 100 | 108 | 122 | 124 | 125 | 127 |
| 70. | 3330-Type | | MMBy | | | | | | | | | | | | | | 2.700 | 6.800 | 13.61 | 22.20 | 29.26 | 35.13 | 40.89 |
| 70a. | 3340–Type at 65 MBy | | MMBy | | | | | | | | | | | | | | | .013 | .481 | 2.67 | 4.29 | 6.24 | 8.19 |
| 73. | Total Off-Line Capacity, GP | 1.27.8 | MMBy | | | | | | | .015 | .150 | .892 | 2.35 | 4.250 | 6.410 | 7.410 | 10.55 | 15.48 | 22.40 | 32.24 | 40.49 | 47.85 | 55.14 |
| 73a. | Mini and SBC | | MMBy | | | | | | | | | | | | .0400 | .1650 | .5250 | 1.095 | 2.120 | 3.455 | 5.275 | 8.036 | 11.55 |
| | **Print Ribbons** | | | | | | | | | | | | | | | | | | | | | | |
| 74. | Shipment Value | | $M | 2 | 4 | 5 | 7 | 10 | 12 | 15 | 19 | 23 | 27 | 34 | 39 | 40 | 45 | 55 | 71 | 71 | 73 | 81 | 88 |
| 75. | Per GP Line Printer | | $k | 1.00 | .98 | .96 | .95 | .94 | .76 | .73 | .70 | .73 | .69 | .75 | .75 | .69 | .65 | .65 | .75 | .73 | .78 | .87 | .95 |
| | **Summary** | | | | | | | | | | | | | | | | | | | | | | |
| | Shipments–For GP Systems, U.S. | | | | | | | | | | | | | | | | | | | | | | |
| 76. | Continuous Forms | | $M | 34 | 50 | 73 | 98 | 144 | 173 | 217 | 268 | 329 | 392 | 486 | 547 | 572 | 638 | 779 | 1012 | 995 | 1032 | 1140 | 1247 |
| 77. | Tabulating Cards | | $M | 27 | 44 | 59 | 73 | 92 | 108 | 130 | 148 | 164 | 166 | 175 | 178 | 179 | 183 | 187 | 191 | 196 | 203 | 208.7 | 215 |
| 78. | Magnetic Tape | | $M | 4 | 11 | 26 | 36 | 55 | 81 | 95 | 89 | 95 | 75 | 76 | 62 | 57 | 65 | 74 | 72 | 83 | 74 | 76 | 79 |
| 79. | Disk Packs | | $M | | | | | | | 1 | 8 | 28 | 48 | 49 | 41 | 31 | 29 | 45 | 64 | 108 | 80 | 76 | 64 |
| 80. | Print Ribbons | | $M | 2 | 4 | 5 | 6 | 9 | 11 | 14 | 17 | 21 | 24 | 31 | 35 | 36 | 41 | 50 | 64 | 64 | 66 | 73 | 79 |
| 81. | Total | 1.27.1 | $B | .067 | .109 | .163 | .213 | .300 | .373 | .457 | .530 | .637 | .705 | .817 | .863 | .875 | .956 | 1.135 | 1.403 | 1.446 | 1.445 | 1.514 | 1.684 |
| 82. | Per GP System in Use | | $k | 21.5 | 24.8 | 26.5 | 26.3 | 25.6 | 22.3 | 21.2 | 19.6 | 20.5 | 19.1 | 20.4 | 20.6 | 19.4 | 19.0 | 19.5 | 22.8 | 23.3 | 24.4 | 27.0 | 29.0 |
| | Percentages Of Total | | | | | | | | | | | | | | | | | | | | | | |
| 83. | Continuous Forms | 1.27.1 | % | 50.7 | 45.9 | 44.8 | 46.0 | 48.0 | 46.4 | 47.5 | 50.6 | 51.6 | 55.6 | 59.5 | 63.4 | 65.4 | 66.7 | 68.6 | 72.1 | 68.8 | 70.9 | 72.4 | 74.0 |
| 84. | Tabulating Cards | 1.27.1 | % | 40.3 | 40.4 | 36.2 | 34.3 | 30.7 | 29.0 | 28.4 | 27.9 | 25.7 | 23.5 | 21.4 | 20.6 | 20.5 | 19.1 | 16.5 | 13.6 | 13.6 | 14.0 | 13.3 | 12.8 |
| 85. | Magnetic Tape | 1.27.1 | % | 6.0 | 10.1 | 16.0 | 16.9 | 18.3 | 21.7 | 20.8 | 16.8 | 14.9 | 10.6 | 9.3 | 7.2 | 6.5 | 6.8 | 6.5 | 5.1 | 5.7 | 5.1 | 4.8 | 4.7 |
| 86. | Disk Packs (Domestic) | 1.27.1 | % | | | | | | | 0.2 | 1.5 | 4.4 | 6.8 | 6.0 | 4.8 | 3.5 | 3.0 | 4.0 | 4.6 | 7.5 | 5.5 | 4.8 | 3.8 |
| 87. | Print Ribbons | | % | 3.0 | 3.7 | 3.1 | 2.8 | 3.0 | 2.9 | 3.1 | 3.2 | 3.3 | 3.4 | 3.8 | 4.1 | 4.1 | 4.3 | 4.4 | 4.6 | 4.4 | 4.5 | 4.6 | 4.7 |
| | Capacity | | | | | | | | | | | | | | | | | | | | | | |
| 90. | Total Tape/Disk Off-Line Capy. | | MMBy | .725 | 3.24 | 9.67 | 20.3 | 37.8 | 66.1 | 106 | 143 | 196 | 258 | 327 | 370 | 418 | 485 | 626 | 776 | 915 | 1104 | 1307 | 1524 |
| | Worldwide Shipments by U.S. Firms | | | | | | | | | | | | | | | | | | | | | | |
| 91. | Continuous Forms | | $M | 34 | 50 | 73 | 98 | 144 | 173 | 217 | 268 | 330 | 394 | 490 | 554 | 581 | 652 | 800 | 1050 | 1050 | 1120 | 1280 | 1450 |
| 92. | Tabulating Cards | | $M | 27 | 44 | 59 | 73 | 92 | 108 | 130 | 148 | 164 | 166 | 175 | 178 | 179 | 183 | 187 | 191 | 196 | 203 | 208.7 | 215 |
| 93. | Magnetic Tape | | $M | 4 | 11 | 26 | 36 | 55 | 81 | 95 | 90 | 96 | 76 | 78 | 64 | 59 | 69 | 78 | 83 | 96 | 91 | 103 | 110 |
| 94. | Disk Packs | | $M | | | | | | | 1 | 8 | 32 | 64 | 73 | 81 | 77 | 70 | 89 | 120 | 216 | 213 | 229 | 221 |
| 95. | Floppy Disks | | $M | | | | | | | | | | | | | | | 4 | 11 | 16 | 27 | 36 | 41 |
| 96. | Print Ribbons | | $M | 2 | 4 | 5 | 7 | 10 | 12 | 15 | 19 | 23 | 27 | 34 | 39 | 40 | 45 | 55 | 71 | 71 | 73 | 81 | 88 |
| 97. | Total | | $B | .067 | .109 | .163 | .214 | .301 | .374 | .458 | .533 | .645 | .727 | .850 | .916 | .936 | 1.019 | 1.213 | 1.526 | 1.645 | 1.727 | 1.938 | 2.125 |

## TABLE II.1.30a DATA PROCESSING INDUSTRY REVENUES

| Line | Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | Revenue Breakdowns | | | | | | | | |
| 11. | Burroughs–Tot. Rev. | $B | 1.040 | 1.284 | 1.533 | 1.702 | 1.902 | 2.127 | 2.460 |
| 12. | % GP Systems | % | 85.9 | 83.2 | 84.3 | 85.6 | 84.8 | 84.3 | 85.4 |
| 14. | Control Data Corp.–Tot. Rev. | $B | .664 | .948 | 1.081 | 1.218 | 1.331 | 1.493 | 1.846 |
| 15. | % GP Systems | % | .100 | .100 | 98.6 | 97.5 | 97.6 | 97.6 | 98.1 |
| 16. | % Mini Systems | % | 0 | 0 | 1.4 | 2.5 | 2.4 | 2.4 | 1.9 |
| 17. | Data General–Tot. Rev. | $B | .030 | .053 | .083 | .112 | .197 | .279 | .410 |
| 18. | Digital Equip. Corp.–Tot. Rev. | $B | .188 | .265 | .422 | .534 | .736 | 1.059 | 1.437 |
| 19. | % GP Systems | % | 1.6 | 1.9 | 6.4 | 6.4 | 3.5 | 5.6 | 1.9 |
| 20. | % Mini Systems | % | 98.4 | 98.1 | 93.6 | 93.6 | 96.5 | 94.4 | 98.1 |
| 21. | General Automation–Tot. Rev. | $B | .016 | .030 | .061 | .058 | .075 | .083 | .111 |
| 25. | Hewlett Packard–Tot. Rev. | $B | .479 | .661 | .884 | .981 | 1.112 | 1.360 | 1.728 |
| 26. | % Mini Systems | % | 12.5 | 14.4 | 17.0 | 24.5 | 27.3 | 28.7 | 31.0 |
| 27. | Honeywell–Tot. Rev. | $B | 2.125 | 2.391 | 2.626 | 2.760 | 2.495 | 2.911 | 3.548 |
| 28. | % GP Systems | % | 33.6 | 32.4 | 30.7 | 27.8 | 32.2 | 31.2 | 30.8 |
| 29. | % Mini Systems | % | 2.8 | 2.9 | 1.9 | 3.3 | 4.5 | 4.5 | 5.6 |
| 30. | Perkin-Elmer–Tot. Rev. | $B | | .019 | .033 | .043 | .055 | .086 | .113 |
| 31. | IBM–Tot. Rev. | $B | 9.533 | 10.993 | 12.675 | 14.437 | 16.304 | 18.133 | 21.076 |
| 32. | % GP Systems, w/Supplies | % | 84.0 | 84.0 | 83.0 | 82.1 | 82.2 | 81.3 | 80.6 |
| 33. | % Mini Systems | % | 0 | 0 | 0 | 0 | .02 | .2 | 0.4 |
| 36. | Nat. Cash Register–Tot. Rev. | $B | 1.558 | 1.816 | 1.979 | 2.165 | 2.313 | 2.522 | 2.611 |
| 37. | % GP Systems | % | 42.2 | 48.7 | 56.7 | 65.4 | 72.4 | 77.1 | 85.8 |
| 41. | Syst. Engineer Labs–Tot. Rev. | $B | .016 | .017 | .015 | .008 | .023 | .035 | .050 |
| 42. | Univac (Sperry Rand)–Tot. Rev. | $B | 2.229 | 2.614 | 3.041 | 3.203 | 3.270 | 3.649 | 4.065e |
| 43. | % GP Systems | % | 43.6 | 41.9 | 41.4 | 43.6 | 43.6 | 46.3 | 48.8 |
| 43a. | %Mini–Systems (Varian) | % | 0.4 | 1.0 | 1.1 | 1.2 | 1.3 | 1.0 | 0.9 |

## TABLE II.1.30a DATA PROCESSING INDUSTRY REVENUES

| Line Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| 44. Varian Associates—Tot. Rev | $B | .204 | .241 | .293 | .310 | .342 | | |
| **Total DP System Revenue** | | | | | | | | |
| Including GP & Mini Systems | | | | | | | | |
| 49. Burroughs | $B | .893 | 1.068 | 1.293 | 1.457 | 1.612 | 1.794 | 2.100 |
| 50. Control Data Corp. | $B | .664 | .948 | 1.081 | 1.218 | 1.331 | 1.493 | 1.846 |
| 51. Data General | $B | .030 | .053 | .083 | .112 | .197 | .279 | .410 |
| 52. Digital Equipment Corp. | $B | .188 | .265 | .422 | .534 | .736 | 1.059 | 1.437 |
| 53. General Automation | $B | .016 | .030 | .061 | .058 | .075 | .083 | .111 |
| 55. Hewlett Packard | $B | .060 | .095 | .150 | .240 | .304 | .390 | .535 |
| 56. Honeywell | $B | .774 | .843 | .856 | .856 | .914 | 1.037 | 1.294 |
| 57. Interdata (Perkin-Elmer) | $B | .010 | .019 | .033 | .043 | .055 | .086 | .113 |
| 58. IBM | $B | 8.008 | 9.234 | 10.510 | 11.850 | 13.400 | 14.765 | 17.074 |
| 59. National Cash Register | $B | .657 | .885 | 1.122 | 1.415 | 1.674 | 1.944 | 2.240 |
| 61. SEL | $B | .016 | .017 | .015 | .008 | .023 | .035 | .050 |
| 62. Univac | $B | .980 | 1.123 | 1.294 | 1.433 | 1.467 | 1.726 | 2.020 |
| 63. Varian Associates | $B | .009 | .027 | .034 | .037 | .042 | | |
| 65. Other Mini Manufacturers | $B | .081 | .066 | .212 | .256 | .316 | .455 | .658 |
| 66. Total Revenue | $B | 12.386 | 14.673 | 17.166 | 19.517 | 22.146 | 25.146 | 29.888 |
| 67. Non-IBM Revenue | $B | 4.378 | 5.439 | 6.656 | 7.667 | 8.746 | 10.381 | 12.814 |
| Percent of Total Revenue | | | | | | | | |
| 68. Burroughs | % | 7.2 | 7.3 | 7.5 | 7.5 | 7.3 | 7.1 | 7.0 |
| 69. Control Data Corp. | % | 5.4 | 6.5 | 6.3 | 6.2 | 6.0 | 5.9 | 6.2 |
| 70. Data General | % | 0.2 | 0.4 | 0.5 | 0.6 | 0.9 | 1.1 | 1.4 |
| 71. Digital Equipment Corp. | % | 1.5 | 1.8 | 2.5 | 2.7 | 3.3 | 4.2 | 4.8 |
| 72. General Automation | % | 0.1 | 0.2 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 |
| 74. Hewlett Packard | % | 0.5 | 0.6 | 0.9 | 1.2 | 1.4 | 1.6 | 1.8 |
| 75. Honeywell | % | 6.2 | 5.7 | 5.0 | 4.4 | 4.1 | 4.1 | 4.3 |
| 76. Interdata | % | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 |
| 77. IBM | % | 64.7 | 62.9 | 61.2 | 60.7 | 60.5 | 58.7 | 57.1 |
| 78. National Cash Register | % | 5.3 | 6.0 | 6.5 | 7.3 | 7.6 | 7.7 | 7.5 |
| 80. SEL | % | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.2 |
| 81. Univac | % | 7.9 | 7.7 | 7.5 | 7.3 | 6.6 | 6.9 | 6.8 |
| 82. Varian Associates | % | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | | |
| 84. Other Mini Manufacturers | % | 0.7 | 0.4 | 1.2 | 1.3 | 1.4 | 1.8 | 2.2 |
| **Mini System Revenue** | | | | | | | | |
| 85. Control Data Corp. | $B | | | .015 | .030 | .032 | .036 | .035 |
| 86. Data General | $B | .030 | .053 | .083 | .112 | .197 | .279 | .410 |
| 87. Digital Equipment Corp. | $B | .185 | .260 | .395 | .500 | .710 | 1.000 | 1.410 |
| 88. General Automation | $B | .016 | .030 | .061 | .058 | .075 | .083 | .111 |
| 89. Hewlett Packard | $B | .060 | .095 | .150 | .240 | .304 | .390 | .535 |
| 90. Honeywell | $B | .060 | .069 | .050 | .090 | .112 | .130 | .200 |
| 91. Interdata | $B | .010 | .019 | .033 | .043 | .055 | .086 | .113 |
| 92. IBM | $B | | | | | .004 | .030 | .080 |
| 93. SEL | $B | .016 | .017 | .015 | .008 | .023 | .035 | .050 |
| 94. Varian Associates (Univac) | $B | .009 | .027 | .034 | .038 | .042 | .036 | .038 |
| 96. Subtotal | $B | .386 | .570 | .836 | 1.119 | 1.554 | 2.105 | 2.982 |
| 97. Total Minisystem Rev. | $B | .467 | .636 | 1.048 | 1.375 | 1.870 | 2.560 | 3.640 |
| % of Tot. Minisystem Rev. | | | | | | | | |
| 98. Control Data Corp. | % | 0.0 | 0.0 | 1.4 | 2.2 | 1.7 | 1.4 | 1.0 |
| 99. Data General | % | 6.4 | 8.3 | 7.9 | 8.1 | 10.5 | 10.9 | 11.3 |
| 100. Digital Equipment Corp. | % | 39.6 | 40.9 | 37.7 | 36.4 | 38.0 | 39.1 | 38.7 |
| 101. General Automation | % | 3.4 | 4.7 | 5.8 | 4.2 | 3.9 | 3.2 | 3.0 |
| 102. Hewlett Packard | % | 12.8 | 14.9 | 14.3 | 17.5 | 16.3 | 15.2 | 14.7 |
| 103. Honeywell | % | 12.8 | 10.8 | 4.8 | 6.5 | 6.0 | 5.1 | 5.5 |
| 104. Interdata | % | 2.1 | 3.0 | 3.1 | 3.1 | 2.9 | 3.4 | 3.1 |
| 105. IBM | % | | | | | 0.2 | 1.2 | 2.2 |
| 106. SEL | % | 3.4 | 2.7 | 1.4 | 0.6 | 1.2 | 1.4 | 1.4 |
| 107. Varian Associates | % | 1.9 | 4.2 | 3.2 | 2.8 | 2.2 | 1.4 | 1.0 |
| 109. Subtotal | | 82.7 | 89.6 | 79.8 | 81.4 | 83.1 | 82.2 | 81.9 |
| **Peripheral Manufacturers** | | | | | | | | |
| 138. Calcomp | $B | | .080 | .130 | .123 | .122 | .118 | .120 |
| 140. Data Products | $B | | .060 | .069 | .086 | .085 | .115 | .139 |
| 141. Mohawk Data Sciences | $B | | .143 | .169 | .170 | .162 | .146 | .153 |
| 142. Pertec Corp. | $B | | .027 | .033 | .048 | .037 | .095 | .132 |
| 145. Recognition Equipment Inc. | $B | | .042 | .043 | .059 | .065 | .075 | .087 |
| 145a. Storage Technology Corp. | $B | | .057 | .075 | .099 | .122 | .162 | .300 |
| 145b. Datapoint | $B | | .019 | .034 | .047 | .072 | .103 | .162 |
| 146. Subtotal | $B | | .428 | .553 | .632 | .665 | .814 | 1.093 |
| 147. Ampex | $B | | .257 | .272 | .242 | .258 | .287 | .322 |
| 148. Electronic Memories & Mag. | $B | | .106 | .111 | .092 | .092 | | |
| 149. Memorex | $B | | .177 | .218 | .264 | .345 | .450 | .633 |
| 150. Telex | $B | | .068 | .090 | .106 | .106 | .119 | .140 |
| 151. Subtotal—All Sales | $B | | 1.036 | 1.244 | 1.336 | 1.466 | 1.670 | 2.188 |
| Periph. Equip. Only | | | | | | | | |
| 152. Ampex | $B | | .116 | .122 | .109 | .115 | .130 | .119 |
| 153. Electronic Memories & Mag. | $B | | .080 | .084 | .070 | .058 | | |
| 154. Memorex | $B | | .177 | .218 | .264 | .310 | .405 | .570 |
| 155. Telex | $B | | .048 | .063 | .075 | .075 | .090 | .107 |
| 156. Total Periph. Equip. | $B | | .849 | 1.040 | 1.150 | 1.223 | 1.439 | 1.889 |

## TABLE II.1.30.1a DP INDUSTRY REVENUE AND PROFITS

| Line Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| **Burroughs Corp.** | | | | | | | | |
| 1. Total Revenue | $B | 1.040 | 1.284 | 1.533 | 1.702 | 1.902 | 2.127 | 2.460 |
| 2. Net Income | $B | .088 | .116 | .143 | .164 | .186 | .215 | .253 |
| 3. % of Revenue | % | 8.5 | 9.0 | 9.3 | 9.6 | 9.8 | 10.1 | 10.3 |
| **Control Data Corp.** | | | | | | | | |
| 4. Total Revenue | $B | .667 | .916 | 1.081 | 1.218 | 1.331 | 1.493 | 1.846 |
| 5. Net Income | $B | .010 | .017 | (.031) | .013 | .013 | .020 | .041 |
| 6. % of Revenue | % | 1.6 | 1.8 | (2.9) | 1.1 | 0.9 | 1.4 | 2.2 |
| **Digital Equipment Corp.** | | | | | | | | |
| 9. Total Revenue | $B | .188 | .265 | .421 | .534 | .736 | 1.059 | 1.437 |
| 8. Net Income | $B | .015 | .024 | .044 | .046 | .073 | .109 | .142 |
| 9. % of Revenue | % | 8.2 | 8.9 | 10.5 | 8.6 | 10.0 | 10.2 | 9.9 |
| **Honeywell, Inc.** | | | | | | | | |
| 10. Info Systems—Rev. | $B | .774 | .843 | .856 | .856 | .914 | 1.037 | |

## TABLE II.1.30.1a DP INDUSTRY REVENUE AND PROFITS

| Line | Item | Units | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| 11. | Operating Profit | $B | .042 | .053 | .034 | .040 | .041 | .079 | |
| 12. | Expense | $B | .020 | .026 | .034 | .025 | .026 | .029 | |
| 13. | Income before Tax | $B | .022 | .033 | - | .015 | .015 | .050 | |
| 14. | Net Income | $B | .010 | .015 | - | .007 | .007 | .023 | |
| 15. | % of Revenue | | 1.3 | 1.8 | 0 | 0.8 | 0.8 | 1.0 | |
| | **NCR** | | | | | | | | |
| 16. | Total Revenue | $B | | 1.676 | 1.832 | 2.021 | 2.136 | 2.312 | 2.611 |
| 17. | Net Income | $B | | .059 | .071 | .051 | .071 | .121 | .194 |
| 18. | % of Revenue | % | | 3.5 | 3.9 | 2.5 | 3.3 | 5.2 | 7.4 |
| | **Sperry-Rand** | | | | | | | | |
| 19. | Computer Syst. & Eq. Rev. | $B | | 1.123 | 1.294 | 1.433 | 1.467 | 1.726 | |
| 20. | Income before Tax | $B | | .100 | .102 | .132 | .135 | .170 | |
| 21. | Net Income | $B | | .053 | .055 | .069 | .070 | .087 | |
| 22. | % of Revenue | | | 4.7 | 4.3 | 4.8 | 4.8 | 5.0 | |
| | **Subtotal** | | | | | | | | |
| 23. | Revenue | $B | | 6.107 | 7.017 | 7.764 | 8.486 | 9.754 | |
| 24. | Net Income | $B | | .284 | .282 | .350 | .420 | .575 | |
| 25. | % of Revenue | % | | 4.65 | 4.02 | 4.51 | 4.95 | 5.90 | |
| | **IBM** | | | | | | | | |
| 26. | Data Processing Rev. | $B | | | 10.5 | 11.9 | 13.4 | 14.838 | 17.154 |
| 27. | Operating Income | $B | | | | | | 4.402 | 5.113 |
| 28. | Expense | $B | | | | | | .095 | .116 |
| 29. | Income before Tax | $B | | | | | | 4.307 | 4.996 |
| 30. | Net Income | $B | | | | | | 2.300 | 2.681 |
| 31. | % of Revenue | % | | | | | | 15.50 | 15.63 |
| 32. | Total Revenue | $B | 9.533 | 10.993 | 12.675 | 14.437 | 16.304 | 18.133 | 21.076 |
| 33. | Net Income | $B | 1.279 | 1.575 | 1.838 | 1.990 | 2.398 | 2.719 | 3.111 |
| 34. | % of Revenue | % | 13.42 | 14.33 | 14.50 | 13.78 | 14.71 | 14.99 | 14.76 |

## TABLE II.1.31.1a SYSTEM MANUFACTURERS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GP Systems in Use, US** | | | | | | | | | | | | | | | | | | | | | | |
| 1. | IBM Total | 1.311.2 | k | 2.545 | 3.520 | 4.860 | 6.545 | 8.890 | 11.690 | 14.170 | 18.031 | 19.930 | 22.900 | 25.317 | 26.771 | 28.479 | 32.305 | 38.333 | 40.490 | 41.133 | 40.107 | 39.882 | 38.808 |
| 2. | First Generation | 1.311.2 | k | 2.542 | 2.640 | 2.350 | 1.820 | 1.170 | .750 | .455 | .303 | .203 | .170 | .049 | .029 | .014 | .006 | .004 | .004 | .003 | | | |
| 7. | Second Generation | 1.311.2 | k | .003 | .880 | 2.510 | 4.725 | 7.720 | 10.940 | 13.090 | 13.330 | 9.977 | 6.896 | 4.646 | 3.297 | 2.916 | 2.384 | 2.079 | 1.676 | 1.397 | 1.107 | .894 | .829 |
| 14. | Third Gen.–360 | 1.311.2 | k | | | | | | | .625 | 3.881 | 8.125 | 13.110 | 17.687 | 19.412 | 17.529 | 14.909 | 10.475 | 8.060 | 6.450 | 5.919 | 5.118 | 4.641 |
| 15. | IBM 360/2x | | k | | | | | | | .002 | .885 | 2.820 | 4.835 | 7.042 | 8.592 | 8.728 | 7.867 | 4.936 | 3.225 | 1.921 | 1.722 | 1.282 | 1.052 |
| 16. | IBM 360/30 | | k | | | | | | | .325 | 1.844 | 2.860 | 4.563 | 6.488 | 5.955 | 4.701 | 3.610 | 2.906 | 2.540 | 2.200 | 2.028 | 1.733 | 1.560 |
| 17. | IBM 360/4x | | k | | | | | | | .285 | 1.010 | 1.682 | 2.358 | 2.600 | 3.047 | 2.547 | 2.216 | 1.478 | 1.256 | 1.148 | 1.193 | 1.146 | 1.092 |
| 18. | IBM 360/50 | | k | | | | | | | .010 | .104 | .512 | .868 | 1.010 | 1.163 | .960 | .731 | .620 | .553 | .521 | .517 | .501 | .495 |
| 19. | IBM 360/6x | | k | | | | | | | .001 | .026 | .227 | .451 | .489 | .589 | .529 | .429 | .488 | .438 | .406 | .422 | .420 | .406 |
| 20. | IBM 360/75, 85, 195 | | k | | | | | | | | .012 | .024 | .034 | .057 | .065 | .063 | .059 | .048 | .048 | .043 | .037 | .036 | .036 |
| 21. | IBM 360/20 | | k | | | | | | | .002 | .885 | 2.819 | 4.786 | 5.989 | 6.913 | 6.575 | 5.457 | 3.186 | 2.270 | 1.630 | 1.404 | 1.082 | .900 |
| 22. | IBM 360/40 | | k | | | | | | | .285 | .996 | 1.549 | 2.149 | 2.463 | 2.929 | 2.466 | 2.141 | 1.414 | 1.205 | 1.104 | 1.151 | 1.102 | 1.050 |
| 23. | IBM 360/65 | | k | | | | | | | .001 | .021 | .219 | .417 | .459 | .540 | .478 | .386 | .451 | .405 | .380 | .401 | .401 | .390 |
| 24. | IBM 370 Family | 1.311.2 | k | | | | | | | | | | | | | .806 | 2.922 | 5.887 | 8.440 | 9.335 | 9.046 | 10.450 | 11.348 |
| 25a. | IBM 370/115 | | k | | | | | | | | | | | | | | | | .805 | 1.375 | 1.287 | 1.152 | 1.040 |
| 25b. | IBM 370/125 | | k | | | | | | | | | | | | | | | .721 | 1.654 | 1.911 | 1.257 | 1.102 | .980 |
| 25c. | IBM 370/135 | | k | | | | | | | | | | | | | | .814 | 2.060 | 2.600 | 2.522 | 2.399 | 1.823 | 1.290 |
| 25ca. | IBM 370/138 | | k | | | | | | | | | | | | | | | | | | .029 | 1.272 | 1.910 |
| 25d. | IBM 370/145 | | k | | | | | | | | | | | | | .353 | 1.066 | 1.592 | 1.820 | 1.784 | 1.774 | 1.603 | 1.210 |
| 25da. | IBM 370/148 | | k | | | | | | | | | | | | | | | | | | | .861 | 1.600 |
| 25e. | IBM 370/155 | | k | | | | | | | | | | | | | .384 | .878 | 1.114 | .657 | .498 | .517 | .476 | .440 |
| 25f. | IBM 370/158 | | k | | | | | | | | | | | | | | | .138 | .600 | .864 | 1.247 | 1.503 | 1.550 |
| 25g. | IBM 370/165 | | k | | | | | | | | | | | | | .069 | .164 | .197 | .142 | .108 | .117 | .120 | .115 |
| 25h. | IBM 370/168 | | k | | | | | | | | | | | | | | | .047 | 1.430 | .258 | .405 | .526 | .650 |
| 25i. | IBM 370/195 | | k | | | | | | | | | | | | | | | .018 | .019 | .015 | .014 | .012 | .013 |
| 25j. | IBM 303x | | k | | | | | | | | | | | | | | | | | | | | .550 |
| 26a. | System 3 | | k | | | | | | | | | | | | 1.290 | 4.013 | 8.816 | 17.340 | 19.975 | 22.070 | 22.378 | 22.068 | 20.750 |
| 26b. | System 3/4 | | k | | | | | | | | | | | | | | | | | | .146 | .511 | .580 |
| 26c. | System 3/6 | | k | | | | | | | | | | | | .004 | 1.270 | 1.512 | 2.824 | 2.930 | 2.583 | 1.706 | .942 | .740 |
| 26d. | System 3/8 | | k | | | | | | | | | | | | | | | | | 1.127 | 3.706 | 5.169 | 4.850 |

## TABLE II.1.31.1a SYSTEM MANUFACTURERS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27. | System 3/10 | | k | | | | | | | | | | | | 1.286 | 2.744 | 7.304 | 14.516 | 15.910 | 15.683 | 11.944 | 8.034 | 6.900 |
| 27e. | System 3/12 | | k | | | | | | | | | | | | | | | | | | 2.175 | 4.458 | 4.550 |
| 27f. | System 3/15 | | k | | | | | | | | | | | | | | | | 1.135 | 2.677 | 2.701 | 2.955 | 3.130 |
| 27h. | IBM 1130 | | k | | | | | | | | .517 | 1.625 | 2.724 | 2.935 | 2.745 | 3.201 | 3.268 | 2.547 | 2.335 | 1.878 | 1.658 | 1.352 | 1.240 |
| 28. | All Other GP Manufacturers | | k | .565 | .880 | 1.290 | 1.555 | 2.810 | 5.010 | 7.430 | 9.069 | 11.070 | 14.100 | 14.683 | 15.129 | 16.521 | 17.895 | 19.967 | 21.010 | 20.967 | 19.493 | 18.318 | 19.152 |
| 29. | Univac–Total with RCA | | k | .317 | .484 | .764 | .783 | 1.460 | 2.900 | 3.938 | 4.283 | 4.504 | 5.026 | 5.455 | 5.453 | 5.641 | 5.722 | 5.545 | 5.069 | 4.550 | 3.827 | 3.735 | 3.846 |
| 33. | Univac 1108 | | | | | | | | | .003 | .023 | .067 | .120 | .114 | .131 | .135 | .130 | .126 | .123 | .122 | .156 | .152 | .152 |
| 33b. | Univac 90/30 | | | | | | | | | | | | | | | | | | | .235 | .337 | .626 | .755 |
| 35. | Honeywell (HIS with GE) | | k | | .044 | .133 | .183 | .336 | .542 | 1.170 | 2.015 | 2.992 | 3.640 | 3.725 | 3.427 | 4.184 | 5.038 | 5.525 | 5.533 | 5.251 | 4.178 | 4.228 | 4.233 |
| 38. | National Cash Register | | k | .035 | .066 | .128 | .323 | .578 | .878 | 1.283 | 1.518 | 1.900 | 3.413 | 2.996 | 3.532 | 3.505 | 3.704 | 4.159 | 4.770 | 4.462 | 3.388 | 3.243 | 3.309 |
| 39. | Burroughs | | k | .160 | .176 | .163 | .176 | .307 | .521 | .713 | .802 | 1.135 | 1.327 | 1.590 | 1.627 | 2.058 | 2.101 | 2.623 | 3.080 | 3.283 | 5.138 | 4.037 | 4.260 |
| 41. | Control Data Corp. | | k | | | .027 | .033 | .073 | .109 | .240 | .347 | .389 | .480 | .498 | .504 | .445 | .485 | .482 | .500 | .490 | .477 | .532 | .605 |
| 42. | CDC 6600 | | k | | | | | | .001 | .006 | .016 | .026 | .045 | .061 | .063 | .056 | .057 | .054 | .056 | .052 | .050 | .047 | .049 |
| 42a. | Others | | k | .053 | .110 | .075 | .057 | .056 | .060 | .086 | .104 | .150 | .214 | .420 | .586 | .688 | .845 | 1.632 | 2.058 | 2.931 | 2.485 | 2.543 | 2.899 |
| 43. | Total, All Manufacturers | | k | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 27.100 | 31.000 | 37.000 | 40.000 | 41.900 | 45.000 | 50.200 | 58.300 | 61.500 | 62.100 | 59.600 | 58.200 | 57.960 |
| 43a. | IDC Adjustment | | k | | | | | | | | .810 | 4.600 | 4.000 | 5.300 | 4.700 | 5.200 | 3.730 | | | | | | |
| | **Mini Systems in Use, US** | | | | | | | | | | | | | | | | | | | | | | |
| 50a. | Computer Automation | | k | | | | | | | | | | | 113 | 333 | 587 | 1528 | 3789 | 5719 | 9496 | 12577 | 16607 | 20806 |
| 51. | Digital Equipment Corp. | | k | | | | | | | 132 | 817 | 2133 | 3271 | 6417 | 9890 | 1228 | 16746 | 21636 | 30253 | 40319 | 50541 | 76804 | 104982 |
| 60. | Hewlett Packard | | k | | | | | | | | | | | 1152 | 2119 | 2579 | 3770 | 5375 | 8811 | 12270 | 15529 | 18899 | 21187 |
| 60a. | HP 2100-A | | k | | | | | | | | | | | 154 | 333 | 538 | 1798 | 2934 | 5152 | 6871 | 8142 | 8999 | 10819 |
| 60b. | Texas Instruments | | k | | | | | | | | | | | | 29 | 123 | 124 | 1382 | 1692 | 5151 | 6278 | 9949 | 13674 |
| 61. | Varian Data Machines | | k | | | | | | | | | | | 934 | 1696 | 2356 | 2937 | 3370 | 4082 | 4102 | 5417 | 6446 | 7142 |
| 62. | Data General | | k | | | | | | | | | | | 231 | 775 | 1781 | 4186 | 7150 | 11728 | 14955 | 26081 | 33985 | 41510 |
| 64. | General Automation | | k | | | | | | | | | | | 205 | 621 | 1197 | 2207 | 3709 | 7093 | 9093 | 12791 | 9704 | 13416 |
| 65. | Others | | | | | | | | | 68 | 383 | 867 | 1929 | 2294 | 4205 | 7058 | 11703 | 15755 | 21570 | 24042 | 24945 | 33107 | 41764 |
| 66. | Total, All Manufacturers | | k | | | | | | | .200 | 1.200 | 3.000 | 5.200 | 11.500 | 20.000 | 28.500 | 45.000 | 65.100 | 96.100 | 126.30 | 162.30 | 214.50 | 275.30 |
| | **SBC Systems in Use U.S.** | | | | | | | | | | | | | | | | | | | | | | |
| 84a. | Basic/Four | | k | | | | | | | | | | | | | .080 | .200 | .390 | .850 | 1.000 | 1.400 | 2.377 | 3.515 |
| 84b. | Burroughs | | k | | | | | | | | | | | | | | | .050 | .220 | .475 | 1.550 | 3.591 | 5.550 |
| 84c. | DEC | | k | | | | | | | | | | | | | | .075 | .150 | .500 | 1.000 | 2.100 | 4.299 | 6.200 |
| 84d. | IBM | | k | | | | | | | | | | | | | | | | | 5.000 | 8.500 | 14.980 | 22.300 |
| 84e. | NCR | | k | | | | | | | | | | | | | | | | | .275 | .685 | 1.168 | 2.475 |
| 84f. | Quantel | | k | | | | | | | | | | | | .030 | .070 | .125 | .300 | .323 | .440 | .509 | .891 | 1.394 |
| 84g. | Wang Labs | | k | | | | | | | | | | | | | | | .260 | 1.400 | 2.900 | 5.900 | 10.772 | 13.110 |
| 84h. | Others | | k | | | | | | | | | | | | .050 | .110 | .330 | .350 | 1.207 | 1.310 | 6.556 | 10.722 | 18.256 |
| 84i. | Total, All Manufacturers | | k | | | | | | | | | | | | .080 | .260 | .730 | 1.500 | 4.500 | 12.400 | 27.200 | 48.800 | 72.800 |

## TABLE II.1.31.1a SYSTEM MANUFACTURERS

| Line | Item | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| | **SBC Systems in Use, W.W.** | | | | | | | |
| 151. | Basic Four | k | .605 | 1.451 | 1.966 | 3.097 | 4.732 | 6.618 |
| 152. | Burroughs | k | .066 | .310 | .638 | 2.391 | 6.453 | 10.699 |
| 153. | DEC | k | .172 | .682 | 1.478 | 3.293 | 6.310 | 9.265 |
| 154. | IBM | k | | | 5.376 | 10.819 | 20.865 | 32.208 |
| 155. | NCR | k | | | .437 | 1.450 | 3.227 | 5.846 |
| 156. | Qantel | k | .258 | .310 | .470 | .706 | 1.147 | 2.096 |
| 157. | Wang Labs | k | .258 | 1.817 | 4.150 | 9.094 | 15.631 | 22.060 |
| 158. | Others | k | .691 | 1.631 | 2.268 | 8.350 | 13.265 | 21.509 |
| 159. | Total | k | 2.050 | 6.200 | 16.800 | 39.200 | 71.700 | 110.30 |
| | **SBC Value in Use, WW** | | | | | | | |
| 160. | Basic Four | $B | .039 | .099 | .105 | .150 | .217 | .330 |
| 161. | Burroughs | $B | .005 | .024 | .039 | .137 | .360 | .556 |
| 162. | DEC | $B | .009 | .035 | .060 | .120 | .260 | .416 |

## TABLE II.1.31.1a SYSTEM MANUFACTURERS

| Item | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|
| 163. IBM | $B | | | .249 | .428 | .858 | 1.460 |
| 164. NCR | $B | | | .034 | .101 | .200 | .334 |
| 165. Qantel | $B | .011 | .015 | .018 | .033 | .051 | .086 |
| 166. Wang Labs | $B | .007 | .054 | .091 | .204 | .312 | .447 |
| 167. Others | $B | .029 | .073 | .105 | .406 | .598 | .890 |
| 168. Total | $B | .100 | .300 | .700 | 1.580 | 2.860 | 4.520 |
| **Mini Systems in Use WW** | | | | | | | |
| 169. Control Data | k | .717 | .95 | 1.09 | 1.65 | 1.87 | 2.82 |
| 170. Data General | k | 9.139 | 15.83 | 20.68 | 35.53 | 47.30 | 58.33 |
| 171. DEC | k | 32.166 | 48.30 | 62.95 | 78.12 | 116.39 | 158.10 |
| 172. H.P. | k | 8.422 | 12.99 | 18.87 | 24.00 | 30.19 | 36.61 |
| 173. HIS GE/Pac | k | 8.602 | 6.36 | 7.07 | 8.00 | 8.71 | 10.06 |
| 174. IBM | k | | | | | | 3.62 |
| 175. Sperry-Univac | k | 3.942 | 5.14 | 6.17 | 8.23 | 9.96 | 10.86 |
| 176. Other | k | 26.701 | 45.73 | 64.76 | 79.77 | 96.78 | 121.50 |
| 177. Total | k | 89.600 | 135.30 | 181.40 | 235.30 | 311.20 | 402.30 |
| **Mini Value in Use, WW** | | | | | | | |
| 178. Control Data | $B | .086 | .088 | .098 | .126 | .184 | .295 |
| 179. Data General | $B | .090 | .171 | .325 | .503 | .832 | 1.170 |
| 180. DEC | $B | .690 | .889 | 1.204 | 1.628 | 2.731 | 3.785 |
| 181. H.P. | $B | .167 | .243 | .400 | .560 | .773 | 1.099 |
| 182. HIS-GE/PAC | $B | .172 | .358 | .438 | .466 | .523 | .580 |
| 183. IBM | $B | | | | | | .102 |
| 184. Sperry-Univac | $B | .079 | .099 | .140 | .257 | .316 | .336 |
| 185. Other | $B | .473 | .822 | 1.170 | 1.691 | 2.009 | 2.798 |
| 186. Total | $B | 1.760 | 2.670 | 3.775 | 5.235 | 7.360 | 10.175 |
| **GP Systems in Use WW** | | | | | | | |
| 187. IBM | k | 66.88 | 70.25 | 74.60 | 74.66 | 76.15 | 73.95 |
| 188. Amdahl | k | | | | | .09 | .20 |
| 189. Itel | k | | | | | | .31 |
| 190. Subtotal | k | 66.88 | 70.25 | 74.60 | 74.66 | 76.24 | 74.46 |
| 191. Burroughs | k | 4.34 | 5.10 | 5.60 | 8.04 | 6.37 | 6.84 |
| 192. CDC | k | .92 | .96 | .93 | .97 | .99 | 1.09 |
| 193. DEC | k | .31 | .34 | .47 | .65 | .83 | 1.01 |
| 194. HIS & Xerox | k | 14.58 | 14.89 | 13.98 | 12.09 | 12.06 | 13.35 |
| 195. NCR | k | 7.68 | 8.73 | 8.23 | 5.83 | 5.93 | 5.95 |
| 196. Univac | k | 9.74 | 9.05 | 8.21 | 7.37 | 7.52 | 7.81 |
| 197. Others | k | 1.55 | 1.98 | 3.39 | 2.89 | 2.85 | 2.69 |
| 198. Total | k | 106.00 | 111.30 | 115.40 | 112.50 | 112.80 | 113.20 |
| **GP Value in Use. WW** | | | | | | | |
| 199. IBM | $B | 33.131 | 36.874 | 41.671 | 48.403 | 55.321 | 63.245 |
| 200. Amdahl | $B | | | | | .336 | .646 |
| 201. Itel | $B | | | | | | .429 |
| 202. Subtotal | $B | 33.131 | 36.874 | 41.671 | 48.403 | 55.657 | 64.320 |
| 203. Burroughs | $B | 2.457 | 3.025 | 3.552 | 4.028 | 4.500 | 4.999 |
| 204. CDC | $B | 1.876 | 2.083 | 2.323 | 2.405 | 2.652 | 2.888 |
| 205. DEC | $B | .223 | .224 | .429 | .456 | .581 | .781 |
| 206. HIS & Xerox | $B | 5.557 | 5.916 | 6.504 | 5.895 | 6.353 | 6.999 |

| Item | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|
| 207. NCR | $B | 1.319 | 1.567 | 1.700 | 1.571 | 1.790 | 1.927 |
| 208. Univac | $B | 3.923 | 4.245 | 4.665 | 5.364 | 5.832 | 6.598 |
| 209. Others | $B | .214 | .267 | .455 | .478 | .435 | .388 |
| 210. Total | $B | 48.700 | 54.200 | 61.300 | 68.600 | 77.800 | 88.900 |
| **Total Systems in Use** | | | | | | | |
| 211. Amdahl | k | | | | | .090 | .200 |
| 212. Basic Four | k | .605 | 1.451 | 1.966 | 3.097 | 4.732 | 6.618 |
| 213. Burroughs | k | 4.406 | 5.410 | 6.238 | 10.431 | 12.823 | 17.539 |
| 214. Control Data | k | 1.637 | 1.910 | 2.020 | 2.620 | 2.860 | 3.910 |
| 215. Data General | k | 9.139 | 15.830 | 20.680 | 35.530 | 47.300 | 58.330 |
| 216. DEC | k | 32.648 | 49.322 | 64.898 | 82.063 | 123.53 | 168.37 |
| 217. H.P. | k | 8.422 | 12.990 | 18.870 | 24.000 | 30.190 | 36.610 |
| 218. HIS | k | 23.182 | 21.250 | 21.050 | 20.090 | 20.770 | 23.410 |
| 219. IBM | k | 66.880 | 70.250 | 79.976 | 85.479 | 97.015 | 109.77 |
| 220. Itel | k | | | | | | .310 |
| 221. NCR | k | 7.680 | 8.730 | 8.667 | 7.280 | 9.157 | 11.796 |
| 222. Qantel | k | .258 | .310 | .470 | .706 | .147 | 2.096 |
| 223. Sperry-Univac | k | 13.682 | 14.190 | 14.380 | 15.600 | 17.480 | 18.670 |
| 224. Wang Labs | k | .258 | 1.817 | 4.150 | 9.094 | 15.631 | 22.060 |
| 225. Others | k | 28.942 | 49.341 | 70.418 | 91.010 | 112.89 | 145.69 |
| **Total Value in Use** | | | | | | | |
| 226. Amdahl | $B | | | | | .336 | .646 |
| 227. Basic Four | $B | .039 | .099 | .105 | .150 | .217 | .330 |
| 228. Burroughs | $B | 2.462 | 3.049 | 3.591 | 4.165 | 4.860 | 5.555 |
| 229. Control Data | $B | 1.962 | 2.171 | 2.421 | 2.531 | 2.836 | 3.183 |
| 230. Data General | $B | .090 | .171 | .325 | .503 | .832 | 1.170 |
| 231. DEC | $B | .922 | 1.148 | 1.693 | 2.204 | 3.572 | 4.982 |
| 232. H.P. | $B | .167 | .243 | .400 | .560 | .773 | 1.099 |
| 233. HIS | $B | 5.729 | 6.274 | 6.942 | 6.361 | 6.876 | 7.579 |
| 234. IBM | $B | 33.131 | 36.874 | 41.290 | 48.831 | 56.179 | 64.807 |
| 235. Itel | $B | | | | | | .429 |
| 236. NCR | $B | 1.319 | 1.567 | 1.734 | 1.672 | 1.990 | 2.261 |
| 237. Qantel | $B | .011 | .015 | .018 | .033 | .051 | .086 |
| 238. Sperry-Univac | $B | 4.002 | 4.344 | 4.805 | 5.621 | 6.148 | 6.934 |
| 239. Wang Labs | $B | .007 | .054 | .091 | .204 | .312 | .447 |
| 240. Others | $B | .716 | 1.162 | 1.730 | 2.575 | 3.042 | 4.076 |
| 241. Total Number | k | 197.65 | 252.80 | 313.60 | 387.00 | 495.70 | 625.80 |
| 242. Total Value | $B | 50.560 | 57.170 | 65.775 | 75.415 | 88.020 | 103.59 |
| **GP, Mini & SBC, % of Value in Use, WW** | | | | | | | |
| 243. Burroughs | % | 4.9 | 5.3 | 5.5 | 5.5 | 5.5 | 5.4 |
| 244. Control Data | % | 3.9 | 3.8 | 3.7 | 3.4 | 3.2 | 3.1 |
| 245. DEC | % | 1.8 | 2.0 | 2.6 | 2.9 | 4.1 | 4.8 |
| 246. HIS | % | 11.3 | 11.0 | 10.6 | 8.4 | 7.8 | 7.3 |
| 247. IBM | % | 65.5 | 64.5 | 63.7 | 64.7 | 63.8 | 62.6 |
| 248. NCR | % | 2.6 | 2.7 | 2.6 | 2.2 | 2.3 | 2.2 |
| 249. Sperry-Univac | % | 7.9 | 7.6 | 7.3 | 7.5 | 7.0 | 6.7 |
| 250. Others | % | 2.1 | 3.1 | 4.0 | 5.4 | 6.3 | 7.9 |

## TABLE II.1.31.2a DISTRIBUTION OF GP SYSTEMS, WW, BY SIZE AND MANUFACTURER, 1977

| Manufacturers | 0-3.2 | 3.2-6.3 | Range of System Sizes, in $k per Month<br>6.3-12.5 | 12.5-25 | 25-50 | 50-100 | Over 100 | Total |
|---|---|---|---|---|---|---|---|---|
| | Number of Systems | | | | | | | |
| Burroughs | 1,950 | 42 | 2,175 | 1,175 | 636 | 265 | 44 | 6,287 |
| CDC | 0 | 0 | 75 | 115 | 341 | 254 | 191 | 976 |
| HIS | 2,655 | 3,129 | 1,832 | 1,831 | 784 | 355 | 112 | 11,288 |
| NCR | 580 | 3,328 | 1,565 | 377 | 0 | 0 | 0 | 5,850 |
| Univac | 1,932 | 1,047 | 2,438 | 341 | 1,044 | 475 | 141 | 7,418 |
| Others | 2,750 | 143 | 202 | 802 | 241 | 184 | 3 | 4,325 |
| Subtotal | 9,867 | 8,279 | 8,287 | 4,641 | 3,046 | 1,533 | 491 | 36,144 |
| IBM | 31,904 | 8,339 | 11,614 | 12,005 | 5,834 | 4,315 | 1,099 | 75,110 |
| Total | 41,771 | 16,618 | 19,901 | 16,646 | 8,880 | 5,848 | 1,590 | 111,254 |
| | System Value, in $M per Month | | | | | | | |
| Burroughs | 5.07 | 0.22 | 17.42 | 26.00 | 20.91 | 17.49 | 6.20 | 93.31 |
| CDC | 0 | 0 | 0.74 | 2.10 | 13.16 | 17.83 | 28.33 | 62.16 |
| HIS | 5.61 | 16.26 | 15.08 | 29.56 | 27.55 | 26.24 | 12.11 | 132.40 |
| NCR | 1.04 | 12.91 | 14.65 | 8.12 | 0 | 0 | 0 | 36.72 |
| Univac | 3.83 | 5.09 | 22.28 | 7.04 | 39.04 | 39.80 | 19.25 | 136.33 |
| Others | 7.42 | 0.57 | 2.06 | 14.24 | 6.99 | 13.61 | .65 | 45.53 |
| Subtotal | 22.97 | 35.05 | 72.23 | 87.05 | 107.65 | 114.97 | 66.54 | 506.46 |
| IBM | 75.57 | 30.30 | 98.57 | 217.66 | 212.70 | 389.95 | 192.19 | 1,216.94 |
| Total | 98.55 | 65.35 | 170.80 | 304.71 | 320.35 | 504.92 | 258.73 | 1,723.40 |
| | Percent Distribution, by Number | | | | | | | |
| Burroughs | 1.8 | 0 | 2.0 | 1.1 | 0.6 | 0.2 | 0 | 5.7 |
| CDC | 0 | 0 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.9 |
| HIS | 2.4 | 3.3 | 1.6 | 1.6 | 0.7 | 0.3 | 0.1 | 10.1 |
| NCR | 0.5 | 3.0 | 1.4 | 0.3 | 0 | 0 | 0 | 5.3 |
| Univac | 1.7 | 0.9 | 2.2 | 0.3 | 0.9 | 0.4 | 0.1 | 6.7 |
| Others | 2.5 | 0.1 | 0.2 | 0.7 | 0.2 | 0.2 | 0 | 3.9 |
| Subtotal | 8.9 | 7.4 | 7.4 | 4.2 | 2.7 | 1.4 | 0.4 | 32.5 |
| IBM | 28.7 | 7.5 | 10.4 | 10.8 | 5.2 | 3.9 | 1.0 | 67.5 |
| Total | 37.5 | 14.9 | 17.9 | 15.0 | 8.0 | 5.3 | 1.4 | 100.0 |
| | Percent Distribution, by Value | | | | | | | |
| Burroughs | 0.3 | 0 | 1.0 | 1.5 | 1.2 | 1.0 | 0.4 | 5.4 |
| CDC | 0 | 0 | 0 | 0.1 | 0.8 | 1.0 | 1.6 | 3.6 |
| HIS | 0.3 | 0.9 | 0.9 | 1.7 | 1.6 | 1.5 | 0.7 | 7.7 |
| NCR | 0.1 | 0.7 | 0.9 | 0.5 | 0 | 0 | 0 | 2.1 |
| Univac | 0.2 | 0.3 | 1.3 | 0.4 | 2.3 | 2.3 | 1.1 | 7.9 |
| Others | 0.4 | 0 | 0.1 | 0.8 | 0.4 | 0.8 | 0 | 2.6 |
| Subtotal | 1.3 | 2.0 | 4.2 | 5.1 | 6.2 | 6.7 | 3.9 | 29.4 |
| IBM | 4.4 | 1.8 | 5.7 | 12.6 | 12.3 | 22.6 | 11.2 | 70.6 |
| Total | 5.7 | 3.8 | 9.9 | 17.7 | 18.6 | 29.3 | 15.0 | 100.0 |

## TABLE II.1.31.2b DISTRIBUTION OF SBC SYSTEMS, WW, BY SIZE AND MANUFACTURERS, 1974 AND 1977

| Manufacturers | 3.9-7.8 | 7.8-15.6 | Range of System Sizes, in $k Purchase Price<br>15.6-31.25 | 31.25-62.5 | 62.5-125 | Over 125 | Total |
|---|---|---|---|---|---|---|---|
| | | Number of SBC Systems | | | | | |
| Basic Four—1974 | 0 | 0 | 0 | 1,600 | 0 | 0 | 1,600 |
| 1977 | 0 | 0 | 0 | 3,926 | 608 | 90 | 4,622 |
| Burroughs—1974 | 0 | 0 | 0 | 343 | 0 | 0 | 343 |
| 1977 | 0 | 0 | 0 | 2,270 | 4,050 | 0 | 6,320 |
| DEC—1977 | 0 | 0 5,100 | | 0 | 1,050 | 0 | 6,150 |
| NCR—1977 | 0 | 0 | 0 | 1,305 | 1,850 | 0 | 3,155 |
| Wang—1974 | 0 | 0 | 0 | 80 | 0 | 0 | 80 |
| 1977 | 0 | 0 15,25 | 0 | 0 | 20 | 0 | 15,270 |
| Other—1974 | 0 | 0 | 321 | 150 | 0 | 0 | 471 |
| 1977 | 105 | 682 | 2,817 | 8,240 | 2,113 | 114 | 14,071 |
| Subtotal—1974 | 0 | 0 | 321 | 2,173 | 0 | 0 | 2,494 |
| 1977 | 105 | 682 | 23,167 | 15,741 | 9,691 | 202 | 49,580 |
| IBM—1977 | 0 | 0 | 0 | 20,310 | 0 | 0 | 20,310 |
| Total—1974 | 0 | 0 | 321 | 2,173 | 0 | 0 | 2,494 |
| 1977 | 105 | 682 | 23,167 | 36,051 | 9,691 | 202 | 69,898 |
| | | Value of SBC Systems in $M | | | | | |
| Basic Four—1974 | | | | 73.60 | 0 | | 73.60 |
| 1977 | 0 | 0 | 0 | 165.74 | 39.52 | 11.44 | 216.70 |

**TABLE II.1.31.2b DISTRIBUTION OF SBC AND MINI SYSTEMS, WW, 1974 AND 1977 (continued)**

| SBC SYSTEMS Manufacturers | Range of System Sizes, in $k Purchase Price 3.9-7.8 | 7.8-15.6 | 15.6-31.25 | 31.25-62.5 | 62.5-125 | Over 125 | Total |
|---|---|---|---|---|---|---|---|
| Burroughs—1974 | 0 | 0 | 0 | 17.84 | 0 | 0 | 17.84 |
| 1977 | 0 | 0 | 0 | 87.44 | 271.35 | 0 | 358.79 |
| DEC—1977 | 0 | 0 | 142.80 | 0 | 115.50 | 0 | 258.30 |
| NCR—1977 | 0 | 0 | 0 | 77.49 | 122.10 | 0 | 199.59 |
| Wang—1974 | 0 | 0 | 0 | 3.20 | 0 | 0 | 3.20 |
| 1977 | 0 | 0 | 309.28 | 0 | 1.60 | 0 | 310.88 |
| Other—1974 | 0 | 0 | 9.26 | 5.84 | 0 | 0 | 15.10 |
| 1977 | 0.74 | 9.18 | 68.34 | 385.00 | 158.95 | 20.38 | 642.58 |
| Subtotal—1974 | 0 | 0 | 9.26 | 100.48 | 0 | 0 | 109.74 |
| 1977 | 0.74 | 9.18 | 520.42 | 715.67 | 709.02 | 31.82 | 1986.84 |
| IBM—1977 | 0 | 0 | 0 | 853.10 | 0 | 0 | 853.10 |
| Total—1974 | 0 | 0 | 9.26 | 100.48 | 0 | 0 | 109.74 |
| 1977 | 0.74 | 9.18 | 520.42 | 1568.77 | 709.02 | 31.82 | 2839.94 |
| | Percent Distribution, by Number of SBC Systems | | | | | | |
| Basic Four—1974 | 0 | 0 | 0 | 64.2 | 0 | 0 | 64.2 |
| 1977 | 0 | 0 | 0 | 5.6 | 0.9 | 0.1 | 6.6 |
| Burroughs—1974 | 0 | 0 | 0 | 13.8 | 0 | 0 | 13.8 |
| 1977 | 0 | 0 | 0 | 3.2 | 5.8 | 0 | 9.0 |
| DEC—1977 | 0 | 0 | 7.3 | 0 | 1.5 | 0 | 8.8 |
| NCR—1977 | 0 | 0 | 0 | 1.9 | 2.6 | 0 | 4.5 |
| Wang—1974 | 0 | 0 | 0 | 3.2 | 0 | 0 | 3.2 |
| 1977 | 0 | 0 | 21.8 | 0 | 0 | 0 | 21.8 |
| Other—1974 | 0 | 0 | 12.9 | 6.0 | 0 | 0 | 18.9 |
| 1977 | 0.2 | 1.0 | 4.0 | 11.8 | 3.0 | 0.2 | 20.1 |
| Subtotal—1974 | 0 | 0 | 12.9 | 87.1 | 0 | 0 | 100.0 |
| 1977 | 0.2 | 1.0 | 33.1 | 22.5 | 13.9 | 0.3 | 70.9 |
| IBM—1977 | 0 | 0 | 0 | 29.1 | 0 | 0 | 29.1 |
| Total—1974 | 0 | 0 | 12.9 | 87.1 | 0 | 0 | 100.0 |
| 1977 | 0.2 | 1.0 | 33.1 | 51.6 | 13.9 | 0.3 | 100.0 |
| | Percent Distribution, by Value of SBC Systems | | | | | | |
| Basic Four—1974 | 0 | 0 | 0 | 67.1 | 0 | 0 | 67.1 |
| 1977 | 0 | 0 | 0 | 5.8 | 1.4 | 0.4 | 7.6 |
| Burroughs—1974 | 0 | 0 | 0 | 16.3 | 0 | 0 | 16.3 |
| 1977 | 0 | 0 | 0 | 3.1 | 9.6 | 0 | 12.6 |
| DEC—1977 | 0 | 0 | 5.0 | 0 | 4.1 | 0 | 9.1 |
| NCR—1977 | 0 | 0 | 0 | 2.7 | 0 | 0 | 4.3 |
| Wang—1974 | 0 | 0 | 0 | 2.9 | 0 | 0 | 2.9 |
| 1977 | 0 | 0 | 10.9 | 0 | 0.1 | 0 | 10.9 |
| Other—1974 | 0 | 0 | 8.4 | 5.3 | 0 | 0 | 13.8 |
| 1977 | 0 | 0.3 | 2.4 | 13.6 | 5.6 | 0.7 | 22.6 |
| Subtotal—1974 | 0 | 0 | 8.4 | 91.6 | 0 | 0 | 100.0 |
| 1977 | 0 | 0.3 | 18.3 | 25.2 | 25.0 | 1.1 | 70.0 |
| IBM—1977 | 0 | 0 | 0 | 30.0 | 0 | 0 | 30.0 |
| Total—1974 | 0 | 0 | 8.4 | 91.6 | 0 | 0 | 100.0 |
| 1977 | 0 | 0.3 | 18.3 | 55.2 | 25.0 | 1.1 | 100.0 |

| MINI SYSTEMS Manufacturers | Range of System Sizes, in $k Purchase Price 1.9-3.9 | 3.9-7.8 | 7.8-15.6 | 15.6-31.25 | 31.25-62.5 | 62.5-125 | Over 125 | Total |
|---|---|---|---|---|---|---|---|---|
| | Number of Mini Systems | | | | | | | |
| Data General—1974 | | 865 | 10,905 | 3,530 | | | | 15,300 |
| 1977 | 0 | 3,560 | 29,950 | 7,180 | 6,880 | 730 | 0 | 48,300 |
| DEC—1974 | | | 25,700 | 17,350 | 1,334 | 2,350 | | 46,734 |
| 1977 | 21,500 | 0 | 64,200 | 9,450 | 15,715 | 4,740 | 2,850 | 118,455 |
| General Automation—1974 | | | | 7,800 | 660 | | | 8,460 |
| 1977 | 900 | 0 | 200 | 12,050 | 1,000 | 0 | 0 | 14,150 |
| Hewlett-Packard—1974 | | | 8,755 | 1,155 | 2,560 | | 100 | 12,570 |
| 1977 | 0 | 500 | 20,600 | 3,770 | 4,920 | 0 | 1,000 | 30,790 |
| Honeywell—1974 | | | 270 | | 4,298 | 1,357 | 256 | 6,181 |
| 1977 | 0 | 0 | 270 | 600 | 4,575 | 3,326 | 28 | 8,799 |
| Interdata—1974 | | | 340 | 861 | 727 | 1,025 | | 2,953 |
| 1977 | 0 | 80 | 1,227 | 4,830 | 1,477 | 1,397 | 364 | 9,375 |
| Texas Instruments—1974 | | | | | 1,700 | | | 1,700 |
| 1977 | 0 | 4,600 | 2,350 | 3,900 | 4,250 | 0 | 0 | 15,100 |
| Univac (Varian)—1974 | | | 2,160 | 2,080 | 530 | 170 | | 4,940 |
| 1977 | 0 | 260 | 2,990 | 2,395 | 3,760 | 620 | 0 | 10,025 |

### TABLE II.1.31.2b DISTRIBUTION OF MINI SYSTEMS, WW, 1974 AND 1977 (continued)

| Manufacturers | Range of System Sizes, in $k Purchase Price 1.9-3.9 | 3.9-7.8 | 7.8-15.6 | 15.6-31.25 | 31.25-62.5 | 62.5-125 | Over 125 | Total |
|---|---|---|---|---|---|---|---|---|
| Other–1974 | 901 | 5,960 | 15,984 | 5,310 | 1,230 | 900 | 918 | 31,203 |
| 1977 | 5,176 | 16,398 | 20,890 | 11,084 | 5,966 | 1,802 | 923 | 62,239 |
| Total–1974 | 901 | 6,825 | 64,114 | 38,086 | 13,039 | 5,802 | 1,274 | 130,041 |
| 1977 | 27,576 | 25,398 | 142,677 | 55,259 | 48,543 | 12,615 | 5,165 | 317,233 |
| Value of Mini Systems in $M | | | | | | | | |
| Data General–1974 | | 6.06 | 111.94 | 72.50 | | | | 190.50 |
| 1977 | 0 | 14.84 | 301.00 | 136.70 | 270.20 | 82.20 | 0 | 804.94 |
| DEC–1974 | | | 308.40 | 432.65 | 62.68 | 184.50 | | 988.23 |
| 1977 | 43.00 | 0 | 929.25 | 255.15 | 564.43 | 395.25 | 456.00 | 2643.08 |
| General Automation–1974 | | | | 161.25 | 33.00 | | | 194.25 |
| 1977 | 2.70 | 0 | 2.00 | 272.45 | 50.00 | 0 | 0 | 327.15 |
| Hewlett-Packard–1974 | | | 131.33 | 21.88 | 97.83 | | 18.50 | 269.54 |
| 1977 | 0 | 2.00 | 309.00 | 71.32 | 181.05 | 0 | 185.00 | 748.37 |
| Honeywell–1974 | | | 2.70 | | 208.39 | 122.71 | 64.17 | 397.97 |
| 1977 | 0 | 0 | 2.70 | 10.80 | 262.42 | 216.84 | 12.32 | 505.08 |
| Interdata–1974 | | | 3.80 | 18.19 | 27.03 | 67.19 | | 116.20 |
| 1977 | 0 | 0.40 | 17.26 | 90.15 | 52.26 | 90.80 | 58.24 | 309.11 |
| Texas Instruments–1974 | | | | | 56.00 | | | 56.00 |
| 1977 | 0 | 23.00 | 35.25 | 117.00 | 170.00 | 0 | 0 | 345.25 |
| Univac (Varian)–1974 | | | 27.94 | 45.31 | 23.85 | 12.85 | | 109.95 |
| 1977 | 0 | 1.30 | 39.28 | 52.02 | 164.40 | 48.85 | 0 | 305.85 |
| Other–1974 | 2.70 | 28.93 | 180.08 | 105.35 | 55.29 | 86.41 | 186.64 | 645.40 |
| 1977 | 14.42 | 82.11 | 223.35 | 206.09 | 271.78 | 188.07 | 159.14 | 1144.95 |
| Total–1974 | 2.70 | 34.99 | 766.18 | 857.13 | 564.08 | 473.65 | 269.31 | 2968.04 |
| 1977 | 60.12 | 123.65 | 1859.09 | 1211.68 | 1986.53 | 1022.02 | 870.70 | 7133.78 |
| Percent Distribution by Number, of Mini Systems | | | | | | | | |
| Data General–1974 | 0 | 0.7 | 8.4 | 2.7 | 0 | 0 | 0 | 11.8 |
| 1977 | 0 | 1.1 | 9.4 | 2.3 | 2.2 | 0.2 | 0 | 15.2 |
| DEC–1974 | 0 | 0 | 19.8 | 13.3 | 1.0 | 1.8 | 0 | 35.9 |
| 1977 | 6.8 | 0 | 20.2 | 3.0 | 5.0 | 1.5 | 0.9 | 37.3 |
| General Automation–1974 | 0 | 0 | 0 | 6.0 | 0.5 | 0 | 0 | 6.5 |
| 1977 | 0.3 | 0 | 0.1 | 3.8 | 0.3 | 0 | 0 | 4.5 |
| Hewlett-Packard–1974 | 0 | 0 | 6.7 | 0.9 | 2.0 | 0 | 0.1 | 9.7 |
| 1977 | 0 | 0.2 | 6.5 | 1.2 | 1.6 | 0 | 0.3 | 9.7 |
| Honeywell–1974 | 0 | 0 | 0.2 | 0 | 3.3 | 1.0 | 0.2 | 4.8 |
| 1977 | 0 | 0 | 0.1 | 0.2 | 1.4 | 1.0 | 0 | 2.8 |
| Interdata–1974 | 0 | 0 | 0.3 | 0.7 | 0.6 | 0.8 | 0 | 2.3 |
| 1977 | 0 | 0 | 0.4 | 1.5 | 0.5 | 0.4 | 0.1 | 3.0 |
| Texas Instruments–1974 | 0 | 0 | 0 | 0 | 1.3 | 0 | 0 | 1.3 |
| 1977 | 0 | 1.5 | 0.7 | 1.2 | 1.3 | 0 | 0 | 4.8 |
| Univac (Varian)–1974 | 0 | 0 | 1.7 | 1.6 | 0.4 | 0.1 | 0 | 3.8 |
| 1977 | 0 | 0.1 | 0.9 | 0.8 | 1.2 | 0.2 | 0 | 3.2 |
| Other–1974 | 0.7 | 4.6 | 12.3 | 4.1 | 0.9 | 0.7 | 0.7 | 24.0 |
| 1977 | 1.6 | 5.2 | 6.6 | 3.5 | 1.9 | 0.6 | 0.3 | 19.6 |
| Total–1974 | 0.7 | 5.2 | 49.3 | 29.3 | 10.0 | 4.5 | 1.0 | 100.0 |
| 1977 | 8.7 | 8.0 | 45.0 | 17.4 | 15.3 | 4.0 | 1.6 | 100.0 |
| Percent Distribution by Value, of Mini Systems | | | | | | | | |
| Data General–1974 | 0 | 0.2 | 3.8 | 2.4 | 0 | 0 | 0 | 6.4 |
| 1977 | 0 | 0.2 | 4.2 | 1.9 | 3.8 | 1.2 | 0 | 11.3 |
| DEC–1974 | 0 | 0 | 10.4 | 14.6 | 2.1 | 6.2 | 0 | 33.3 |
| 1977 | 0.6 | 0 | 13.0 | 3.6 | 7.9 | 5.5 | 6.4 | 37.1 |
| General Automation–1974 | 0 | 0 | 0 | 5.4 | 1.1 | 0 | 0 | 6.5 |
| 1977 | 0 | 0 | 0 | 3.8 | 0.7 | 0 | 0 | 4.6 |
| Hewlett-Packard–1974 | 0 | 0 | 4.4 | 0.7 | 3.3 | 0 | 0.6 | 9.1 |
| 1977 | 0 | 0 | 4.3 | 1.0 | 2.5 | 0 | 2.6 | 10.5 |
| Honeywell–1974 | 0 | 0 | 0.1 | 0 | 7.0 | 4.1 | 2.2 | 13.4 |
| 1977 | 0 | 0 | 0 | 0.2 | 3.7 | 3.0 | 0.2 | 7.1 |
| Interdata–1974 | 0 | 0 | 0.1 | 0.6 | 0.9 | 2.3 | 0 | 3.9 |
| 1977 | 0 | 0 | 0.2 | 1.3 | 0.7 | 1.3 | 0.8 | 4.3 |
| Texas Instruments | 0 | 0 | 0 | 0 | 1.9 | 0 | 0 | 1.9 |
| 1977 | 0 | 0.3 | 0.5 | 1.6 | 2.4 | 0 | 0 | 4.8 |
| Univac (Varian)–1974 | 0 | 0 | 0.9 | 1.5 | 0.8 | 0.4 | 0 | 3.7 |
| 1977 | 0 | 0 | 0.6 | 0.7 | 2.3 | 0.7 | 0 | 4.3 |
| Other–1974 | 0.1 | 1.0 | 6.1 | 3.5 | 1.9 | 2.9 | 6.3 | 21.7 |
| 1977 | 0.2 | 1.2 | 3.1 | 2.9 | 3.8 | 2.6 | 2.2 | 16.0 |
| Total–1974 | 0.1 | 1.2 | 25.8 | 28.9 | 19.0 | 16.0 | 9.1 | 100.0 |
| 1977 | 0.8 | 1.7 | 26.1 | 17.0 | 27.8 | 14.3 | 12.2 | 100.0 |

## TABLE II.1.31.2c CONSOLIDATED DISTRIBUTION OF GP, MINI AND SBC SYSTEMS, WW, 1974 AND 1977

| Rental Per Month ($k) / Purchase Prices ($k) | 1.9-3.9 | 3.9-7.8 | 7.8-15.6 | 15.6-31.25 | Range of System Sizes 0.78-1.56 / 31.25-62.5 | 1.56-3.2 / 62.5-125 | 3.2-6.3 / 125-250 | 6.3-12.5 / 250-500 |
|---|---|---|---|---|---|---|---|---|
| | | Number of Systems | | | | | | |
| GP—1974 | | | | | 4,468 | 50,686 | 17,703 | 15,924 |
| 1977 | | | | | 1,135 | 40,636 | 16,618 | 19,901 |
| Mini—1974 | 901 | 6,825 | 64,714 | 38,086 | 13,039 | 5,802 | 1,072 | 202 |
| 1977 | 27,576 | 25,398 | 142,677 | 55,259 | 48,543 | 12,615 | 5,137 | 28 |
| SBC—1974 | | | | 321 | 1,830 | 343 | | |
| 1977 | | 105 | 682 | 23,167 | 36,051 | 9,691 | 184 | 18 |
| Total—1974 | 901 | 6,825 | 64,114 | 38,407 | 19,337 | 56,831 | 18,775 | 16,126 |
| 1977 | 27,576 | 25,503 | 143,359 | 78,426 | 85,729 | 62,942 | 21,939 | 19,947 |
| | | Value of Systems, in $B | | | | | | |
| GP—1974 | | | | | 0.25 | 5.91 | 3.71 | 7.58 |
| 1977 | | | | | 0.06 | 4.33 | 2.91 | 7.61 |
| Mini—1974 | 0 | 0.04 | 0.77 | 0.86 | 0.56 | 0.47 | 0.20 | 0.07 |
| 1977 | 0.06 | 0.12 | 1.86 | 1.21 | 1.99 | 1.02 | 0.86 | 0.01 |
| SBC—1974 | | | | 0 | 0.08 | 0.02 | | |
| 1977 | | 0 | 0.01 | 0.52 | 1.57 | 0.71 | 0.03 | 0 |
| Total—1974 | 0 | 0.04 | 0.77 | 0.87 | 0.89 | 6.40 | 3.91 | 7.65 |
| 1977 | 0.06 | 0.12 | 1.87 | 1.73 | 3.62 | 6.06 | 3.80 | 7.63 |
| | | Percent Distribution, by Number | | | | | | |
| GP—1974 | | | | | 1.8 | 20.7 | 7.2 | 6.5 |
| 1977 | | | | | 0.2 | 8.2 | 3.3 | 4.0 |
| Mini—1974 | 0.4 | 2.8 | 26.2 | 15.6 | 5.3 | 2.4 | 0.4 | 0.1 |
| 1977 | 5.5 | 5.1 | 28.6 | 11.1 | 9.7 | 2.5 | 1.0 | 0 |
| SBC—1974 | | | | 0.1 | 0.8 | 0.1 | | |
| 1977 | | 0 | 0.1 | 4.7 | 7.2 | 1.9 | 0 | |
| Total—1974 | 0.4 | 2.8 | 26.2 | 15.7 | 7.9 | 23.3 | 7.7 | 6.6 |
| 1977 | 5.5 | 5.1 | 28.8 | 15.7 | 17.2 | 12.6 | 4.4 | 4.0 |
| | | Percent Distribution, by Value | | | | | | |
| GP—1974 | | | | | 0.4 | 10.3 | 6.5 | 13.2 |
| 1977 | | | | | 0.1 | 5.0 | 3.4 | 8.8 |
| Mini—1974 | 0 | 0.1 | 1.3 | 1.5 | 1.0 | 0.8 | 0.3 | 0.1 |
| 1977 | 0.1 | 0.1 | 2.1 | 1.4 | 2.3 | 1.2 | 1.0 | 0 |
| SBC—1974 | | | | 0 | 0.1 | 0 | | |
| 1977 | | | 0 | 0.6 | 1.8 | 0.8 | 0 | 0 |
| Total—1974 | 0 | 0.1 | 1.3 | 1.5 | 1.6 | 11.2 | 6.8 | 13.4 |
| 1977 | 0.1 | 0.1 | 2.1 | 2.0 | 4.2 | 7.0 | 4.4 | 8.8 |

Source: An analysis of the *EDP/IR* censuses published 4/30/75 and 5/19/78.

## TABLE II.1.31.2c CONSOLIDATED DISTRIBUTION OF SYSTEMS

| Rental/Month ($k): / Purchase Prices ($k): | Range of System Sizes 12.5-25 / 500-1000 | 25-50 / 1k-2k | 50-100 / 2k-4k | Over 100 / Over 4k | Total |
|---|---|---|---|---|---|
| | Number of Systems | | | | |
| GP—1974 | 12,546 | 6,046 | 3,819 | 652 | 111,844 |
| 1977 | 16,646 | 8,880 | 5,848 | 1,590 | 111,254 |
| Mini—1974 | | | | | 130,041 |
| 1977 | | | | | 317,233 |
| SBC—1974 | | | | | 2,494 |
| 1977 | | | | | 69,898 |
| Total—1974 | 12,546 | 6,046 | 3,819 | 652 | 244,379 |
| 1977 | 16,646 | 8,880 | 5,849 | 1,590 | 498,385 |
| | Value of Systems, in $B | | | | |
| GP—1974 | 10.97 | 9.64 | 12.26 | 3.89 | 54.20 |
| 1977 | 13.58 | 14.28 | 22.50 | 11.52 | 76.80 |
| Mini—1974 | | | | | 2.97 |
| 1977 | | | | | 7.13 |
| SBC—1974 | | | | | 0.11 |
| 1977 | | | | | 2.84 |
| Total—1974 | 10.97 | 9.64 | 12.26 | 3.89 | 57.28 |
| 1977 | 13.58 | 14.28 | 22.50 | 11.52 | 86.77 |

| Rental/Month ($k): / Purchase Prices ($k): | Range of System Sizes 12.5-25 / 500-1000 | 25-50 / 1k-2k | 50-100 / 2k-4k | Over 100 / Over 4k | Total |
|---|---|---|---|---|---|
| | Percent Distribution, by Number | | | | |
| GP—1974 | 5.1 | 2.5 | 1.6 | 0.3 | 45.8 |
| 1977 | 3.3 | 1.8 | 1.2 | 0.3 | 22.3 |
| Mini—1974 | | | | | 53.2 |
| 1977 | | | | | 63.7 |
| SBC—1974 | | | | | 1.0 |
| 1977 | | | | | 14.0 |
| Total—1974 | 5.1 | 2.5 | 1.6 | 0.3 | 100.0 |
| 1977 | 3.3 | 1.8 | 1.2 | 0.3 | 100.0 |
| | Percent Distribution, by Value | | | | |
| GP—1974 | 19.2 | 16.8 | 21.4 | 6.8 | 94.6 |
| 1977 | 15.7 | 16.5 | 25.9 | 13.3 | 88.5 |
| Mini—1974 | | | | | 5.2 |
| 1977 | | | | | 8.2 |
| SBC—1974 | | | | | 0.2 |
| 1977 | | | | | 3.3 |
| Total—1974 | 19.2 | 16.8 | 21.4 | 6.8 | 100.0 |
| 1977 | 15.7 | 16.5 | 25.9 | 13.3 | 100.0 |

## TABLE II.1.31.3a THE TOP FIFTY COMPANIES IN DATA PROCESSING

| | 1973 | 1974 | 1975 | | 1976 | | 1977 | | 1978 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $B | $B | % | $B | % | $B | % | $B | % | $B |
| 1. IBM | 8.695 | 9.887 | 77 | 11.116 | 78 | 12.72 | 81 | 14.765 | 81 | 17.07 |
| 2. Burroughs | 1.091 | 1.303 | 85 | 1.447 | 86 | 1.630 | 87 | 1.844 | 87 | 2.107 |
| 3. NCR | .726 | .792 | 44 | .960 | 48 | 1.100 | 62 | 1.574 | 74 | 1.932 |
| 4. Control Data | .929 | 1.079 | 98 | 1.218 | 98 | 1.331 | 66 | 1.513 | 68 | 1.867 |
| 5. Sperry Rand | .958 | 1.124 | 43 | 1.295 | 45 | 1.430 | 45 | 1.472 | 48 | 1.807 |
| 6. DEC | .265 | .422 | 100 | .534 | 100 | .736 | 100 | 1.059 | 100 | 1.437 |
| 7. Honeywell | 1.147 | 1.260 | 48 | 1.324 | 47 | 1.428 | 36 | 1.037 | 37 | 1.294 |
| 8. Hewlett-Packard | .165 | .221 | 25 | .250 | 30 | .335 | 30 | .402 | 38 | .657 |
| 9. Memorex | .177 | .218 | 100 | .264 | 90 | .310 | 90 | .405 | 90 | .570 |
| 10. Itel | .086 | .103 | 72 | .147 | 73 | .189 | 71 | .286 | 71 | .487 |
| 11. TRW | .195 | .224 | 10 | .250 | 10 | .295 | 11 | .350 | 12 | .466 |
| 12. Data General | .053 | .083 | 100 | .108 | 100 | .161 | 100 | .255 | 100 | .380 |
| 13. Amdahl | | | | | 100 | .093 | 100 | .189 | 100 | .321 |
| 14. Storage Technology | .057 | .075 | 100 | .092 | 100 | .122 | 100 | .162 | 100 | .300 |
| 15. Automatic Data Processing | .083 | .103 | 92 | .143 | 95 | .178 | 97 | .238 | 97 | .290 |
| 16. 3M | .153 | .176 | 6 | .180 | 6 | .211 | 6 | .240 | 6 | .280 |
| 17. Northern Telecom Systems | | | | | | | | | 100 | .275 |
| 18. Computer Sciences | .120 | .147 | 100 | .177 | 75 | .165 | 75 | .176 | 92 | .255 |
| 19. Xerox | .060 | .072 | 2 | .080 | 3 | .120 | 4 | .209 | 4 | .236 |
| 20. Electronic Data Systems | .109 | .114 | 100 | .119 | 100 | .133 | 96 | .157 | 97 | .211 |
| 21. Management Assistance | .067 | .077 | 100 | .094 | 100 | .123 | 100 | .155 | 100 | .205 |
| 22. Texas Instruments | .051 | .063 | 4 | .060 | 4 | .066 | 8 | .160 | 8 | .204 |
| 23. General Electric | .174 | .201 | 1.5 | .200 | 1 | .185 | 1 | .200 | 1 | .190 |
| 24. Harris | .061 | .070 | 17 | .080 | 18 | .092 | 22 | .145 | 20 | .174 |
| 25. Wang Laboratories | .031 | .042 | 65 | .050 | 85 | .082 | 85 | .114 | 85 | .168 |
| 26. Datapoint | .019 | .034 | 100 | .047 | 94 | .068 | 100 | .103 | 100 | .162 |
| 27. Mohawk Data Sciences | .143 | .169 | 100 | .170 | 100 | .162 | 100 | .146 | 100 | .153 |
| 28. Tymshare | .035 | .046 | 100 | .056 | 100 | .082 | 100 | .101 | 100 | .150 |
| 29. System Development | | | | | 77 | .085 | 80 | .104 | 100 | .145 |
| 30. Four-Phase Systems | | | | | 100 | .063 | 100 | .089 | 100 | .136 |
| 31. Pertec Computer | .027 | .033 | 100 | .105 | | | 100 | .095 | 100 | .132 |
| 32. Perkin-Elmer | | | | | 21 | .073 | 24 | .103 | 24 | .131 |
| 33. McDonnell Douglas | .120 | .123 | 5 | .160 | 2 | .077 | 3 | .112 | 3 | .128 |
| 34. Tektronix | .028 | .038 | 15 | .049 | 17 | .062 | 22 | .100 | 21 | .126 |
| 35. Dataproducts | .053 | .067 | 88 | .084 | 88 | .075 | 90 | .104 | 90 | .125 |
| 36. Teletype | .062 | .070 | 50 | .078 | 50 | .090 | 41 | .110 | 41 | .124 |
| 37. California Computer Products | .076 | .123 | 95 | .116 | 96 | .116 | 97 | .114 | 100 | .120 |
| 38. Ampex | .116 | .122 | 45 | .109 | 45 | .115 | 45 | .130 | 37 | .119 |
| 39. Bunker Ramo | .146 | .157 | 42 | .120 | 34 | .107 | 31 | .105 | 31 | .119 |
| 40. General Instrument | .048 | .064 | 17 | .071 | 22 | .084 | 23 | .106 | 23 | .116 |
| 41. Telex | .048 | .064 | 71 | .075 | 71 | .075 | 76 | .090 | 76 | .107 |
| 42. General Automation | .030 | .061 | 100 | .056 | 100 | .071 | 100 | .084 | 100 | .098 |
| 43. Raytheon | .048 | .058 | 3 | .060 | 3 | .074 | 3 | .085 | 3 | .097 |
| 44. Tandy | | | | | | | | | 9 | .096 |
| 45. Planning Research | | | | | | | 37 | .069 | 43 | .096 |
| 46. Prime Computer | | | | | | | | | 100 | .094 |
| 47. Informatics | | | | | 100 | .059 | 100 | .076 | 100 | .093 |
| 48. Recognition Equipment | .042 | .043 | 100 | .059 | 92 | .060 | 93 | .070 | 93 | .081 |
| 49. Wyly | .072 | .080 | 90 | .060 | 97 | .062 | 97 | .069 | 100 | .079 |
| 50. Centronics | .024 | .042 | 100 | .042 | | | | | 100 | .075 |
| 51. Sycor | .032 | .040 | 100 | .055 | 100 | .067 | 100 | .077 | | |
| 52. Litton Industries | | | | | | | 2 | .070 | | |
| 53. General Telephone & Elect. | .051 | .057 | 1 | .060 | 1 | .065 | 1 | .075 | | |
| 54. Data 100 | .043 | .070 | 100 | .096 | 98 | .120 | 100 | .138 | | |
| 55. Boeing | .047 | .052 | 1.4 | .050 | 1.4 | .055 | | | | |
| 56. Electrnoic Memories & Magnetics | .074 | .078 | 71 | .070 | 63 | .058 | | | | |
| 57. Inforex | .038 | .052 | 100 | .057 | 100 | .063 | | | | |
| 58. Greyhound Computer | .046 | .052 | 100 | .061 | | | | | | |
| 59. Varian Associates | .036 | .044 | 15 | .047 | | | | | | |
| 60. Decision Data Computer | .018 | .041 | 100 | .040 | | | | | | |
| Total, 50 Companies | 18.73 | 21.75 | | 22.241 | | 25.32 | | 29.632 | | 36.09 |

Source: Data/50. The dollar figures show DP industry revenues; the percent figures show what percent of *total* company revenue is derived from DP.

## TABLE II.1.310a SYSTEM COMPANIES

| Line | Item | Figure | Units | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| | **Burroughs Corp.** | | | | | | | |
| 1. | Total Revenue | 1.310.1 | $B | 1.533 | 1.702 | 1.902 | 2.127 | 2.460 |
| 2. | Net Income | | $B | .143 | .164 | .186 | .215 | .253 |
| 3. | % of Revenue | 1.310.2 | % | 9.3 | 9.6 | 9.8 | 10.1 | 10.3 |
| | Revenue Analyses–% Tot. Rev. | | | | | | | |
| 9. | B–Standard Equipment | 1.310.1 | % | 66.6 | 65.9 | 62.9 | 61.9 | 62.0 |
| 10. | Large & Medium Systems | | % | 39.1 | 39.7 | 39.8 | 41.1 | 41.5 |
| 11. | Small & Business Minis | | % | 20.1 | 20.3 | 17.8 | | |
| 12. | Small Applications Mach. | | % | 7.3 | 5.9 | 5.4 | | |
| 13. | Custom Products & Components | | % | 3.7 | 2.3 | 2.3 | 2.6 | 2.4 |
| 14. | Field Engineering Services | | % | 17.8 | 19.7 | 21.8 | 22.4 | 22.7 |
| 15. | Business Forms & Supplies | | % | 10.5 | 10.6 | 11.3 | 11.4 | 11.4 |
| 16. | C–Business Machine Group | | % | 46.6 | 44.5 | 42.3 | 43.2 | 43.3 |
| 17. | International Group | 1.310.2 | % | 37.2 | 40.4 | 41.6 | 40.2 | 41.3 |
| 18. | Defense, Space, etc. Group | | % | 6.8 | 5.6 | 5.4 | 5.9 | 5.0 |
| 19. | Business Forms Group | | % | 7.8 | 7.9 | 9.0 | 9.1 | 8.8 |
| 25. | Rental Equipment Value–Gross | | $B | .938 | 1.071 | 1.147 | 1.190 | 1.306 |
| 26. | Net | | $B | .536 | .597 | .623 | .622 | .684 |
| 27. | R & D Expenses | | $B | .085 | .100 | .107 | .122 | .143 |
| 28. | % of Total Revenue | 1.310.2 | % | 5.5 | 5.9 | 5.6 | 5.7 | 5.8 |
| | **Honeywell (and GE)** | | | | | | | |
| 29. | Total Revenue (Sales) | 1.310.3 | $B | 2.626 | 2.760 | 2.495 | 2.911 | 3.548 |
| 30. | Net Income | | $B | .076 | .078 | .113 | .145 | |
| 31. | % of Revenue | 1.310.4 | % | 2.9 | 2.8 | 4.5 | 5.0 | |
| | Revenue Analysis–% Tot. Rev. | | | | | | | |
| 32. | A–Home & Building Controls | | % | 19.3 | 19.5 | 27.7 | 26.8 | 25.0 |
| 33. | Automation Systems | 1.310.3 | % | 15.9 | 15.5 | 18.5 | 19.0 | 20.1 |
| 34. | Aerospace & Defense | 1.310.3 | % | 15.9 | 15.1 | 17.2 | 18.6 | 18.5 |
| 35. | Information Systems | 1.310.3 | % | 47.0 | 48.0 | 36.6 | 35.6 | 36.5 |
| 36. | Photographic Products | 1.310.3 | % | 1.9 | 2.0 | | | |
| 37. | B–International Revenue | 1.310.4 | % | 40.7 | 44.1 | 28.9 | 29.1 | 29.3 |
| 38. | Equip. Leased to Others–Gross | | $B | 1.439 | 1.494 | 1.123 | 1.042 | 1.043 |
| 39. | Net | | $B | .732 | .730 | .509 | .495 | .489 |
| 40. | R & D Expenses | | $B | .170 | .164 | .125 | .152 | .187 |
| 41. | % of Tot. Revenue | 1.310.4 | % | 6.5 | 5.9 | 5.0 | 5.2 | 5.3 |
| 47. | Information Systems Revenue | | $B | 1.233 | 1.324 | .914 | 1.037 | 1.294 |
| 47a. | Revenue pre divesture | | $B | 1.233 | 1.324 | 1.428 | | |
| 47b. | Revenue post divesture | | $B | .856 | .856 | .914 | 1.037 | 1.294 |
| 48. | % of Total Revenue | 1.310.3 | % | 47.0 | 48.0 | 36.6 | 35.6 | 36.5 |
| | **National Cash Register** | | | | | | | |
| 49. | Total Revenue | 1.310.5 | $B | 1.979 | 2.165 | 2.313 | 2.522 | 2.611 |
| 50. | Net Income | | $B | .087 | .072 | .096 | .144 | .318 |
| 51. | % of Revenue | 1.310.6 | % | 4.4 | 3.3 | 4.2 | 5.7 | 12.2 |
| | Revenue Anal.–% of Tot. Rev. | | | | | | | |
| 52. | A–Equipment Revenue | | % | 56.8 | 56.9 | 56.7 | 56.5 | 59.8 |

| Line | Item | Figure | Units | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| 53. | Sales Revenue | | % | 44.3 | 45.5 | 45.3 | 45.3 | 48.1 |
| 54. | Rental Revenue | | % | 12.5 | 11.3 | 11.4 | 11.1 | 11.7 |
| 55. | a.Retail Systems | 1.310.5 | % | 17.7 | 16.8 | | | |
| 56. | Accounting Machines | 1.310.5 | % | 19.1 | 19.1 | | | |
| 57. | D.P. Systems | 1.310.5 | % | 15.8 | 17.9 | | | |
| 57a. | Other Products | | % | 4.2 | 3.0 | | | |
| 57b. | b. Computer Systems | | % | 19.5 | 21.3 | 21.4 | 21.9 | 24.8 |
| 57c. | Terminal & DE Syst. | | % | 14.9 | 21.2 | 27.5 | 30.8 | 33.0 |
| 57d. | Free–Standing Equip. | | % | 22.3 | 14.3 | 7.7 | 3.8 | 2.0 |
| 57e. | c. Computer Systems | | % | | 23.0 | 23.5 | 23.3 | 26.6 |
| 57f. | Retail Term. & Systems | | % | | 9.6 | 12.9 | 16.5 | 17.2 |
| 57g. | Financial Term. & Syst. | | % | | 8.1 | 9.8 | 10.1 | 11.0 |
| 57h. | GP Term. & Syst. | | % | | 1.9 | 2.7 | 2.8 | 3.0 |
| 57i. | Mechanical | | % | | 14.3 | 7.7 | 3.8 | 2.0 |
| 58. | Services | 1.310.5 | % | 22.2 | 22.8 | 23.4 | 24.4 | 28.0 |
| 59. | Supplies | 1.310.5 | % | 9.7 | 9.5 | 8.7 | 8.4 | 9.1 |
| 60. | Other | | % | 11.3 | 10.9 | 11.3 | 10.8 | 3.1 |
| 60a. | Supplies & Other | | % | 21.0 | 20.4 | 20.0 | 19.2 | 12.2 |
| 61. | B–International Revenue | 1.310.6 | % | 51.2 | 51.9 | 49.0 | 49.6 | |
| 63. | Rental Equipment Value–Gross | | $B | .678 | .718 | .713 | .662 | .677 |
| 64. | Net | | $B | .289 | .339 | .341 | .277 | .245 |
| 65. | R & D Expenses | | $B | .074 | .085 | .094 | .118 | .138 |
| 66. | % of Tot. Revenue | 1.310.6 | % | 3.7 | 3.9 | 4.1 | 4.7 | 5.3 |
| | **Univac (Sperry Rand)** | | | | | | | |
| 67. | Total Revenue | 1.310.7 | $B | 3.041 | 3.203 | 3.270 | 3.649 | |
| 68. | Net Income | | $B | .131 | .145 | .157 | .177 | |
| 69. | % of Revenue | 1.310.8 | % | 4.3 | 4.5 | 4.8 | 4.9 | |
| | Revenue Anal.–% of Tot. Rev. | | | | | | | |
| 70. | A–Commercial Products, US | | % | 41.2 | 38.8 | 39.5 | 41.8 | |
| 71. | International | 1.310.8 | % | 43.1 | 44.8 | 43.4 | 41.8 | |
| 72. | US Govt. Contracts | | % | 15.7 | 16.4 | 17.1 | 16.4 | |
| 73. | B–Business Machines, etc. | | % | 46.0 | 45.6 | 44.0 | | |
| 74. | Instruments & Controls | 1.310.7 | % | 22.4 | 23.0 | 24.0 | | |
| 75. | Hydraulic & Farm Equip. | 1.310.7 | % | 27.8 | 27.7 | 28.9 | | |
| 76. | Other Prod. & Serv. | 1.310.7 | % | 3.8 | 3.7 | 3.1 | | |
| 76a. | E–Computer Systems & Equip. | | % | 42.6 | 44.7 | 44.9 | 47.3 | |
| 76b. | Farm Equipment | | % | 17.6 | 19.4 | 20.4 | 20.6 | |
| 76c. | Guidance & Control Eq. | | % | 15.1 | 15.1 | 15.7 | 15.8 | |
| 76d. | Fluid Power Equip. | | % | 11.8 | 9.8 | 9.9 | 10.2 | |
| 76e. | Other, Adjustments, etc. | | % | 13.0 | 11.0 | 9.2 | 6.1 | |
| 81. | Rental Equip. Value–Gross | | $B | .641 | .626 | .582 | .594 | |
| 82. | Net | | $B | .202 | .182 | .159 | .158 | |
| 83. | R & D Expenses | | $B | .163 | .159 | .168 | .195 | |
| 84. | % of Tot. Revenue | 1.310.8 | % | 5.4 | 5.0 | 5.1 | 5.3 | |

Source: Corporate Annual Reports.

## TABLE II.1.311a INTERNATIONAL BUSINESS MACHINES CORP.

| Line | Item | Figure | Units | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| 1. | **Revenue**—Total | 1.311.3 | $B | 12.675 | 14.437 | 16.304 | 18.133 | 21.076 |
| 1a. | Av. 5-Yr. Growth Rate | | % | 12.0 | 14.0 | 14.5 | 13.7 | 13.9 |
| 2. | DP Systems | 1.311.3 | $B | 9.89 | 11.1 | 12.7 | | |
| 3. | % Total Revenue | 1.311.4 | % | 78 | 77 | 78 | | |
| | Percent Total Revenue | | | | | | | |
| 3a. | DP Segment | | % | 82.9 | 82.1 | 82.2 | 81.4 | 81.0 |
| 3b. | Equipment | | % | 72.7 | 71.9 | 71.9 | 70.1 | 68.6 |
| 3c. | Sales | | % | 19.6 | 17.7 | 23.2 | 25.4 | 27.7 |
| 3d. | Rentals & Services | | % | 53.1 | 54.2 | 48.7 | 44.7 | 40.9 |
| 3e. | Services, Programs & Supp. | | % | 10.2 | 10.2 | 10.3 | 11.3 | 12.4 |
| 3f. | Sales | | % | 3.3 | 3.0 | 2.8 | 2.8 | 2.5 |
| 3g. | Rentals & Services | | % | 6.9 | 7.2 | 7.5 | 8.5 | 9.9 |
| 3h. | Office Products Segment | | % | 14.0 | 14.7 | 14.7 | 15.6 | 16.1 |
| 3i. | Sales | | % | 7.8 | 7.7 | 7.6 | 8.0 | 8.5 |
| 3j. | Rentals & Services | | % | 6.2 | 7.0 | 7.1 | 7.6 | 7.6 |
| 3k. | All Other Segments | | % | 3.1 | 3.2 | 3.1 | 3.0 | 2.9 |
| 3l. | Sales | | % | 3.0 | 3.1 | 3.0 | 2.9 | 2.8 |
| 3m. | Rentals & Services | | % | .1 | .1 | .1 | .1 | .1 |
| 8. | All Sales | 1.311.5 | $B | 4.282 | 4.545 | 5.959 | 7.090 | 8.755 |
| 9. | % Total Revenue | | % | 33.8 | 31.5 | 36.5 | 39.1 | 41.5 |
| 10. | All Service & Rentals | 1.311.5 | $B | 8.394 | 9.891 | 10.345 | 11.043 | 12.321 |
| 11. | % Total Revenue | 1.311.5 | % | 66.2 | 68.5 | 63.5 | 60.9 | 58.5 |
| 11a. | DP Net Backlog | | $M/mo | 122 | 122 | 153 | 285 | 375 |
| 12. | **Costs**—Sales | | $B | 1.427 | 1.631 | 1.960 | 2.256 | 2.838 |
| 13. | % Sales Revenue | 1.311.6 | % | 33.3 | 35.9 | 32.9 | 31.8 | 32.4 |
| 14. | Service & Rentals | | $B | 3.327 | 3.718 | 3.866 | 4.042 | 4.646 |
| 15. | % Service Revenue | 1.311.6 | % | 39.6 | 37.6 | 37.4 | 36.6 | 37.7 |
| 16. | Total | 1.311.7 | $B | 4.754 | 5.349 | 5.826 | 6.298 | 7.484 |
| 17. | % Total Revenue | 1.311.6 | % | 37.5 | 37.1 | 35.7 | 34.7 | 35.5 |
| 18. | Gross Profit | | $B | 7.921 | 9.088 | 10.478 | 11.835 | 13.592 |
| 19. | % Total Revenue | | % | 62.5 | 62.9 | 64.3 | 65.3 | 64.5 |
| 20. | Indirect Costs—Total | | $B | 4.759 | 5.665 | 6.408 | 7.178 | 8.151 |
| 21. | % Total Revenue | | % | 37.5 | 39.2 | 39.3 | 39.6 | 38.7 |
| 24. | Engineering, R & D | 1.311.7 | $B | .890 | .946 | 1.012 | 1.142 | 1.255 |
| 25. | % Total Revenue | 1.311.8 | % | 7.0 | 6.6 | 6.2 | 6.3 | 6.0 |
| 30. | Interest, etc. | | $B | .069 | .063 | .045 | .040 | .055 |
| 31. | % Total Revenue | | % | 0.5 | 0.4 | 0.3 | 0.2 | 0.3 |
| 32. | Operating Income | 3.11.8a | $B | 3.094 | 3.360 | 4.025 | 4.617 | 5.386 |
| 33. | % Total Revenue | | % | 24.4 | 23.3 | 24.7 | 25.5 | 25.6 |
| 34. | Other Income | | $B | .341 | .361 | .494 | .475 | .412 |
| 35. | Net Earnings Before Taxes | | $B | 3.435 | 3.721 | 4.519 | 5.092 | 5.798 |
| 36. | Net Earnings After Taxes | 1.311.7 | $B | 1.838 | 1.990 | 2.398 | 2.719 | 3.111 |
| 37. | % Total Revenue | 1.311.8 | % | 14.5 | 13.8 | 14.7 | 15.0 | 14.8 |
| 38. | **Employees**—Total | 311.15 | k | 292.4 | 288.6 | 292.0 | 310.2 | 325.5 |
| 39. | Domestic | 311.15 | k | | 156.9 | 158.8 | 170.7 | 180.9 |
| 40. | % Tot. Employees | | % | | 54.4 | 54.4 | 55.0 | 55.6 |
| 41. | W.T.C. | | k | | 131.7 | 133.2 | 139.5 | 144.6 |

| Line | Item | Figure | Units | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| 42. | % Tot. Employees | 311.15 | % | | 45.6 | 45.6 | 45.0 | 44.4 |
| 43. | Revenue Per Employee | 311.16 | $k | 43.3 | 50.0 | 55.8 | 58.5 | 64.7 |
| 44. | Deflated | 311.16 | $k | 25.4 | 26.9 | 28.5 | 28.3 | 29.2 |
| 45. | **W.T.C. Revenue**—Total | 1.311.9 | $B | 5.947 | 7.271 | 8.154 | 9.125 | 11.040 |
| 46. | % Total Revenue | 1.311.9 | % | 46.9 | 50.4 | 50.0 | 50.3 | 52.4 |
| 47. | Av. 5-Yr. Growth Rate | 311.9b | % | 19.0 | 19.9 | 19.1 | 17.1 | 16.5 |
| 66. | Net Earnings After Taxes | 311.10 | $M | 919.8 | 1105.7 | 1318.0 | | |
| 66.a | Restated ($705M, 1973) | | $M | 734. | 853. | 1056.6 | 1228.0 | 1560.1 |
| 67. | % of W.T.C Revenue | | % | 15.5 | 15.2 | 16.2 | | |
| 67a. | As Restated | | % | 12.3 | 11.7 | 13.0 | 13.5 | 14.1 |
| 68. | % of Total Earnings | 311.10 | % | 50.0 | 55.6 | 55.0 | | |
| 68a. | As Restated | | % | 39.9 | 42.9 | 44.1 | 45.2 | 50.1 |
| 69. | Revenue Per Employee | 311.16 | $k | | 55.2 | 61.2 | 65.4 | 76.3 |
| 70. | **Domestic Revenue—Total** | 1.311.9 | $B | 6.728 | 7.166 | 8.150 | 9.008 | 10.036 |
| 71. | % Total Revenue | | % | 53.1 | 49.6 | 50.0 | 49.7 | 47.6 |
| 72. | Av. 5-Yr. Growth Rate | 311.9b | % | 7.4 | 9.4 | 10.9 | 10.9 | 11.4 |
| 91. | Net Earnings After Taxes | 311.10 | $M | 918.2 | 884.3 | 1080 | | |
| 91a. | Restated ($870M, 1973) | | $M | 1104 | 1137 | 1341.4 | 1491.0 | 1550.9 |
| 92a. | As Restated | | % | 16.4 | 15.9 | 16.5 | 16.6 | 15.5 |
| 92. | % of Domestic Revenue | | % | 13.6 | 12.3 | 13.3 | | |
| 93. | Revenue Per Employee | 311.16 | $k | | 45.7 | 51.3 | 52.8 | 55.5 |
| 94. | **Assets**—Total, WW | 311.17 | $B | 14.027 | 15.530 | 17.723 | 18.978 | 20.771 |
| 96. | Inventories—Total | 311.18 | $B | .688 | .740 | .770 | .994 | 1.561 |
| 97. | Finished Goods | | $B | .233 | .290 | .288 | .281 | .352 |
| 98. | % Total Inventories | 311.18 | % | 33.9 | 39.2 | 37.5 | 28.3 | |
| 99. | Work in Process | | $B | .299 | .315 | .361 | .579 | 1.037 |
| 100. | % Total Inventories | 311.18 | % | 43.5 | 42.6 | 46.9 | 58.4 | |
| 101. | Raw Materials | | $B | .070 | .064 | .056 | .051 | .064 |
| 102. | % Total Inventories | 311.18 | % | 10.2 | 8.6 | 7.3 | 5.1 | |
| 103. | Supplies | | $B | .086 | .071 | .064 | .081 | .109 |
| 104. | % Total Inventories | 311.18 | % | 12.5 | 9.6 | 8.3 | 8.2 | |
| 105. | Total Property, Gross, WW | 311.19 | $B | 14.017 | 15.037 | 15.677 | 17.071 | 19.175 |
| 106. | Land & Buildings—WW | | $B | 2.008 | 2.357 | 2.652 | 2.985 | 3.447 |
| 109. | Factory & Office Equip. | | $B | 2.374 | 2.742 | 2.963 | 3.356 | 3.989 |
| 110. | Rental Machines & Parts—WW Bal | | $B | 8.514 | 9.634 | 9.938 | 10.061 | 10.729 |
| 111. | Added this Year | 311.20 | $B | | 1.550 | 1.831 | 2.475 | 2.723 |
| 112. | Retirements & Sales | 311.20 | $B | | 1.246 | 1.708 | 1.807 | 1.713 |
| 113. | Closing Balance | 311.20 | $B | 9.634 | 9.938 | 10.061 | 10.729 | 11.740 |
| 114. | Depreciation Balance | | $B | 4.764 | 5.302 | 5.774 | 6.189 | 6.345 |
| 115. | Chgd. to P & L this Year | | $B | | 1.416 | 1.435 | 1.513 | 1.480 |
| 116. | Chgd. to Manufct'ng Overhead | | $B | | .025 | .021 | .027 | .034 |
| 117. | Retirements this Year | | $B | | .999 | 1.010 | 1.385 | 1.198 |
| 118. | Closing Balance | | $B | 5.302 | 5.774 | 6.189 | 6.345 | 6.661 |
| 119. | Rental Machines & Parts—Net | | $B | 4.332 | 4.194 | 4.250 | 4.384 | 5.079 |
| 120. | % of Tot. Prop—Land & Build. | | % | 14.3 | 15.7 | 16.9 | 17.5 | |
| 123. | Factory & Office Equip. | 311.19 | % | 16.9 | 18.2 | 18.9 | 19.7 | |
| 124. | Rental Machines & Parts | 311.19 | % | 68.7 | 66.1 | 64.2 | 62.8 | |

Source: Corporate Annual Reports.

## TABLE II.1.4.2a PERSONNEL

| Line | Item | Figure | Units | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| | **User Personnel** | | | | | | | |
| | U.S. Government Man-Years | | | | | | | |
| 1. | Systems Analysts | | k | 14.11 | 14.39 | 13.79 | 17.48 | |
| 2. | Programmers | | k | 18.84 | 19.30 | 19.06 | 19.81 | |
| 3. | SA & P | | k | 32.95 | 33.69 | 32.85 | 37.29 | |
| 4. | Keypunch Operators | | k | 12.59 | 16.14 | 15.19 | 16.68 | |
| 5. | Operations | | k | 30.23 | 30.76 | 30.63 | 29.24 | |
| 6. | Total | | k | 75.77 | 80.59 | 78.67 | 83.21 | |
| 7. | Total–All ADP Man-Yrs. | | k | 114.29 | 117.37 | 114.01 | 122.30 | |
| | U.S. Govt. Computers | | | | | | | |
| 15. | Total | | k | 7.830 | 8.649 | 9.648 | 11.124 | |
| 16. | General Management | | k | 3.487 | 3.622 | 3.829 | 4.408 | |
| | U.S. Clerical Worker Sample | | | | | | | |
| 18. | Keypunch Operators | | k | 109.1 | 102.3 | 99.8 | 109.8 | 106.5 |
| 19. | No. of Covered Employees | | M | 20.2 | 18.7 | 18.6 | 21.2 | 21.3 |
| 20. | Total Non-Govt. Employees | | M | | | | | |
| | U.S. Labor Force | | | | | | | |
| 21. | All Occupations | 1.4.1 | M | 90.3 | 91.8 | 93.9 | | |
| 22. | Prof. Techn., etc. | 1.4.1 | % | 14.0 | 14.4 | 14.7 | | |
| 23. | Clerical, etc. | 1.4.1 | % | 17.5 | 17.6 | 17.7 | | |
| 24. | Subtotal | 1.4.1 | % | 31.5 | 32.0 | 32.4 | | |
| | Govt. Man-Yrs. Per GM Comp. | | | | | | | |
| 41. | All ADP | | | 32.78 | 32.40 | 29.78 | 27.75 | |
| 43. | Systems Analysts | | | 4.05 | 3.97 | 3.60 | 3.97 | |
| 44. | Programmers | | | 5.40 | 5.33 | 4.98 | 4.49 | |
| 45. | SA & P | | | 9.45 | 9.30 | 8.58 | 8.46 | |
| 46. | Keypunch Operators | | | 3.61 | 4.46 | 3.97 | 3.78 | |
| 47. | Operations | | | 8.67 | 8.49 | 8.00 | 6.63 | |
| 48. | Total | | | 21.73 | 22.25 | 20.55 | 18.88 | |
| 48a | Corrected U.S. Government | | | | | | | |
| | U.S. Govt. Man-Years Ratios | | | | | | | |
| 49. | Prog. to SA | | | 1.34 | 1.34 | 1.38 | 1.13 | |
| 50. | Keypunch Opr. to SA & P | | | .38 | .48 | .46 | .45 | |
| | Personnel per $100k Value | | | | | | | |
| 50a. | SA & P | | | 1.12 | 1.11 | 1.10 | 1.08 | 1.07 |
| 50b. | Computer Operators | | | .58 | .58 | .58 | .58 | .58 |
| | Personnel Ratios | | | | | | | |
| 50c. | Prog. per SA | | | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 |
| 50d. | Keypunch op. per keybrd. | | | 1.20 | 1.20 | 1.20 | 1.20 | 1.20 |
| | DoloT76 Estimates | | | | | | | |
| 50e. | Prog. per GP comp. | | | | 2.9 | 2.8 | 2.7 | 2.6 |
| 50f. | Prog. per Total Comps. | | | | .98 | .85 | .7 | .55 |
| 50g. | Estimated Prog.–GP comp. | | | | 180 | 166 | 157 | 150 |
| 50h. | Total Comps. | | | | 204 | 215 | 225 | 220 |
| | Summary | | | | | | | |
| 51. | No. of–Systems Analysts | 1.4.2 | k | 150 | 170 | 190 | 215 | 245 |
| 52. | Programmers | 1.4.2 | k | 210 | 235 | 265 | 300 | 345 |
| 53. | SA & Programmers | | k | 360 | 405 | 455 | 515 | 590 |
| 54. | Computer Operators | 1.4.2 | k | 180 | 210 | 235 | 275 | 320 |
| 55. | Keypunch Operators | 1.4.2 | k | 540 | 545 | 555 | 555 | 545 |
| 56. | Total User Personnel | 1.4.2 | k | 1080 | 1160 | 1245 | 1345 | 1455 |

| Line | Item | Figure | Units | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| | **Supplier Personnel** | | | | | | | |
| 58. | SIC 3573, Dept. of Commerce | | k | 176.7 | 162.5 | 165.7 | 188 | 216 |
| | Manufacturing Direct Labor | | | | | | | |
| 60. | SIC 3573–Production Workers | | k | 86.8 | 73.8 | 71.3 | 87 | 109 |
| 61. | D.L. as Percent of Shipments | | % | 8.7 | 8.5 | 6.8 | 6.8 | 6.8 |
| 62. | Total Direct Labor | | $B | .810 | .810 | .711 | .898 | 1.051 |
| 63. | Total D.L. Employees | | k | 88.1 | 81.0 | 72.4 | 89.8 | 103.0 |
| 63a. | US GP D.L. Employees | 1.4.3 | k | 58.6 | 47.7 | 38.3 | 44.9 | 49.3 |
| | Development Personnel–IBM | | | | | | | |
| 82a. | Total Development Personnel | | | 6558 | 6865 | 6765 | 7175 | 7390 |
| 87. | Total Dev. Cost | | $M | 355 | 415 | 440 | 500 | 550 |
| 88. | IBM Reported R & D Exp. | | $M | 890 | 946 | 1012 | 1142 | 1255 |
| | Development Personnel–Non-IBM | | | | | | | |
| 105a. | Total Development Personnel | | | 8677 | 8934 | 9200 | 9474 | 9757 |
| | Development Cost–Non-IBM | | | | | | | |
| 108. | Total Dev. Cost | | $M | 459 | 526 | 584 | 645 | 712 |
| | Summary | | | | | | | |
| 109. | Total Hardware Dev. Cost | | $M | 512 | 595 | 644 | 721 | 792 |
| 110. | Total Software Dev. Cost | | $M | 302 | 346 | 380 | 424 | 470 |
| 111. | Total Dev. Cost | | $M | 814 | 941 | 1024 | 1145 | 1262 |
| 112. | Dev. Cost as Percent of GP Rev | | % | 5.5 | 5.6 | 5.5 | 5.6 | 5.3 |
| 113. | Total Dev. Engineers | 1.4.3 | k | 7.88 | 8.27 | 8.37 | 8.79 | 9.05 |
| 114. | Total Dev. Programmers | 1.4.3 | k | 7.36 | 7.53 | 7.60 | 7.86 | 8.10 |
| 115. | Total Dev. Professionals | | k | 15.24 | 15.80 | 15.97 | 16.65 | 17.15 |
| | Sales Personnel | | | | | | | |
| 116. | Pers. per $1M Ordered | | | 2.7 | 2.65 | 2.6 | 2.55 | 2.5 |
| 117. | U.S. Orders | | $B | 5.905 | 5.570 | 6.065 | 7.000 | 8.000 |
| 118. | Sales Personnel | 1.4.4 | k | 15.94 | 14.76 | 15.77 | 17.85 | 20.00 |
| | Maintenance Personnel | | | | | | | |
| 119. | CE's per $1M In Use | | | .48 | .48 | .48 | .48 | .48 |
| 120. | Maintenance Personnel | 1.4.4 | k | 14.50 | 16.22 | 18.19 | 20.59 | 23.38 |
| | Summary | | | | | | | |
| 121. | No. of–Mfg. Employees | | k | 58.6 | 47.7 | 38.3 | 44.9 | 49.3 |
| 122. | Development Personnel | | k | 15.2 | 15.8 | 16.0 | 16.7 | 17.2 |
| 123. | Sales Personnel | | k | 15.9 | 14.8 | 15.8 | 17.9 | 20.0 |
| 124. | Maintenance Pers. | | k | 14.5 | 16.2 | 18.2 | 20.6 | 23.4 |
| 125. | Total | 1.4.5 | k | 104.2 | 94.5 | 88.3 | 100.1 | 109.9 |
| | Gilchrist Study | | | | | | | |
| 126. | Employment–Mfg. | 1.4.5 | k | | | | | |
| 127. | Maintenance, Prog. | | k | | | | | |
| 128. | Sales, Marketing | | k | | | | | |
| 129. | Administrative, R & D | | k | 853 | | | | |
| 130. | Total | 1.4.5 | k | | | | | |
| | Total Emplmt. (NyboP77)U.S. | | | | | | | |
| 130a. | Manufacturing Industry | 1.4.5 | k | 209.5 | | | | |
| 130b. | Service Industries | 1.4.5 | k | 138.5 | | | | |
| 130c. | Comp. Mfg. & Service Ind | 1.4.5 | k | 348 | | | | |
| 130d. | Computer Related | | k | 111 | | | | |
| 130e. | Others | | k | 237 | | | | |
| 130f. | Computer Relt'd.,Comp. Users | | k | 742 | | | | |
| 130g. | Total Computer Related | | k | 853 | | | | |

## TABLE II.1.4.3a SALARIES AND WAGES

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | **User Personnel** | | | | | | | | |
| | Datamation Magazine | | | | | | | | |
| 1. | System Analysts–Lead | | $/wk | 338 | 362 | 402 | 439 | 434 | 397 |
| 2. | Grade A | | $/wk | 272 | 295 | 327 | 342 | 346 | 353 |
| 3. | Programmer–Lead | | $/wk | 307 | 320 | 353 | 371 | 395 | 363 |
| 4. | Grade A | | $/wk | 232 | 246 | 272 | 283 | 289 | 266 |
| 5. | Computer Operator–Lead | | $/wk | 228 | 251 | 262 | 272 | 279 | 263 |
| 6. | Grade A | | $/wk | 171 | 181 | 190 | 202 | 211 | 205 |
| 7. | Keypunch Operator–Lead | | $/wk | 158 | 161 | 177 | 189 | 198 | 195 |
| 8. | Grade A | | $/wk | 136 | 142 | 157 | 160 | 171 | 172 |
| | U.S. Govt. Employees | | | | | | | | |
| 9. | Dig. Comp. Systems Admin. | | $/wk | | 475 | 501 | 539 | | |
| 10. | Computer Specialist | | $/wk | | 372 | 394 | 421 | | |
| 11. | Computer Operator | | $/wk | | 222 | 234 | 249 | | |
| 13. | Comp. Aid & Techn'n. | | $/wk | | 176 | 185 | 194 | | |
| 14. | Data Transcriber | | $/wk | | 146 | 155 | 161 | | |
| | U.S. Clerical | | | | | | | | |
| 15. | Key Entry Operators I | | $/wk | 116 | 124 | 137 | 147 | 155 | 164 |
| 16. | Key Entry Operators II | | $/wk | 133 | 144 | 158 | 170 | 180 | 194 |
| | Estimated Averages | | | | | | | | |
| 17. | System Analysts | 1.4.6 | $/wk | 340 | 360 | 372 | 400 | 438 | 469 |
| 18. | Programmers | 1.4.6. | $/wk | 270 | 280 | 294 | 319 | 341 | 363 |
| 19. | Computer Operators | 1.4.6 | $/wk | 200 | 215 | 225 | 238 | 250 | 263 |
| 20. | Keypunch Operators | 1.4.6 | $/wk | 140 | 150 | 162 | 174 | 184 | 195 |
| | **Supplier Personnel** | | | | | | | | |
| | Manufacturing Direct Labor | | | | | | | | |
| 22. | Electronic Comp'ng (3573) | | $/hr | 4.33 | 4.60 | 5.00 | 4.91 | | |
| 23. | Calc & Acctg Mach (3574) | | $/hr | 4.45 | 4.80 | 4.64 | 4.90 | | |
| 24. | Radio & TV Receivers (365x) | | $/hr | | 3.92 | 4.34 | 4.83 | | |

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | Development Personnel | | | | | | | | |
| 25. | U.S. White-Collar–Eng. V | | $/wk | 377 | 397 | 431 | 463 | 493 | 538 |
| 26. | Engineer I | | $/wk | 216 | 229 | 248 | 268 | 281 | 306 |
| 27. | Engineer VIII | | $/wk | 567 | 605 | 656 | 697 | 732 | 810 |
| 28. | Drafters II | | $/wk | 189 | 201 | 216 | 231 | 247 | 264 |
| 29. | Eng. Technician III | | $/wk | 192 | 202 | 219 | 236 | 253 | 270 |
| | Estimated Averages | | | | | | | | |
| 30. | M'fctng. Direct Labor | 1.4.7a | $/hr | 4.33 | 4.60 | 5.00 | 4.91 | 5.00 | 5.10 |
| 31. | Dev. Programmers | 1.4.7a | $/wk | 377 | 390 | 431 | 463 | 493 | 521 |
| 32. | Engineers | 1.4.7a | $/wk | 377 | 390 | 431 | 463 | 493 | 521 |
| 33. | Technicians | | $/wk | 190 | 200 | 220 | 236 | 253 | 269 |
| 34. | Draftsmen | | $/wk | 190 | 200 | 215 | 230 | 247 | 265 |
| 35. | Customer Engr. | 1.4.7a | $/wk | 228 | 240 | 264 | 283 | 304 | 320 |
| 36. | Sales–Salesmen | | $/wk | 453 | 480 | 496 | 533 | 584 | 625 |
| 37. | System Analysts | | $/wk | 340 | 360 | 372 | 400 | 438 | 469 |
| | **Clerical Personnel** | | | | | | | | |
| | U.S. Government | | | | | | | | |
| 38. | Mail and File Clerk | | $/wk | | 154 | 164 | 172 | | |
| 40. | Secretary | | $/wk | | 209 | 220 | 230 | | |
| 41. | Clerk-Typist | | $/wk | | 143 | 152 | 160 | | |
| | U.S. Clerical | | | | | | | | |
| 42. | File Clerk I | | $/wk | 93 | 98 | 106 | 113 | 117 | 127 |
| 43. | File Clerk II | | $/wk | 103 | 109 | 120 | 128 | 138 | 152 |
| 44. | Stenographers, General | | $/wk | 125 | 134 | 150 | 163 | 175 | 189 |
| 45. | Secretary II | | $/wk | 158 | 158 | | 186 | 194 | 206 |
| 46. | Typist I | | $/wk | 105 | 112 | 122 | 131 | 138 | 150 |
| 47. | Typist II | | $/wk | 122 | 130 | 143 | 153 | 165 | 178 |
| | Estimated Averages | | | | | | | | |
| 48. | File Clerk | 1.4.8a | $/wk | 103 | 110 | 120 | 128 | 138 | 152 |
| 49. | Clerk Typist | 1.4.8a | $/wk | 114 | 121 | 133 | 142 | 152 | 164 |
| 50. | Secretary | 1.4.8a | $/wk | 158 | 170 | 178 | 186 | 194 | 206 |

**TABLE II.2.10a THE IMPORTANT COMPUTERS**

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **GP System Populations, US** | | | | | | | | | | | | | | | | | | | | | | |
| 2. | GP Systems in Use | | k | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 27.100 | 31.000 | 37.000 | 40.000 | 41.900 | 45.000 | 50.200 | 58.300 | 61.500 | 62.100 | 59.600 | 58.200 | 57.960 |
| 18. | IBM 1401–No. in Use | | k | | .260 | 1.773 | 3.148 | 5.227 | 6.295 | 5.487 | 5.664 | 3.819 | 2.528 | 1.730 | 1.481 | 1.268 | 1.133 | 1.029 | .823 | .648 | .590 | .501 | .500 |
| 19. | Average Rental | | $k/mo | | 2.5 | 2.5 | 2.5 | 3.5 | 4.5 | 4.5 | 6.6 | 6.48 | 6.2 | 6.2 | 6.2 | 6.2 | 3.7 | 3.7 | 3.7 | 3.775 | 3.7 | 3.7 | 3.7 |
| 20. | Total Monthly Rental | | $M/mo | | .65 | 4.43 | 7.87 | 18.29 | 28.33 | 24.69 | 37.38 | 24.75 | 15.67 | 10.73 | 9.18 | 7.86 | 4.19 | 3.81 | 3.05 | 2.45 | 2.18 | 1.85 | 1.85 |
| 21. | IBM 7094 I & II–No. in Use | | k | | | | .001 | .073 | .248 | .185 | .180 | .186 | .170 | .075 | .075 | .064 | .055 | .051 | .042 | | | | |
| 22. | Average Rental | | $k/mo | | | | 70 | 70 | 70 | 72.5 | 72.5 | 75.5 | 75.5 | 73.4 | 73.4 | 73.4 | 73.4 | 73.4 | 73.4 | | | | |
| 23. | Total Monthly Rental | | $M/mo | | | | .07 | 5.11 | 17.36 | 13.41 | 13.05 | 14.04 | 12.84 | 5.51 | 5.51 | 4.70 | 4.04 | 3.74 | 3.08 | | | | |
| 24. | IBM 1460–No. in Use | | k | | | | | .093 | .706 | 1.748 | 1.313 | .903 | .524 | .141 | .142 | .068 | .055 | .051 | .047 | .026 | .018 | .014 | .014 |
| 25. | Average Rental | | $k/mo | | | | | 9.8 | 9.8 | 9.0 | 11.5 | 10.93 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 | 10.0 | 10.0 | 10.0 | 10.0 | 9.6 |
| 26. | Total Monthly Rental | | $M/mo | | | | | .91 | 6.92 | 15.73 | 15.10 | 10.16 | 5.14 | 1.38 | 1.392 | .67 | .54 | .50 | .47 | .26 | .18 | .14 | .13 |
| 27. | IBM 360/30–No. in Use | | k | | | | | | | .325 | 1.841 | 2.860 | 4.563 | 6.488 | 5.955 | 4.702 | 3.610 | 2.906 | 2.540 | 2.200 | 2.028 | 1.733 | 1.560 |
| 28. | Average Rental | | $k/mo | | | | | | | 7.2 | 7.5 | 8.5 | 8.8 | 10.5 | 12.3 | 12.3 | 11.0 | 11.0 | 11.4 | 11.4 | 10.9 | 11.2 | 11.2 |
| 29. | Total Monthly Rental | | $M/mo | | | | | | | 2.34 | 13.81 | 24.31 | 40.15 | 68.12 | 73.25 | 57.83 | 39.71 | 31.97 | 28.96 | 25.08 | 22.11 | 19.41 | 17.47 |
| 30. | IBM 360/40–No. in Use | | k | | | | | | | .285 | .996 | 1.549 | 2.149 | 2.463 | 2.929 | 2.466 | 2.141 | 1.414 | 1.205 | 1.104 | 1.151 | 1.102 | 1.050 |
| 31. | Average Rental | | $k/mo | | | | | | | 14.5 | 15.0 | 15.0 | 16.8 | 19.3 | 22.0 | 22.0 | 19.6 | 19.4 | 20.4 | 20.0 | 18.4 | 19.0 | 19.0 |
| 32. | Total Monthly Rental | | $M/mo | | | | | | | 4.13 | 14.94 | 23.24 | 36.10 | 47.54 | 64.44 | 54.25 | 41.96 | 27.43 | 24.58 | 22.08 | 21.18 | 20.94 | 19.95 |
| 32a. | IBM 370/145–No. in Use | | k | | | | | | | | | | | | | .353 | 1.066 | 1.591 | 1.820 | 1.784 | 1.774 | 1.603 | 1.210 |
| 32b. | Average Rental | | $k/mo | | | | | | | | | | | | | 28.9 | 24.7 | 27.8 | 31.7 | 31.7 | 36.5 | 38.5 | 39.0 |
| 32c. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | 10.20 | 26.33 | 44.23 | 57.69 | 56.55 | 64.75 | 61.72 | 47.19 |
| 33. | IBM 370/155–No. In Use | | k | | | | | | | | | | | | | .384 | .878 | 1.114 | .657 | .498 | .517 | .476 | .440 |
| 34. | Average Rental | | $k/mo | | | | | | | | | | | | | 50.9 | 51.7 | 53.35 | 60.3 | 60.3 | 67.0 | 70.0 | 72.0 |
| 35. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | 19.55 | 45.40 | 59.43 | 39.62 | 30.03 | 34.64 | 33.32 | 31.68 |
| 35a. | IBM 370/135–No. in Use | | k | | | | | | | | | | | | | | .814 | 2.059 | 2.600 | 2.522 | 2.399 | 1.823 | 1.290 |
| 35b. | Average Rental | | $k/mo | | | | | | | | | | | | | | 13.5 | 16.2 | 17.5 | 17.5 | 19.1 | 20.5 | 20.5 |
| 35c. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | | 10.99 | 33.36 | 45.5 | 44.14 | 45.73 | 37.37 | 26.45 |
| 35d. | IBM 370/158–No. in Use | | k | | | | | | | | | | | | | | | .138 | .600 | .864 | 1.247 | 1.503 | 1.550 |
| 35e. | Average Rental | | $K/mo | | | | | | | | | | | | | | | 59.2 | 67.5 | 67.5 | 95.0 | 100.0 | 104.0 |
| 35f. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | | | 8.17 | 40.5 | 58.32 | 118.5 | 150.3 | 161.2 |
| 35g. | IBM 370/168–No. in Use | | k | | | | | | | | | | | | | | | .047 | .143 | .258 | .405 | .526 | .650 |
| 35h. | Average Rental | | $k/mo | | | | | | | | | | | | | | | 110.2 | 126.7 | 126.0 | 177.0 | 185.0 | 194.0 |
| 35i. | Total Monthly Rental | | $M/mo | | | | | | | | | | | | | | | 5.18 | 18.12 | 32.51 | 71.69 | 97.31 | 126.1 |
| | Number in Use | | | | | | | | | | | | | | | | | | | | | | |
| 37. | IBM 305 | | k | .610 | .950 | 1.064 | .756 | .514 | .350 | .138 | .103 | .067 | .051 | .007 | .002 | .001 | .001 | | | | | | |
| 38. | IBM 1620 | | k | | .050 | .415 | 1.103 | 1.138 | 1.263 | 1.382 | 1.232 | .826 | .732 | .608 | .360 | .337 | .327 | .304 | .265 | .203 | .133 | .110 | .094 |
| 39. | Univac 1004 | | k | | | | | .548 | 1.787 | 2.600 | 2.500 | 1.932 | 1.712 | 1.359 | 1.123 | 1.006 | .881 | .824 | .771 | .527 | .318 | .256 | .240 |
| 40. | IBM 360/20 | | k | | | | | | | .002 | .887 | 2.819 | 4.786 | 5.989 | 6.913 | 6.575 | 5.457 | 3.186 | 2.270 | 1.630 | 1.404 | 1.082 | .900 |
| 41. | IBM System 3/10 | | k | | | | | | | | | | | | 1.286 | 2.744 | 7.304 | 14.516 | 15.910 | 15.683 | 11.944 | 8.034 | 6.900 |
| 41a. | IBM System 3/6 | | k | | | | | | | | | | | | .004 | 1.270 | 1.512 | 2.824 | 2.930 | 2.583 | 1.706 | .942 | .740 |
| 42. | IBM 707x | | k | | | .192 | .200 | .379 | .428 | .276 | .238 | .163 | .132 | .155 | .144 | .108 | .095 | .094 | .092 | .086 | .091 | .077 | .062 |
| 42a. | Burroughs 5000/5500 | | k | | | | | .019 | .031 | .039 | .047 | .067 | .085 | .125 | .114 | .125 | .095 | .077 | .078 | .048 | .049 | .043 | .037 |
| 42b. | IBM System 3/8 | | k | | | | | | | | | | | | | | | | | 1.127 | 3.706 | 5.169 | 4.850 |
| 43. | CDC 6600 | | k | | | | | | .001 | .006 | .016 | .026 | .045 | .061 | .063 | .056 | .057 | .054 | .056 | .052 | .050 | .047 | .049 |
| 44. | IBM 360/65 | | k | | | | | | | .001 | .021 | .219 | .417 | .459 | .540 | .478 | .386 | .451 | .405 | .380 | .401 | .401 | .390 |
| 45. | Univac 1108 | | k | | | | | | | .003 | .023 | .067 | .120 | .114 | .131 | .135 | .130 | .126 | .123 | .122 | .156 | .152 | .152 |
| 45a. | IBM 3033 | | | | | | | | | | | | | | | | | | | | | | .220 |
| | **Mini System Popul'ns, U.S.** | | | | | | | | | | | | | | | | | | | | | | |
| 46. | Mini Systems in Use | | k | | | | | | | .200 | 1.200 | 3.000 | 5.200 | 11.50 | 20.00 | 28.50 | 45.00 | 65.10 | 96.10 | 126.3 | 162.3 | 214.5 | 275.3 |
| 50. | DEC PDP-8 | | k | | | | | | | .095 | .550 | 1.070 | 1.129 | 1.190 | 1.185 | .950 | .930 | | | | | | |
| 50a. | HIS–DDP–116 | | k | | | | | | | .034 | .136 | .175 | .203 | .175 | .172 | | | | | | | | |
| 51. | DEC PDP-8L,I | | k | | | | | | | | | | 1.000 | 3.617 | 6.080 | 5.355 | 4.830 | 4.383 | | | | | |

## TABLE II.2.10a THE IMPORTANT COMPUTERS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52. | DEC PDP-8/E,M | | k | | | | | | | | | | | | | 2.290 | 4.815 | 7.815 | 11.490 | 13.50 | 15.50 | 17.50 | 19.50 |
| 52a. | DEC PDP-11/05,10 | | k | | | | | | | | | | | | | | 1.400 | 3.135 | 5.215 | 8.600 | 12.44 | 15.24 | 17.16 |
| 52aa. | DEC PDP-11/03,LSI-11, | | k | | | | | | | | | | | | | | | | | 2.000 | 4.150 | 18.650 | 39.650 |
| 52b. | HP 2100-A | | k | | | | | | | | | | | | | | .465 | 3.320 | 5.415 | 7.500 | 7.700 | 7.850 | 7.900 |
| | **SBC System Popul'ns, U.S.** | | | | | | | | | | | | | | | | | | | | | | |
| 52c. | SBC Systems in Use | | k | | | | | | | | | | | | .080 | .260 | .730 | 1.500 | 4.500 | 12.400 | 27.200 | 48.800 | 72.800 |
| 52d. | Qantel V | | k | | | | | | | | | | | | .030 | .070 | .125 | .200 | .125 | | | | |
| 52e. | Clary Datacomp | | k | | | | | | | | | | | | .020 | .100 | .100 | .100 | | | | | |
| 52f. | Basic/Four 400 | | k | | | | | | | | | | | | | .050 | .150 | .300 | .640 | .750 | .920 | 1.400 | 1.900 |
| 52g. | Wang 2200 | | k | | | | | | | | | | | | | | | .150 | .500 | 1.150 | 5.900 | 9.900 | 11.260 |
| 52h. | IBM System/32 | | k | | | | | | | | | | | | | | | | | 5.000 | 8.000 | 14.800 | 13.300 |
| | **GP System Performance** | | | | | | | | | | | | | | | | | | | | | | |
| 56. | IBM 7090 at 45.47 Kops | | Mops | .091 | 2.956 | 5.775 | 7.912 | 9.549 | 1.728 | 1.682 | 1.501 | .728 | 1.182 | 1.273 | 1.273 | .818 | .864 | .773 | .591 | | | | |
| 57. | IBM 1401 at 1.2 Kops | | Mops | | .312 | 2.128 | 3.778 | 6.272 | 7.554 | 6.584 | 6.797 | 4.583 | 3.034 | 2.076 | 1.777 | 1.522 | 1.360 | 1.235 | .988 | .778 | .708 | .601 | .600 |
| 58. | IBM 7094II at 95.9 Kops | | Mops | | | | .096 | 7.000 | 23.78 | 17.74 | 17.26 | 17.83 | 16.30 | 7.193 | 7.193 | 6.138 | 5.275 | 4.891 | 4.028 | | | | |
| 59. | CDC 6600 at 4091.3 Kops | | Mops | | | | | | 4.091 | 24.55 | 65.46 | 106.37 | 184.11 | 249.6 | 257.8 | 229.1 | 233.2 | 220.9 | 229.1 | 212.7 | 204.6 | 192.3 | 200.5 |
| 60. | BGH 5000/5500 at 544.2 Kops | | Mops | | | | | .304 | 6.26 | 21.2 | 25.58 | 36.46 | 46.26 | 68.03 | 62.04 | 68.03 | 51.70 | 41.91 | 42.45 | 26.12 | 26.67 | 23.40 | 20.14 |
| 61. | IBM 360/65 at 809.7 Kops | | Mops | | | | | | | .810 | 17.00 | 177.3 | 337.6 | 371.7 | 437.2 | 387.0 | 312.5 | 365.2 | 327.9 | 307.7 | 324.7 | 324.7 | 315.8 |
| 62. | Univac 1108 at 2088.1 Kops | | Mops | | | | | | | 6.264 | 48.03 | 139.9 | 250.6 | 238.0 | 273.5 | 281.9 | 271.5 | 263.1 | 256.8 | 254.8 | 325.7 | 317.4 | 317.4 |
| 62a. | IBM 370/155 at 1203 Kops | | Mops | | | | | | | | | | | | | 462.0 | 1056 | 1340 | 790.4 | 599.1 | 622.0 | 572.6 | 529.3 |
| 62b. | IBM 370/145 at 445.8 Kops | | Mops | | | | | | | | | | | | | 157.4 | 475.2 | 709.3 | 811.4 | 795.3 | 790.8 | 714.6 | 539.4 |
| 62c. | IBM 370/158 at 2.423 Mops | | Mops | | | | | | | | | | | | | | | 334 | 1,454 | 2,093 | 3,021 | 1,642 | 3,755 |
| 62d. | IBM 370/168 at 6.008 Mops | | Mops | | | | | | | | | | | | | | | 282 | 859 | 1,550 | 2,433 | 3,160 | 3,905 |
| 62e. | IBM 3033 at 19.019 Mops | | Mops | | | | | | | | | | | | | | | | | | | | 4,184 |
| | **Greatest Value in Use** | | | | | | | | | | | | | | | | | | | | | | |
| 63. | GP System Value in Use, US | | $M/mo | 30.45 | 42.39 | 59.20 | 79.20 | 103.4 | 136.4 | 177.3 | 213.6 | 281.8 | 356.8 | 434.1 | 486.4 | 529.5 | 561.4 | 620.5 | 686.4 | 768.2 | 861.4 | 975.0 | 1106.8 |
| | Percent of Total GP Value, US | | | | | | | | | | | | | | | | | | | | | | |
| 65. | IBM 650 | 2.10.4 | % | 27.9 | 16.9 | 9.2 | 5.5 | 2.3 | 1.1 | 0.6 | 0.3 | 0.2 | 0.1 | | | | | | | | | | |
| 66. | Univac I | 20.10.5 | % | 7.0 | 4.7 | 2.5 | 1.6 | 0.8 | 0.5 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | | | | | | | | | |
| 67. | IBM 704 | 2.10.5 | % | 13.3 | 8.3 | 4.9 | 3.0 | 1.6 | 0.8 | 0.6 | 0.4 | 0.2 | 0.2 | 0.1 | | | | | | | | | |
| 68. | IBM 705 | 2.10.5 | % | 17.2 | 12.0 | 8.5 | 5.0 | 2.7 | 1.4 | 0.8 | 0.7 | 0.4 | 0.3 | 0.2 | .1 | .1 | | | | | | | |
| 69. | IBM 7090 | 2.10.4 | % | 0.4 | 9.8 | 13.7 | 14.1 | 13.0 | 1.8 | 1.3 | 1.0 | 0.4 | 0.5 | 0.4 | .4 | .2 | .2 | .2 | .1 | | | | |
| 70. | IBM 1401 | 2.10.4 | % | | 1.5 | 7.5 | 9.9 | 17.7 | 20.8 | 13.9 | 17.5 | 8.8 | 4.4 | 2.5 | 1.9 | 1.5 | .7 | .6 | .4 | .3 | .3 | .2 | .2 |
| 71. | IBM 7094 | 2.10.5 | % | | | | | 4.9 | 12.7 | 7.6 | 6.1 | 5.0 | 3.6 | 1.3 | 1.1 | .9 | .7 | .6 | .5 | | | | |
| 72. | IBM 1460 | 2.10.5 | % | | | | | .8 | 5.1 | 8.9 | 7.1 | 3.6 | 1.4 | 0.3 | .3 | .1 | .1 | .1 | .1 | | | | |
| 73. | IBM 360/30 | 2.10.4 | % | | | | | | | 1.3 | 6.5 | 8.6 | 11.3 | 15.7 | 15.1 | 10.9 | 7.1 | 5.2 | 4.2 | 3.3 | 2.6 | 2.0 | 1.6 |
| 74. | IBM 360/40 | 2.10.5 | % | | | | | | | 2.3 | 7.0 | 8.3 | 10.1 | 11.0 | 13.2 | 10.3 | 7.5 | 4.4 | 3.6 | 2.9 | 2.5 | 2.2 | 1.8 |
| 74a. | IBM 370/145 | 2.10.5 | % | | | | | | | | | | | | | 1.9 | 4.7 | 7.1 | 8.4 | 7.4 | 7.5 | 6.3 | 4.3 |
| 75. | IBM 370/155 | 2.10.4 | % | | | | | | | | | | | | | 3.7 | 8.1 | 9.6 | 5.8 | 3.9 | 4.0 | 3.4 | 2.9 |
| 75a. | IBM 370/135 | 2.10.5 | % | | | | | | | | | | | | | | 2.0 | 5.4 | 6.6 | 5.7 | 5.3 | 3.8 | 2.4 |
| 75b. | IBM 370/158 | | % | | | | | | | | | | | | | | | 1.3 | 5.9 | 7.6 | 13.7 | 15.4 | 14.6 |
| 75c. | IBM 370/168 | | % | | | | | | | | | | | | | | | 0.8 | 2.6 | 4.2 | 8.3 | 10.0 | 11.4 |
| 76. | Sum of Two Greatest | | % | 45.1 | 28.9 | 22.9 | 24.0 | 30.7 | 33.5 | 22.8 | 24.6 | 17.4 | 21.4 | 26.7 | 28.3 | 21.2 | 15.6 | 16.7 | 15.0 | 15.0 | 22.0 | 25.4 | 26.0 |
| | **Greatest Number in Use** | | | | | | | | | | | | | | | | | | | | | | |
| | % of Tot. GP Syst. in Use, US | | | | | | | | | | | | | | | | | | | | | | |
| 77. | IBM 650 | 2.10.1 | % | 50.0 | 29.5 | 16.1 | 10.1 | 4.2 | 1.8 | 1.0 | 0.5 | 0.3 | 0.2 | | | | | | | | | | |
| 78. | Burroughs 205 | 2.10.2 | % | 4.1 | 2.7 | 1.7 | 0.9 | 0.5 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | | | | | | | | | | |
| 79. | IBM 305 | 2.10.2 | % | 19.6 | 21.6 | 17.3 | 9.3 | 4.4 | 2.1 | 0.6 | 0.4 | 0.2 | 0.1 | | | | | | | | | | |
| 80. | IBM 1401 | 2.10.1 | % | | 5.9 | 28.8 | 38.9 | 44.7 | 37.7 | 25.4 | 20.9 | 12.3 | 6.8 | 4.3 | 3.5 | 2.8 | 2.3 | 1.8 | 1.3 | 1.0 | 1.0 | 0.9 | 0.9 |
| 81. | IBM 1620 | 2.10.2 | % | | 1.1 | 6.7 | 13.6 | 9.7 | 7.6 | 6.4 | 4.5 | 2.7 | 2.0 | 1.5 | 0.9 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 |
| 82. | Univac 1004 | 2.10.2 | % | | | | | 4.7 | 10.7 | 12.0 | 9.2 | 6.2 | 4.6 | 3.4 | 2.7 | 2.2 | 1.8 | 1.4 | 1.3 | 0.9 | 0.5 | 0.4 | 0.4 |

## TABLE II.2.10a THE IMPORTANT COMPUTERS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 83. | IBM 360/30 | 2.10.1 | % | | | | | | | 1.5 | 6.8 | 9.2 | 12.3 | 16.2 | 14.2 | 10.5 | 7.2 | 5.0 | 4.1 | 3.5 | 3.4 | 3.0 | 2.7 |
| 84. | IBM 360/20 | 2.10.1 | % | | | | | | | | 3.3 | 9.1 | 12.9 | 15.0 | 16.5 | 14.6 | 10.9 | 5.5 | 3.7 | 2.6 | 2.4 | 1.9 | 1.6 |
| 85. | IBM System 3/10 | 2.10.1 | % | | | | | | | | | | | | 3.1 | 6.1 | 14.5 | 24.9 | 25.9 | 25.3 | 20.0 | 13.8 | 11.9 |
| 85a. | IBM System 3/6 | 2.10.2 | % | | | | | | | | | | | | | 2.8 | 3.0 | 4.8 | 4.8 | 4.2 | 2.9 | 1.6 | 1.3 |
| 85b. | IBM System 3/8 | | % | | | | | | | | | | | | | | | | | 1.8 | 6.2 | 8.9 | 8.4 |
| 86. | Sum of Two Greatest | | % | 69.6 | 51.1 | 45.1 | 52.5 | 54.4 | 48.4 | 37.4 | 30.1 | 21.5 | 25.2 | 31.2 | 30.7 | 25.1 | 25.4 | 30.4 | 30.7 | 29.5 | 26.2 | 22.7 | 20.3 |
| | % of Tot. Mini Syst in Use, US | | | | | | | | | | | | | | | | | | | | | | |
| 90. | DEC PDP-8 | 2.10.3 | % | | | | | | | 47.5 | 45.8 | 35.7 | 21.7 | 10.3 | 5.9 | 3.3 | 2.1 | | | | | | |
| 90a. | HIS DDP 116 | | % | | | | | | | 17.0 | 11.3 | 5.8 | 3.9 | 1.5 | 0.9 | | | | | | | | |
| 91. | DEC PDP-8/L,I | 2.10.3 | % | | | | | | | | | | 19.2 | 31.5 | 30.4 | 18.8 | 10.7 | 6.7 | | | | | |
| 92. | DEC PDP-8/E,M | 2.10.3 | % | | | | | | | | | | | | | 8.0 | 10.7 | 12.0 | 12.0 | 10.7 | 9.6 | 8.2 | 7.1 |
| 92a. | DEC PDP-11/05,10 | 2.10.3 | % | | | | | | | | | | | | | | 3.1 | 4.8 | 5.4 | 6.8 | 7.7 | 7.1 | 6.2 |
| 92aa. | DEC PDP-11/03,LSI-11 | | k | | | | | | | | | | | | | | | | | 1.6 | 2.6 | 4.0 | 14.4 |
| 92b. | HP 2100-A | 2.10.3 | % | | | | | | | | | | | | | | 1.0 | 5.1 | 5.6 | 5.9 | 4.7 | 3.7 | 2.9 |
| 93. | Sum of Two Greatest | | % | | | | | | | 64.5 | 57.1 | 41.5 | 40.9 | 41.8 | 36.3 | 26.8 | 21.4 | 18.7 | 17.6 | 16.6 | 17.3 | 15.3 | 21.5 |
| | % Tot. SBC Syst. in Use, U.S. | | | | | | | | | | | | | | | | | | | | | | |
| 93a. | Qantel V | | % | | | | | | | | | | | | 37.5 | 26.9 | 17.1 | 13.3 | 2.8 | | | | |
| 93b. | Clary Datacomp | | % | | | | | | | | | | | | 25.0 | 38.5 | 13.7 | 6.7 | | | | | |
| 93c. | Basic/Four 400 | | % | | | | | | | | | | | | | 19.2 | 20.5 | 20.0 | 14.2 | 6.0 | 3.4 | 2.9 | 2.6 |
| 93d. | Wang 2200 | | % | | | | | | | | | | | | | | | 10.0 | 11.1 | 9.3 | 21.7 | 20.3 | 15.5 |
| 93e. | IBM System/32 | | % | | | | | | | | | | | | | | | | | 40.3 | 29.4 | 30.3 | 18.3 |
| 93f. | Sum of Two Greatest | | % | | | | | | | | | | | | 62.5 | 65.4 | 37.6 | 33.3 | 25.3 | 49.6 | 51.1 | 50.6 | 33.8 |
| | **Greatest Perform. In Use** | | | | | | | | | | | | | | | | | | | | | | |
| 94. | Population–Included | | k | 2.86 | | 5.99 | | 13.756 | | 26.360 | | | | | | | | | | | | | |
| 95. | Missing | | k | 0.7 | | 0.8 | | .114 | | .210 | | | | | | | | | | | | | |
| 96. | Average Performance–IBM | | kops | 1.128 | | 2.31 | | 4.04 | | 6.58 | | | 32.9 | | 39.9 | | 88.8 | | 105.1 | | 178 | | 443 |
| 97. | Non-IBM Systems | | kops | .727 | | 2.77 | | 4.08 | | 16.29 | | | | | | | | | | | | | |
| 98. | Missing Systems (Assumed) | | kops | .727 | | 2.77 | | 4.08 | | 16.29 | | | | | | | | | | | | | |
| 99. | Total Non-IBM | | kops | .727 | | 2.77 | | 4.08 | | 16.29 | | | 67.0 | | 74.1 | | 100.0 | | 125.0 | | 160 | | 475 |
| 100. | Average System Performance | | Kops | 1.063 | 1.7 | 2.399 | 3.1 | 4.048 | 6.5 | 9.860 | 20 | 33 | 45.8 | | 52.4 | | 92.8 | | 112.6 | | 172.1 | | 450 |
| 101. | Total US GP Operations/Sec | | Mops | 3.31 | 7.48 | 14.8 | 25.1 | 47.4 | 108.6 | 213.0 | 542 | 1,023 | 1,698 | 2,000 | 2,194 | 3,200 | 4,657 | 5,600 | 6,925 | 8,500 | 10,258 | 13,000 | 26,064 |
| | % of Tot. Perf. In Use By: | | | | | | | | | | | | | | | | | | | | | | |
| 102. | IBM 650 | 2.10.6 | % | 13.7 | 5.1 | 2.0 | 0.9 | 0.3 | 0.1 | | | | | | | | | | | | | | |
| 103. | IBM 704 | 2.10.6 | % | 14.5 | 5.6 | 2.3 | 1.1 | 0.4 | 0.1 | | | | | | | | | | | | | | |
| 104. | IBM 705 III | 2.10.6 | % | 39.6 | 17.0 | 8.5 | 3.9 | 1.5 | 0.4 | 0.2 | | | | | | | | | | | | | |
| 105. | IBM 709 | 2.10.7 | % | 16.4 | 5.5 | 2.1 | 1.5 | 0.3 | 0.1 | | | | | | | | | | | | | | |
| 106. | IBM 7090 | 2.10.6 | % | 2.7 | 39.5 | 39.0 | 31.5 | 20.1 | 1.6 | 0.8 | 0.3 | | | | | | | | | | | | |
| 107. | IBM 1401 | 2.10.7 | % | | 4.2 | 14.4 | 15.1 | 13.2 | 7.0 | 3.1 | 1.3 | 0.4 | 0.2 | | | | | | | | | | |
| 108. | IBM 7094 II | 2.10.6 | % | | | | 0.4 | 14.8 | 21.9 | 8.3 | 3.2 | 1.7 | 1.0 | .3 | .3 | .2 | | | | | | | |
| 109. | CDC 6600 | 2.10.6 | % | | | | | | 3.9 | 11.5 | 12.1 | 10.4 | 10.8 | 12.5 | 11.8 | 7.2 | 5.0 | 3.9 | 3.3 | 2.5 | 2.0 | 1.5 | |
| 110. | BGH 5500 | 2.10.7 | % | | | | | 0.6 | 5.8 | 10.0 | 4.7 | 3.6 | 2.7 | 3.4 | 2.8 | 2.1 | 1.1 | | | | | | |
| 111. | IBM 360/65 | 2.10.6 | % | | | | | | | 0.4 | 3.1 | 17.3 | 19.9 | 18.6 | 19.9 | 12.1 | 6.7 | 6.5 | 4.7 | 3.6 | 3.2 | 2.5 | 1.2 |
| 112. | Univac 1108 | 2.10.7 | % | | | | | | | 2.9 | 8.9 | 13.7 | 14.8 | 11.9 | 12.5 | 8.8 | 5.8 | 4.7 | 3.7 | 3.0 | 3.2 | 2.4 | 1.2 |
| 113. | IBM 370/155 | 2.10.6 | % | | | | | | | | | | | | | 14.4 | 22.7 | 23.9 | 11.4 | 7.0 | 6.1 | 4.4 | 2.0 |
| 114. | IBM 370/145 | 2.10.7 | % | | | | | | | | | | | | | 4.9 | 10.2 | 12.7 | 11.7 | 9.4 | 7.7 | 5.5 | 2.1 |
| 114a. | IBM 370/158 | | % | | | | | | | | | | | | | | | 6.0 | 21.0 | 24.6 | 29.5 | 28.0 | 14.4 |
| 114b. | IBM 370/168 | | % | | | | | | | | | | | | | | | 5.0 | 12.4 | 18.2 | 23.7 | 24.3 | 15.0 |
| 114c. | IBM 3033 | | % | | | | | | | | | | | | | | | | | | | | 16.1 |
| 115. | Sum of the Two Greatest | | % | 56.0 | 56.5 | 53.4 | 46.6 | 34.9 | 28.9 | 21.5 | 21.0 | 31.0 | 34.7 | 31.1 | 32.4 | 26.5 | 32.9 | 36.6 | 33.4 | 42.8 | 53.2 | 52.3 | 31.1 |

## TABLE II.2.11.1a SYSTEM CHARACTERISTICS

| | Manufacturers: Model Numbers: | | IBM S/32 | IBM S3/8 | IBM 370/168-3 | IBM 370/158-3 | IBM S3/12 | IBM S3/4 | IBM S1/3 | IBM S1/5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 2/75 | 6/75 | 6/75 | 9/75 | 3/76 | 6/76 | 11/76 | 11/76 |
| 3. | Word Length | bits | 8D | 8D | 32D | 16D | 8D | 8D | 16 | 16 |
| | **Processor Performance** | | | | | | | | | |
| 4. | Memory Cycle Time | µsec | .600 | 1.52 | .080 | .115 | 1.52 | 1.52 | .80 | .660 |
| 5. | Raw Speed—Add | µsec | 150.8 | 26 | .16e | .933 | 26 | 26 | 8.4 | 2.42 |
| 6. | Multiply | µsec | 18560e | 3200 | .78e | 1.991 | 3200 | 3200 | 13.2 | 10.78 |
| 6a. | Logic Operation | µsec | 27.5 | 7 | .26e | .380 | 7 | 7 | 4.2 | 1.54 |
| 11. | Addition Rate | Kops | 6.6 | 38.5 | 6250 | 1072 | 38.5 | 38.5 | 119 | 413.2 |
| 12a. | Weighted Opns/Sec. | Kops | 0.93 | 5.4 | 5236e | 1014.3 | 5.4 | 5.4 | 115.7 | 352.4 |
| 14. | Knight Index Commc'l. | Kops | 1.41 | 8.73 | 6008 | 2423 | 10.9 | 9.7 | 91.8 | 315.8 |
| 15. | Time Per Dollar | Sec/$ | 572 | 312 | 3.37 | 6.24 | 164 | 480 | 500 | 392 |
| 17. | Ops./$—Commercial | Kop/$ | 809.8 | 2723 | 20266 | 15123 | 1795 | 4654 | 45828 | 123950 |
| 18a. | Memory Bit Rate | Bit/&msec | 13.3 | 5.3 | 400 | 139 | 5.3 | 5.3 | 20 | 24.2 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 5.6 | 43.6 | 62.4 | 17.7 | 21.3 | 120.0 | | |
| 41a. | Processor Ops./$ | kop/$ | 1.19 | 9.9 | 60.0 | 40.0 | 6.05 | 30.3 | | |
| | Performance Ratios | | | | | | | | | |
| 42c. | Computer | | | | 3031 | | | | | |
| 42d. | Ratio | | | | 2.6 | | | | | |
| 42e. | Computer | | | | 370/135 | 370/135 | | | | |
| 42f. | Ratio (IDC) | | | | 13.8 | 5.0 | | | | |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | IC | IC | IC | IC | IC | IC | IC | IC |
| 70. | Bits Per Access | | 8 | 8 | 64 | 128 | 8 | 8 | 16 | 16? |
| 71. | Cycle Time | µsec | .600 | 1.52 | .480 | 1.035 | 1.52 | 1.52 | .80 | .660 |
| 72. | Minimum Size | kwords | 16K | 16K | 1024K | 512K | 32K | 64K | 8K | 8K |
| 73. | Bytes | kbytes | 16K | 16K | 1024K | 512K | 32K | 64K | 16K | 16K |
| 74. | Maximum Size | kwords | 32K | 64K | 8192K | 6144K | 96K | 64K | 64K | 128K |
| 75. | Bytes | kbytes | 32K | 64K | 8192K | 6144K | 96K | 64K | 128K | 256K |
| 76. | Increment Size | kbytes | 8K | 32K | 1024K | 512K | 16K | | 16K | 16K |
| 77. | Price | $k | .878 | 8.0 | 253.0 | 126.5 | 2.7 | | 1.51 | 1.75 |
| 78. | Rental | $k/mo | .042 | .20 | 5.72 | 2.86 | .10 | | | |
| 79. | Maintenance | $/mo | 2.5 | 35 | 130 | 75 | 5 | | 6 | 6 |
| 80. | Price Per Byte | $/by | .107 | .244 | .241 | .241 | .165 | | .092 | .107 |
| 81. | Maint. Cost Per $100k | $/mo | 284.7 | 437.5 | 51.4 | 59.3 | 185.2 | | 397.4 | 342.9 |
| 82. | Price: Rental Ratio | | 20.9 | 40.0 | 44.2 | 44.2 | 27.0 | | | |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 33.56 | 26.1 | 3175.5 | 1897.2 | 50.465 | 19.15 | 4.36 | 6.165 |
| 85. | Rental | $k/mo | .825 | .65 | 68.21 | 40.67 | 1.328 | .60 | | |
| 86. | Maintenance | $/mo | 160 | 115 | 4755 | 2170 | 215 | 145 | 76 | 73 |
| 87. | Memory Included | kbytes | 16K | 16K | 1024K | 512K | 32K | 64K | 16K | 16K |
| 88. | Processor Alone—Price | $k | 31.804 | 22.1 | 2922.5 | 1770.7 | 45.065 | 8.35 | 2.85 | 4.415 |
| 89. | Rental | $k/mo | .741 | .55 | 62.49 | 37.81 | 1.128 | .20 | | |
| 90. | Maintenance | $/mo | 155 | 97.5 | 4625 | 2095 | 205 | 125 | 70 | 67 |
| 91. | Maint. Per $100k | $/mo | 487.4 | 441.2 | 158.3 | 118.3 | 454.9 | 1497 | 2456 | 1517 |
| 92. | Price: Rental Ratio | | 42.9 | 40.2 | 46.8 | 46.8 | 40.0 | 41.8 | | |
| 93. | System Rentals—*EDP/IR* | $k/mo | 1.09 | 2.0 | 185.0 | 100.0 | 3.8 | 1.3 | 1.25 | 1.59 |
| 93a. | System Price *EDD/IR* | $k | 42 | | | | | | 50 | |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | 640 | | 8575 | 4150 | | | | |
| 100. | Floor Space | $ft.^2$ | 16.77 | | 65.23 | 48.82 | | | | |
| 101. | Volume | $ft.^3$ | 53.11 | | 403.9 | 199.7 | | | | |
| 102. | Electrical Load | kva | 0.8 | | 62.8 | 13.7 | | | | |
| 103. | Heat Dissipation | kBTU/hr | 2.0 | | 137.2 | 42.1 | | | | |
| 104. | Density—Weight | $lb/ft.^3$ | 12.1 | | 21.2 | 20.8 | | | | |
| 105. | Heat Per Cu. Ft. | kBTU/hr | .038 | | .340 | .210 | | | | |
| 106. | Price Per Pound | $/lb. | 49.7 | | 340.8 | 426.7 | | | | |

**TABLE II.2.11.1a SYSTEM CHARACTERISTICS**

| | Manufacturers: Model Numbers: | | IBM 370/138 | IBM 370/148 | IBM S/34 | IBM 3031 | IBM 3032 | IBM 3033 | IBM 4331 | IBM 4341 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 11/76 | 3/77 | 12/77 | 3/78 | 3/78 | 3/78 | /79 | /79 |
| 3. | Word Length | bits | 16D | 32D | 8D | 64D | 64D | 64D | 8D | 8D |
| | **Processor Performance** | | | | | | | | | |
| 4. | Memory Cycle Time | μsec | .935 | .540 | .600 | .115 | .080 | 0.058 | 1.30 | 0.3e |
| 5. | Raw Speed—Add | μsec | 2.640 | 1.238 | 68.5 | .5e | .17e | .08e | 2.1 | 0.6e |
| 6. | Multiply | μsec | 25.19 | 16.0 | 8431e | 3.0e | 1.0e | 0.5e | 29.2 | 8.3e |
| 6a. | Logic Operation | μsec | .935 | .7e | 12.5 | .6e | .2e | .1e | 0.8 | 0.6e |
| 11. | Addition Rate | Kops | 378.8 | 807.8 | 14.6 | 2000 | 5882 | 12500 | 476.2 | 1667 |
| 12a. | Weighted Opns/Sec. | Kops | 265.4 | 506.0 | 2.05 | 1600 | 4728 | 9900 | 289.4 | 1015 |
| 14. | Knight Index Commc'l. | Kops | 495.5 | 1013.7 | 4.99 | 2317 | 6921 | 19019 | 564 | 1863 |
| 15. | Time Per Dollar | Sec/$ | 29.7 | 18.1 | 392 | 10.2 | 5.5 | 3.47 | 82.1 | 33.0 |
| 17. | Ops./$—Commercial | Kop/$ | 14724 | 18335 | 1959 | 23700 | 37885 | 65932 | 46310 | 61494 |
| 18a. | Memory Bit Rate | Bit/&msec | 17.1 | 59.3 | 13.3 | 556.5 | 800 | 1103 | 24.6 | 107 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | 39.3 | 32.4 | 12.4 | 58.3 | 89.0 | 119.8 | 175.0 | 167.2 |
| 41a. | Processor Ops./$ | kop/$ | 38.4 | 40.6 | 4.23 | 67.5 | 104.7 | 182.3 | 207.3 | 186.9 |
| | Performance Ratios | | | | | | | | | |
| 42a. | Computer | | | | | 158.3 | 3031 | 3031 | 115 | 138 |
| 42b. | Ratio | | | | | 1.3 | 2.6 | 4.5 | 4.0 | 3.2 |
| 42c. | Computer | | | | | | 168.3 | 168.3 | 138 | |
| 42d. | Ratio | | | | | | 1.25 | 1.7 | .93 | |
| 42e. | Computer | | 3135 370/1 | 35 | | 370/135 | 370/135 | 370/135 | /135 | 370/135 |
| 42f. | Ratio (IDC) | | 1.3 | 2.7 | | 6.0 | 13.8 | 24.8 | 1.2 | 4.1 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | IC | IC | IC | IC | IC | IC | IC | IC |
| 70. | Bits Per Access | | 16 | 32 | 8 | 64 | 64 | 64 | 32 | 32 |
| 71. | Cycle Time | μsec | .935 | .540 | .600 | .690 | .320 | .696 | 1.30 | |
| 72. | Minimum Size | kwords | 512K | 1024K | 32K | 2048K | 2048K | 4096K | 512K | 2048K |
| 73. | Bytes | kbytes | 512K | 1024K | 32K | 2048K | 2048K | 4096K | 512K | 2048K |
| 74. | Maximum Size | kwords | 1024K | 2048K | 128K | 6144K | 6144K | 16384K | 1024K | 4096K |
| 75. | Bytes | kbytes | 1024K | 2048K | 128K | 6144K | 6144K | 16384K | 1024K | 4096K |
| 76. | Increment Size | kbytes | 512K | 1024K | 16K | 1024K | 2048K | 4096K | 512K | 2048K |
| 77. | Price | $k | 55.0 | 110.0 | 1.6 | 75.0 | 172.0 | 305.0 | 7.50 | 30.0 |
| 78. | Rental | $k/mo | 1.9 | 3.8 | .044 | 3.04 | 6.85 | 12.34 | .224 | .881 |
| 79. | Maintenance | $/mo | 60 | 170 | 5 | 140 | 320 | 600 | 10 | 40 |
| 80. | Price Per Byte | $/by | .105 | .105 | .098 | .072 | .082 | .073 | .014 | .014 |
| 81. | Maint. Cost Per $100k | $/mo | 109.0 | 154.5 | 312.5 | 186.7 | 186.0 | 196.7 | 133.3 | 133.3 |
| 82. | Price: Rental Ratio | | 28.9 | 28.9 | 36.4 | 24.7 | 25.1 | 24.7 | 33.5 | 34.1 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 367.06 | 707.14 | 26.30 | 1000.00 | 1900.0 | 3380.0 | 67.34 | 247.68 |
| 85. | Rental | $k/mo | 9.956 | 19.378 | .825 | 27.497 | 48.11 | 77.43 | 1.923 | 7.100 |
| 86. | Maintenance | $/mo | 1308 | 2267 | 145 | 3070 | 6500 | 8000 | 162 | 497 |
| 87. | Memory Included | kbytes | 512K | 1024K | 32K | 2048K | 2048K | 4096K | 512K | 2048K |
| 88. | Processor Alone—Price | $k | 312.06 | 597.14 | 23.10 | 850.0 | 1728.0 | 3075.0 | 59.84 | 217.68 |
| 89. | Rental | $k/mo | 8.056 | 15.578 | .737 | 21.417 | 41.26 | 65.09 | 1.698 | 6.219 |
| 90. | Maintenance | $/mo | 1248 | 2097 | 135 | 2790 | 6180 | 7400 | 152 | 457 |
| 91. | Maint. Per $100k | $/mo | 400 | 351.1 | 584.4 | 328.2 | 357.6 | 240.7 | 254.0 | 209.9 |
| 92. | Price: Rental Ratio | | 38.7 | 38.3 | 31.3 | 39.7 | 41.9 | 47.2 | 35.2 | 35.0 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 21.0 | 34.5 | 1.59 | 61.0 | 114.0 | 180.0 | 7.6 | 18.9 |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | 3165 | 3820 | 884 | 2725 | 6600 | 8425 | | |
| 100. | Floor Space | $ft.^2$ | 40.61 | 59.17 | 11.19 | 27.47 | 53.66 | 62.95 | | |
| 101. | Volume | $ft.^3$ | 118.6 | 211.3 | 44.78 | 161.4 | 334.5 | 394.9 | | |
| 102. | Electrical Load | kva | 13.9 | 19.0 | 1.30 | 6.0 | 49.0 | 54.5 | | |
| 103. | Heat Dissipation | kBTU/hr | 45.50 | 55.48 | 3.4 | 17.40 | 101.95 | 130.75 | | |
| 104. | Density—Weight | $lb/ft.^3$ | 26.7 | 18.1 | 19.7 | 16.9 | | 21.3 | | |
| 105. | Heat Per Cu. Ft. | kBTU/hr | .384 | .262 | .076 | .108 | | .331 | | |
| 106. | Price Per Pound | $/lb. | 98.6 | 156.3 | 26.1 | 311.9 | | 365.0 | | |

## TABLE II.2.11.1a SYSTEM CHARACTERISTICS

| | Manufacturers: Model Numbers: | | IBM S38/3 | IBM S38/5 | IBM 8130 | IBM 8140 | BGH 6700 | BGH 1710 |
|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | /79 | /79 | /79 | /79 | 11/69 | 8/72 |
| 3. | Word Length | bits | 8D | 8D | 32 | 32 | 48 | 1D |
| | **Processor Performance** | | | | | | | |
| 4. | Memory Cycle Time | μsec | 1.10 | 0.60 | 1.50 | .80 | .77 | 1.00 |
| 5. | Raw Speed—Add | μsec | | | | | 0.2 | 4e |
| 6. | Multiply | μsec | | | | | 2.0 | 35e |
| 6a. | Logic Operation | μsec | | | | | 0.2e | 2e |
| 11. | Addition Rate | Kops | | | | | 5000 | 250 |
| 12a. | Weighted Opns/Sec. | Kops | | | | | 3448 | 180 |
| 14. | Knight Index Commc'l. | Kops | | | | | 8886 | 108.4 |
| 15. | Time Per Dollar | Sec/$ | | | | | 9.2 | 277.3 |
| 17. | Ops./$—Commercial | Kop/$ | | | | | 81540 | 30052 |
| 18a. | Memory Bit Rate | Bit/&msec | 7.2 | 7.2 | 21.3 | 40.0 | 62.3 | 24.0 |
| | Other Perf. Measures | | | | | | | |
| 39. | Additions Per $ | M | | | | | 409.7 | 219.4 |
| 41a. | Processor Ops./$ | kop/$ | | | | | 728 | 95.1 |
| | **Memory** | | | | | | | |
| 69. | Type (if not core) | | IC | IC | IC | IC | | IC |
| 70. | Bits Per Access | | 32 | 32 | 16 | 16 | 48 | 24 |
| 71. | Cycle Time | μsec | 1.10 | .60 | 1.50 | .80 | .77 | 1.00 |
| 72. | Minimum Size | kwords | 512K | 512K | 256K | 256K | 64K | 24K |
| 73. | Bytes | kbytes | 512K | 512K | 256K | 256K | 384K | 24K |
| 74. | Maximum Size | kwords | 1024K | 1536K | 512K | 384K | 1024K | 64K |
| 75. | Bytes | kbytes | 1024K | 1536K | 512K | 384K | 6144K | 64K |
| 76. | Increment Size | kbytes | 256K | 256K | 128K | 128K | 384K | 8K |
| 77. | Price | $k | 5.0 | 7.0 | 2.25 | 6.24 | 84.0 | 1.545 |
| 78. | Rental | $k/mo | .161 | .230 | .082 | .306 | 2.3 | .067 |
| 79. | Maintenance | $/mo | 21 | 29 | 7.5 | 30.0 | | 11.9 |
| 80. | Price Per Byte | $/by | .019 | .026 | .017 | .048 | .214 | .189 |
| 81. | Maint. Cost Per $100k | $/mo | 420.0 | 414.3 | 333.3 | 480.8 | | 770 |
| 82. | Price: Rental Ratio | | 31.1 | 30.4 | 27.4 | 20.4 | 36.5 | 23.1 |
| | **Processor—Sys. Price** | | | | | | | |
| 84. | Processor—Price | $k | 61.55 | 91.075 | 24.0 | 33.06 | 289.43 | 26.554 |
| 85. | Rental | $k/mo | 1.733 | 2.532 | .705 | 1.128 | 7.615 | .912 |
| 86. | Maintenance | $/mo. | 301 | 360 | 122 | 173 | | 129 |
| 87. | Memory Included | kbytes | 512K | 512K | 256K | 256K | 0 | 24K |
| 88. | Processor Alone—Price | $k | 51.55 | 77.075 | 19.5 | 20.58 | 289.43 | 21.919 |
| 89. | Rental | $k/mo | 1.411 | 2.072 | .541 | .516 | 7.615 | .711 |
| 90. | Maintenance | $/mo | 259 | 302 | 107 | 113 | | 93.3 |
| 91. | Maint. Per $100k | $/mo | 502.4 | 391.8 | 548.7 | 549.0 | | 425.7 |
| 92. | Price: Rental Ratio | | 36.5 | 37.2 | 36.0 | 39.9 | 38.0 | 30.8 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 3.6 | 9.7 | | | 68.0 | 2.25 |
| | **Physical Char.** | | | | | | | |
| 99. | Processor—Weight | lb. | 1330 | 1330 | | | | |
| 100. | Floor Space | $ft.^2$ | 14.34 | 14.34 | | | | |
| 101. | Volume | $ft.^3$ | 59.15 | 59.15 | | | | |
| 102. | Electrical Load | kva | 2.5 | 2.5 | | | | |
| 103. | Heat Dissipation | kBTU/hr. | 7.5 | 7.5 | | | | |
| 104. | Density—Weight | $lb/ft.^3$ | 22.5 | 22.5 | | | | |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | .127 | .127 | | | | |
| 106. | Price Per Pound | $/lb. | 38.8 | 58.0 | | | | |

## TABLE II.2.11.1a SYSTEM CHARACTERISTICS

| | Manufacturers: Model Numbers: | | DEC 11-20 | DEC 11-10 | DEC 11-45 | DEC 11-40 | DEC 11-70 | DEC 11-03 | DEC 11-04 | DEC 11-34 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 6/70 | 9/72 | 9/72 | 3/73 | 7/75 | 8/75 | 8/75 | 3/76 |
| 3. | Word Length | bits | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| | **Processor Performance** | | | | | | | | | |
| 4. | Memory Cycle Time | μsec | 1.20 | .90 | .300 | .90 | .24 | 1.2 | .725 | .725 |
| 5. | Raw Speed—Add | μsec | 4.44 | 5.87 | 1.21 | 2.84 | | 7.45 | 5.57 | 4.38 |
| 6. | Multiply | μsec | 228 | 304 | 71 | 174 | | 457 | 292 | 234 |
| 6a. | Logic Operation | μsec | 2.05 | 2.10 | .53 | 1.58 | | 4.03 | 2.33 | 1.90 |
| 11. | Addition Rate | Kops | 225 | 170 | 826 | 352 | | 134 | 179.5 | 228.3 |

**TABLE II.2.11.1a SYSTEM CHARACTERISTICS (continued)**

| | Manufacturers: / Model Numbers: | | DEC 11-20 | DEC 11-10 | DEC 11-45 | DEC 11-40 | DEC 11-70 | DEC 11-03 | DEC 11-04 | DEC 11-34 |
|---|---|---|---|---|---|---|---|---|---|---|
| 12a. | Weighted Opns/Sec. | Kops | 64 | 48.1 | 212.8 | 87.7 | | 33.4 | 50.3 | 63.0 |
| 14. | Knight Index Commc'l. | Kops | 76.6 | 59.6 | 435.9 | 161.6 | | 39.9 | 59.9 | 122.0 |
| 15. | Time Per Dollar | Sec/$ | 891 | 2080 | 312 | 832 | | 12480 | 1664 | 713 |
| 17. | Ops./$—Commercial | Kop/$ | 68263 | 123980 | 136000 | 134475 | | 498106 | 99590 | 87000 |
| 18a. | Memory Bit Rate | bit/μsec | 13.3 | 17.8 | 53.3 | 17.8 | 66.7 | 13.3 | 22.1 | 22.1 |
| | Performance Ratios | | | | | | | | | |
| 42a. | Computer | | 11-03 | 11-03 | | 11-03 | 11-03 | | 11-03 | 11-03 |
| 42b. | Ratio | | 3.1 | 2.5 | | 3.6 | 3.6 | | 2.8 | 3.5 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | | | IC | | | IC | IC | IC |
| 70. | Bits Per Access | | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| 71. | Cycle Time | μsec. | 1.20 | .90 | .300 | .90 | 1.20 | .55 | .725 | .725 |
| 72. | Minimum Size | kwords | 4K | 4K | 32K | 8K | 64K | 4K | 4K | 16K |
| 73. | Bytes | kbytes | 8K | 8K | 64K | 16K | 128K | 8K | 8K | 32K |
| 74. | Maximum Size | kwords | 32K | 28K | 124K | 128K | 1024K | 32K | 28K | 124K |
| 75. | Bytes | kbytes | 64K | 56K | 248K | 256K | 2048K | 64K | 56K | 248K |
| 76. | Increment Size | kbytes | | 8K | 8K | 12K | 128K | 8K | 16K | 32K |
| 77. | Price | $k | | 1.5 | 4.62 | 2.7 | 18.59 | .625 | 1.7 | 2.2 |
| 79. | Maintenance | $/mo | | 5 | 25 | 27 | 70 | 13 | 22 | 25 |
| 80. | Price Per Byte | $/by | | .183 | .564 | .220 | .142 | .076 | .104 | .067 |
| 81. | Maint. Cost Per $100k | $/mo | | 333.3 | 541.1 | 1000 | 376.5 | 2080 | 1294 | 1136 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | | 5.995 | 50.4 | 16.8 | 63.0 | 1.995 | 3.995 | 9.05 |
| 86. | Maintenance | $/mo. | | 69 | 354 | 120 | 281 | 37 | 54 | 87 |
| 87. | Memory Included | kbytes | | 8K | 64K | 16K | 128K | 8K | 16K | 32K |
| 88. | Processor Alone—Price | $k | | 4.495 | 13.44 | 13.20 | 44.41 | 1.370 | 2.295 | 6.85 |
| 90. | Maintenance | $/mo | | 64 | 154 | 84 | 211 | 24 | 32 | 62 |
| 91. | Maint. Per $100k | $/mo | | 1293 | 1146 | 636.4 | 475.1 | 1752 | 1394 | 905.1 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 0.7 | .30 | 2.0 | .75 | 4.0 | .050 | .375 | .875 |
| 93a. | System Price EDD/IR | $k | 28 | 12 | 80 | 30 | 160 | 2 | 15 | 35 |

**TABLE II.2.11.1a SYSTEM CHARACTERISTICS**

| | Manufacturers: / Model Numbers: | | DEC VAX780 | G.A. SPC16/40 | HP 21MXM | HIS 700 | HIS 62 | NCR C101 | TI 980B | Univac 1106 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 5/78 | 5/70 | 6/74 | 6/72 | 10/74 | 10/72 | 10/72 | 12/69 |
| 3. | Word Length | bits | 32 | 16 | 16 | 16 | 8D | 8D | 16 | 36 |
| | **Processor Performance** | | | | | | | | | |
| 4. | Memory Cycle Time | μsec. | .200 | 1.4 | .65 | .775 | 1.00 | 1.2 | .75 | 1.50 |
| 5. | Raw Speed—Add | μsec. | 0.4 | 1.4 | 1.9 | | 17e | 28.8 | 1.75 | 1.50 |
| 6. | Multiply | μsec. | 6.4 | 12.6 | 12.5 | | 2100e | 127.2 | 6.25 | 3.67 |
| 6a. | Logic Operation | μsec | 1.5 | 2.8 | 2.6 | | 5e | 7. e | 4.0 | 1.5e |
| 11. | Addition Rate | Kops | 2500 | 714.3 | 526.3 | | 58.8 | 34.7 | 571.4 | 667 |
| 12a. | Weighted Opns/Sec. | Kops | 1429 | 510.2 | 411.5 | | 8.3 | 29.7 | 506.3 | 621.7 |
| 14. | Knight Index Commc'l. | Kops | 828.4 | 147.5 | 444.3 | | 21.0 | 26.5 | 136.8 | 951 |
| 15. | Time Per Dollar | Sec/$ | 97.5 | 99.8 | 1664 | | 152.2 | 218.9 | 624 | 15.6 |
| 17. | Ops./$—Commercial | Kop/$ | 80766 | 14723 | 739300 | | 3201 | 5795 | 83560 | 14830 |
| 18a. | Memory Bit Rate | bit/μsec | 160 | 11.4 | 24.6 | 20.6 | 16.0 | 6.7 | 21.3 | 24.0 |
| | Other Perf. Measures | | | | | | | | | |
| 39. | Additions Per $ | M | | | | | 65.4 | 37.7 | | 57.2 |
| 41a. | Processor Ops./$ | kop/$ | | | | | 23.4 | 28.7 | | 81.7 |
| | **Memory** | | | | | | | | | |
| 69. | Type (if not core) | | IC | | IC | | IC | | IC | |
| 70. | Bits Per Access | | 64 | 16 | 16 | 16 | 16 | 16 | 16 | 36 |
| 71. | Cycle Time | μsec. | .600 | 1.4 | .65 | .775 | 1.00 | 1.2 | .75 | 1.50 |
| 72. | Minimum Size | kwords | 32K | 4K | 64K | 8K | 48K | 16K | 8K | 128K |
| 73. | Bytes | kbytes | 128K | 8K | 128K | 16K | 48K | 16K | 16K | 768K |
| 74. | Maximum Size | kwords | 256K | 32K | 896K | 64K | 228K | 128K | 64K | 512K |
| 75. | Bytes | kbytes | 1024K | 64K | 1792K | 128K | 228K | 128K | 128K | 3072K |
| 76. | Increment Size | kbytes | 128K | 8K | 128K | 8K | 16K | 16K | 8K | 128K |
| 77. | Price | $k | 22.5 | 2.6 | 5.25 | 3.2 | 4.677 | 10.0 | 1.4 | 220.51 |
| 78. | Rental | $k/mo | | | | .115 | .108 | .325 | | 5.29 |
| 79. | Maintenance | $/mo | 70 | 26 | 53 | 30 | 15 | 17 | 7 | 789 |
| 80. | Price Per Byte | $/by | .172 | .317 | .040 | .391 | .285 | .610 | .171 | 1.68 |
| 81. | Maint. Cost Per $100k | $/mo | 311.1 | 1000 | 1010 | 937.5 | 320.7 | 170 | 500 | 357.8 |

**TABLE II.2.11.1a SYSTEM CHARACTERISTICS (continued)**

| | Manufacturers: Model Numbers: | | DEC VAX780 | G.A. SPC16/40 | HP 21MXM | HIS 700 | HIS 62 | NCR C101 | TI 980B | Univac 1106 |
|---|---|---|---|---|---|---|---|---|---|---|
| 82. | Price: Rental Ratio | | | | | 27.8 | 43.3 | 30.8 | | 41.7 |
| | **Processor—Sys. Price** | | | | | | | | | |
| 84. | Processor—Price | $k | 128.6 | 5.55 | 4.75 | 7.6 | 36.88 | 26.6 | 5.15 | 348.82 |
| 85. | Rental | $k/mo | | | | .260 | .885 | .900 | | 7.267 |
| 86. | Maintenance | $/mo. | 692 | 60 | 66 | 40 | 150 | 156 | 95 | 1822 |
| 87. | Memory Included | kbytes | 128K | 8K | 0K | 0 | 48K | 16K | 8K | 0 |
| 88. | Processor Alone—Price | $k | 106.1 | 2.95 | 4.75 | 7.6 | 22.85 | 16.6 | 3.75 | 348.82 |
| 89. | Rental | $k/mo | | | | .260 | .561 | .575 | | 7.267 |
| 90. | Maintenance | $/mo | 622 | 34 | 66 | 40 | 105 | 139 | 88 | 1822 |
| 91. | Maint. Per $100k | $/mo | 586.2 | 1153 | 1389 | 526.3 | 459.5 | 837.3 | 2347 | 522.3 |
| 92. | Price: Rental Ratio | | | | | 29.2 | 40.7 | 28.9 | | 48.0 |
| 93. | System Rentals—*EDP/IR* | $k/mo | 6.4 | 6.25 | .375 | 1.625 | 4.1 | 2.85 | 1.0 | 40.0 |
| 93a. | System Price EDD/IR | $k | 256 | 25 | 15 | 65 | | | 40 | |
| | **Physical Char.** | | | | | | | | | |
| 99. | Processor—Weight | lb. | | | | | | | 80 | |
| 100. | Floor Space | ft.$^2$ | | | | | | | 3.18 | |
| 101. | Volume | ft.$^3$ | | | | | | | 3.25 | |
| 102. | Electrical Load | kva | | | | | | | 600 | |
| 104. | Density—Weight | lb/ft.$^3$ | | | | | | | 24.6 | |
| 106. | Price Per Pound | $/lb. | | | | | | | 46.9 | |

**TABLE II.2.11.1a SYSTEM CHARACTERISTICS**

| | Manufacturers: Model Numbers: | | Univac 1110 | Univac 90-30 | Univac 1180 | Univac 1160 | Wang 2200T |
|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr | 6/72 | 2/75 | 3/77 | /80 | 4/73 |
| | **Processor Performance** | | | | | | |
| 3. | Word Length | bits | 36 | 8D | 36 | 36 | 8D |
| 4. | Memory Cycle Time | μsec. | .48 | .600 | .100 | .580 | |
| 5. | Raw Speed—Add | μsec. | 0.30 | 5.4 | | | 800 |
| 6. | Multiply | μsec. | 1.50 | 39.6 | | | 3800 |
| 6a. | Logic Operation | μsec | .59 | 3.6 | | | |
| 11. | Addition Rate | Kops | 3333 | 185 | | | 1.25 |
| 12a. | Weighted Opns/Sec. | Kops | 2778 | 140.6 | | | 1.05 |
| 14. | Knight Index Commc'l. | Kops | 2106 | 127.5 | | | |
| 15. | Time Per Dollar | Sec/$ | 6.9 | 76.1 | | | |
| 17. | Ops./$—Commercial | Kop/$ | 14583 | 9706 | | | |
| 18a. | Memory Bit Rate | bit/μsec | 75.0 | 53.3 | | | |
| | Other Perf. Measures | | | | | | |
| 39. | Additions Per $ | M | 140.1 | 89.2 | | | |
| 41a. | Processor Ops./$ | kop/$ | 88.5 | 61.5 | | | |
| | **Memory** | | | | | | |
| 69. | Type (if not core) | | Wire | IC | IC | IC | |
| 70. | Bits Per Access | | 36 | 16 | 144 | 36 | |
| 71. | Cycle Time | μsec. | .48 | .600 | .600 | .580 | |
| 72. | Minimum Size | kwords | 32K | 32K | 512K | 512K | |
| 73. | Bytes | kbytes | 192K | 32K | 2048K | 2048K | 16K |
| 74. | Maximum Size | kwords | 256K | 512K | 4096K | 1024K | |
| 75. | Bytes | kbytes | 1536K | 512K | 16384K | 4096K | 32K |
| 76. | Increment Size | kbytes | 64K | 32K | 2048K | 1024K | 8K |
| 77. | Price | $k | 125.0 | 12.096 | 200.0 | 30.48 | 1.3 |
| 78. | Rental | $k/mo | 4.50 | .340 | 5.44 | .725 | |
| 79. | Maintenance | $/mo | 779 | 48 | 300 | 50 | 10 |
| 80. | Price Per Byte | $/by | 1.91 | .369 | .095 | .029 | .159 |
| 81. | Maint. Cost Per $100k | $/mo | 623.2 | 396.8 | 150.0 | 164.0 | 769.2 |
| 82. | Price: Rental Ratio | | 27.8 | 35.6 | 36.8 | 42.0 | |
| | **Processor—Sys. Price** | | | | | | |
| 84. | Processor—Price | $k | 617.856 | 70.632 | 1621.69 | 318.98 | 5.0 |
| 85. | Rental | $k/mo | 14.85 | 1.635 | 38.29 | 7.59 | |
| 86. | Maintenance | $/mo. | 2870 | 349 | 2525 | 1150 | 43 |
| 87. | Memory Included | kbytes | 0 | 32K | 2048K | 2048K | 16K |
| 88. | Processor Alone—Price | $k | 617.856 | 58.266 | 1421.69 | 258.02 | 2.4 |
| 89. | Rental | $k/mo | 14.85 | 1.295 | 32.85 | 6.14 | |
| 90. | Maintenance | $/mo | 2870 | 301 | 2225 | 1050 | 23 |
| 91. | Maint. Per $100k | $/mo | 464.5 | 516.6 | 156.5 | 406.9 | 958.3 |

### TABLE II.2.11.1a SYSTEM CHARACTERISTICS (continued)

| | Manufacturers: Model Numbers: | | Univac 1110 | Univac 90-30 | Univac 1180 | Univac 1160 | Wang 2200T |
|---|---|---|---|---|---|---|---|
| 92. | Price: Rental Ratio | | 41.6 | 45.0 | 43.3 | 42.0 | |
| 93. | System Rentals—*EDP/IR* | $k/mo | 90.1 | 8.2 | | | |
| 93a. | System PriceEDP/IR | $k | | | | | 19.0 |
| | **Physical Char.** | | | | | | |
| 99. | Processor—Weight | lb. | | 1600 | | | 40 |
| 100. | Floor Space | $ft.^2$ | | 14.61 | | | 2.11 |
| 101. | Volume | $ft.^3$ | | 71.00 | | | 1.73 |
| 102. | Electrical Load | kva | | 3.2 | | | .22 |
| 103. | Heat Dissipation | kBTU/hr. | | 9.6 | | | |
| 104. | Density—Weight | $lb/ft.^3$ | | 22.5 | | | 23.1 |
| 105. | Heat Per Cu. Ft. | kBTU/hr. | | .135 | | | |
| 106. | Price Per Pound | $/lb. | | 36.4 | | | 125 |

### TABLE II.2.11.2a SYSTEM MEMORY CAPACITY AND PRICE

| | Units | Memory Capacity and Price | | | | |
|---|---|---|---|---|---|---|
| IBM 370/138 ('76) | | | | | | |
| Memory Capy. | kby | 512 | 1024 | | | |
| Price | $k | 350.0 | 435.0 | | | |
| Rental | k$/mo | 9.6 | 12.55 | | | |
| Maintenance | $/mo | 1275 | 1335 | | | |
| Incremental Cost | $/by | | 0.162 | | | |
| Maint. Cost/$100k | $/mo | 364.3 | 306.9 | | | |
| IBM 370/148 ('76) | | | | | | |
| Memory Capy. | kby | 1024 | 2048 | | | |
| Price | $k | 689.0 | 859.0 | | | |
| Rental | k$/mo | 19.0 | 24.9 | | | |
| Maintenance | $/mo | 2235 | 2405 | | | |
| Incremental Cost | $/by | | 0.162 | | | |
| Maint. Cost/$100k | $/mo | 324.4 | 280.0 | | | |
| IBM S3/4 ('76) | | | | | | |
| Memory Capy. | kby | 64 | | | | |
| Price | $k | 19.15 | | | | |
| Rental | k$/mo | 0.6 | | | | |
| Maintenance | $/mo | 145 | | | | |
| Incremental Cost | $/by | | | | | |
| Maint. Cost/$100k | $/mo | 757.2 | | | | |
| IBM S3/8 ('75) | | | | | | |
| Memory Capy. | kby | 16 | 32 | 48 | 64 | |
| Price | $k | 26.10 | 30.10 | 34.10 | 38.10 | |
| Rental | k$/mo | 0.65 | 0.750 | 0.849 | 0.950 | |
| Maintenance | $/mo | 115 | 120 | 150 | 155 | |
| Incremental Cost | $/by | | 0.244 | 0.244 | 0.244 | |
| Maint. Cost/$100k | $/mo | 440.6 | 398.7 | 439.9 | 406.8 | |
| IBM S3/12 ('76) | | | | | | |
| Memory Capy. | kby | 32 | 48 | 64 | | |
| Price | $k | 50.465 | 53.165 | 55.865 | | |
| Rental | k$/mo | 1.328 | 1.428 | 1.528 | | |
| Maintenance | $/mo | 215 | 220 | 225 | | |
| Incremental Cost | $/by | | 0.165 | 0.165 | | |
| Maint. Cost/$100k | $/mo | 426.0 | 413.8 | 402.8 | | |
| IBM S3/15 ('74) | | | | | | |
| Memory Capy. | kby | 48 | 64 | 96 | 128 | |
| Price | $k | 63.0 | 67.0 | 78.0 | 86.0 | |
| Rental | k$/mo | 1.51 | 1.61 | 1.86 | 2.06 | |
| Maintenance | $/mo | 210 | 215 | 220 | 230 | |
| Incremental Cost | $/by | | 0.244 | 0.336 | 0.244 | |
| Maint. Cost/$100k | $/mo | 333.3 | 320.9 | 282.1 | 267.4 | |
| IBM 3031 ('78) | | | | | | |
| Memory Capy. | kby | 2048 | 3072 | 4096 | 5120 | 6144 |
| Price | $k | 830 | 940 | 1050 | 1175 | 1285 |
| Rental | k$/mo | 23.45 | 27.25 | 31.05 | 35.36 | 39.16 |
| Maintenance | $/mo | 2450 | 2590 | 2730 | 2930 | 3070 |
| Incremental Cost | $/by | | 0.105 | 0.105 | 0.119 | 0.105 |
| Maint. Cost/$100k | $/mo | 295.2 | 275.5 | 260.0 | 249.4 | 238.9 |

**TABLE II.2.11.2a SYSTEM MEMORY CAPACITY AND PRICE (continued)**

| | Units | Memory Capacity and Price | | | | |
|---|---|---|---|---|---|---|
| IBM 3032 ('78) | | | | | | |
| Memory Capy. | kby | 2048 | 4096 | 6144 | | |
| Price | $k | 1590 | 1832 | 2058 | | |
| Rental | k$/mo | 40.7 | 49.07 | 56.88 | | |
| Maintenance | $/mo | 5700 | 6020 | 6310 | | |
| Incremental Cost | $/by | | 0.115 | 0.108 | | |
| Maint. Cost/$100k | $/mo | 358.5 | 328.6 | 306.6 | | |
| IBM 3033 ('78) | | | | | | |
| Memory Capy. | kby | 4096 | 6144 | 8192 | 12288 | 16384 |
| Price | $k | 3070 | 3295 | 3515 | 3703 | 4003 |
| Rental | k$/mo | 70.02 | 77.80 | 85.40 | 95.65 | 107.81 |
| Maintenance | $/mo | 7200 | 7520 | 7800 | 8415 | 8975 |
| Incremental Cost | $/by | | 0.107 | 0.105 | | 0.072 |
| Maint. Cost/$100k | $/mo | 234.5 | 228.2 | 221.9 | 227.2 | 224.2 |
| IBM 370/135 ('71) | | | | | | |
| Memory Capy. | kby | 96 | 144 | 192 | 240 | |
| Price | $k | 260.4 | 304.4 | 348.5 | 392.5 | |
| Rental | k$/mo | 5.25 | 6.15 | 7.05 | 7.95 | |
| Maintenance | $/mo | 570 | 610 | 650 | 690 | |
| Incremental Cost | $/by | | .895 | .897 | .895 | |
| Maint. Cost/$100k | $/mo | 218.9 | 200.4 | 186.5 | 175.8 | |
| IBM 370/145 ('71) | | | | | | |
| Memory Capy. | kby | 160 | 208 | 256 | 384 | 512 |
| Price | $k | 543.6 | 586.8 | 630.0 | 769.2 | 884.4 |
| Rental | k$/mo | 11.325 | 12.225 | 13.125 | 16.025 | 18.425 |
| Maintenance | $/mo | 1250 | 1290 | 1330 | 1452 | 1553 |
| Incremental Cost | $/by | | .879 | .879 | 1.062 | .879 |
| Maint. Cost/$100k | $/mo | 229.9 | 219.8 | 211.1 | 188.8 | 175.6 |
| IBM 370/155 ('71) | | | | | | |
| Memory Capy. | kby | 256 | 512 | 1024 | 1536 | 2048 |
| Price | $k | 1020.0 | 1154.4 | 1442.4 | 1783.2 | 2071.2 |
| Rental | k$/mo | 21.50 | 24.55 | 31.05 | 38.65 | 45.15 |
| Maintenance | $/mo | 2450 | 2740 | 3330 | 3980 | 4570 |
| Incremental Cost | $/by | | .513 | .549 | .650 | .549 |
| Maint. Cost/$100k | $/mo | 240.2 | 238.2 | 230.9 | 223.2 | 220.6 |
| IBY 370/165 ('71) | | | | | | |
| Memory Capy. | kby | 512 | 1024 | 1536 | 2048 | 3072 |
| Price | k$/mo | 1848.0 | 2116.8 | 2400.0 | 2678.4 | 3254.4 |
| Rental | $k/mo | 39.0 | 45.1 | 51.5 | 57.8 | 70.8 |
| Maintenance | $/mo | 4540 | 5130 | 5740 | 6370 | 7630 |
| Incremental Cost | $/by | | .513 | .540 | .531 | .549 |
| Maint. Cost/$100k | $/mo | 245.7 | 242.3 | 239.2 | 237.8 | 234.5 |
| IBM 370/158 ('73) | | | | | | |
| Memory Capy. | kby | 512 | 1024 | 2048 | 3072 | 4096 |
| Price | $k | 1615.2 | 1730.1 | 1959.9 | 2238.7 | 2468.5 |
| Rental | k$/mo | 33.3 | 35.9 | 41.1 | 47.3 | 52.5 |
| Maintenance | $/mo | 1940 | 2000 | 2120 | 2400 | 2520 |
| Incremental Cost | $/by | | .219 | .219 | .266 | .219 |
| Maint. Cost/$100k | $/mo | 120.1 | 115.6 | 108.2 | 107.2 | 102.1 |
| IBM 370/168 ('73) | | | | | | |
| Memory Capy. | kby | 1024 | 2048 | 4096 | 6144 | 7168 |
| Price | $k | 2611.9 | 2841.7 | 3311.1 | 3819.7 | 4049.5 |
| Rental | k$/mo | 53.8 | 59.0 | 69.6 | 81.0 | 86.2 |
| Maintenance | $/mo | 4230 | 4350 | 4750 | 5150 | 5270 |
| Incremental Cost | $/by | | .219 | .224 | .243 | .219 |
| Maint. Cost/$100k | $/mo | 162.0 | 153.1 | 143.5 | 134.9 | 130.1 |
| IBY 370/115 ('74) | | | | | | |
| Memory Capy. | kby | 64 | 96 | 128 | 160 | |
| Price | $k | 142.9 | 152.6 | 162.3 | 172.0 | |
| Rental | k$/mo | 2.945 | 3.145 | 3.345 | 3.545 | |
| Maintenance | $/mo | 250 | 255 | 260 | 265 | |
| Incremental Cost | $/by | | .296 | .296 | .296 | |
| Maint. Cost/$100k | $/mo | 174.9 | 167.1 | 160.2 | 154.1 | |

Source: *IBM Consultants Manual*, various editions.

**TABLE II.2.11.3a IBM PRODUCT PRICE TRENDS I (1978)**

| | All Units | | | New Units Only | | |
|---|---|---|---|---|---|---|
| | DPD | GSD | Total | DPD | GSD | Total |
| **Number in Sample** | | | | | | |
| Processors | 62 | 34 | 96 | 19 | 12 | 31 |
| Processor Storage | 4 | 4 | 8 | 0 | 0 | 0 |
| Controllers | 20 | 0 | 20 | 0 | 0 | 0 |
| Magnetic Tape Units | 18 | 0 | 18 | 0 | 0 | 0 |
| Moving Head Files | 13 | 20 | 33 | 7 | 5 | 12 |
| Head-Per-Track Files | 2 | 0 | 2 | 0 | 0 | 0 |
| Card Equipment | 14 | 4 | 18 | 0 | 0 | 0 |
| Line Printers | 17 | 7 | 24 | 2 | 0 | 2 |
| Total | 150 | 69 | 219 | 28 | 17 | 45 |
| **Price-Rental Ratio** | | | | | | |
| Processors | 43.6 | 25.7 | 37.3 | 35.0 | 30.1 | 33.1 |
| Processor Storage | 42.2 | 19.7 | 30.9 | | | |
| Controllers | 36.4 | | 36.4 | | | |
| Magnetic Tape Units | 38.3 | | 38.3 | | | |
| Moving-Head Files | 33.1 | 26.9 | 29.4 | 35.7 | 21.7 | 29.8 |
| Head-Per-Track Files | 32.5 | | 32.5 | | | |
| Card Equipment | 41.2 | 33.1 | 39.4 | | | |
| Line Printers | 36.4 | 26.6 | 33.5 | 32.8 | | 32.8 |
| Total—All Units | 39.9 | 26.2 | 35.6 | 35.0 | 27.6 | 32.2 |
| **Maintenance Price Per $100k Sales Price ($/mo.)** | | | | | | |
| Processors | 205 | 446 | 290 | 321 | 448 | 370 |
| Processor Storage | 137 | 244 | 190 | | | |
| Controllers | 275 | | 275 | | | |
| Magnetic Tape Units | 591 | | 591 | | | |
| Moving-Head Files | 391 | 771 | 621 | 295 | 1015 | 595 |
| Head-Per-Track Files | 327 | | 327 | | | |
| Card Equipment | 554 | 1437 | 750 | | | |
| Line Printers | 741 | 959 | 804 | 667 | | 667 |
| Total—All Units | 370 | 638 | 454 | 339 | 615 | 443 |
| **Average Purchase Price ($k)** | | | | | | |
| Processors | 769.0 | 46.2 | 513.0 | 1221.0 | 61.5 | 772.0 |
| Processor Storage | 183.0 | 52.0 | 118.0 | | | |
| Controllers | 44.7 | | 44.7 | | | |
| Magnetic Tape Units | 31.5 | | 31.5 | | | |
| Moving-Head Files | 143.0 | 16.8 | 66.4 | 210.3* | 9.22 | 126.5 |
| Head-Per-Track Files | 161.0 | | 161.0 | | | |
| Card Equipment | 25.6 | 10.8 | 22.3 | | | |
| Line Printers | 35.7 | 8.8 | 27.9 | 39.2 | | 39.2 |
| Total—All Units | 353.0 | 32.2 | 252.0 | 883.9 | 46.1 | 567.0 |

*Would be $45.6k without the 3851-A4 at $1198.1k. Source: *IBM Consultants Manual.*

**TABLE II.2.11.4a IBM PRODUCT PRICE TRENDS II**

| | Units | 1971 | 1973 | 1975 | 1978 | 1979 |
|---|---|---|---|---|---|---|
| **Processors** | | | | | | |
| 1401-C6—Purchase | $k | | * | * | 137.25 | |
| Rental | $/mo | | | | 2825 | |
| Maintenance | | | | | 147 | |
| Ratios-Purchase | | | | | 1.03 | |
| Rental | | | | | 1.03 | |
| Maint. | | | | | 1.73 | |
| 2030-D—Purchase | $k | * | * | * | 84.96 | |
| Rental | $/mo | | | | 1950 | |
| Maintenance | $/mo | | | | 156 | |
| Ratios-Purchase | $/mo | | | | .997 | |
| Rental | | | | | 1.10 | |
| Maint. | | | | | 1.56 | |
| 5410-A6—Purchase | $k | * | * | * | 24.96 | |
| Rental | $/mo | | | | 1304 | |
| Maintenance | $/mo | | | | 70.5 | |

**TABLE II.2.11.4a IBM PRODUCT PRICE TRENDS II (continued)**

| | Units | 1971 | 1973 | 1975 | 1978 | 1979 |
|---|---|---|---|---|---|---|
| Ratios-Purchase | | | | | .517 | |
| Rental | | | | | 1.32 | |
| Maint. | | | | | 2.35 | |
| 3135-GF—Purchase | $k | 348.5 | 369.3 | 415.0 | 317.1 | |
| Rental | $/mo | 7050 | 7470 | 8385 | 8385 | |
| Maintenance | $/mo | 650 | 520 | 622 | 560 | |
| Ratios-Purchase | | 1.0 | 1.06 | 1.19 | .91 | |
| Rental | | 1.0 | 1.06 | 1.19 | 1.19 | |
| Maint. | | 1.0 | .80 | .96 | .86 | |
| 3138-I—Purchase | $k | | | 350.0+ | 278.6 | |
| Rental | $/mo | | | 9600+ | 9600 | |
| Maintenance | $/mo | | | 1275+ | 1275 | |
| Ratios-Purchase | | | | 1.00 | .796 | |
| Rental | | | | 1.00 | 1.00 | |
| Maint. | | | | 1.00 | 1.00 | |
| 5404-A18—Purchase | $k | | | 19.15+ | 15.32 | |
| Rental | $/mo | | | 600+ | 659 | |
| Maintenance | $/mo | | | 145+ | 160 | |
| Ratios-Purchase | | | | 1.00 | .800 | |
| Rental | | | | 1.00 | 1.10 | |
| Maint. | | | | 1.00 | 1.10 | |
| **Magnetic Tape Units** | | | | | | |
| 2401-4—Purchase | $k | * | * | * | 16.53 | |
| Rental | $/mo | | | | 432 | |
| Maintenance | $/mo | | | | 136 | |
| Ratios-Purchase | | | | | .918 | |
| Rental | | | | | 1.12 | |
| Maint. | | | | | 1.84 | |
| 2420-7—Purchase | $k | * | * | * | 50.59 | |
| Rental | $/mo | | | | 1140 | |
| Maintenance | $/mo | | | | 198 | |
| Ratios-Purchase | | | | | .927 | |
| Rental | | | | | 1.09 | |
| Maint. | | | | | 1.65 | |
| 3410-1—Purchase | $k | 7.7 | 7.85 | 7.065 | 7.065 | |
| Rental | $/mo | 185 | 188 | 206 | 206 | |
| Maintenance | $/mo | 45 | 45.75 | 53.5 | 61.5 | |
| Ratios-Purchase | | 1.00 | 1.02 | .917 | .917 | |
| Rental | | 1.00 | 1.02 | 1.11 | 1.11 | |
| Maint. | | 1.00 | 1.02 | 1.19 | 1.37 | |
| **Moving-Head Files** | | | | | | |
| 2311-1—Purchase | $k | * | * | * | 16.51 | |
| Rental | $/mo | | | | 639 | |
| Maintenance | $/mo | | | | 82.5 | |
| Ratios-Purchase | | | | | .628 | |
| Rental | | | | | 1.11 | |
| Maint. | | | | | 1.62 | |
| 2314-1—Purchase | $k | * | * | 199.45 | 199.45 | |
| Rental | $/mo | | | 5890 | 5890 | |
| Maintenance | $/mo | | | 677 | 816 | |
| Ratios-Purchase | | | | .816 | .816 | |
| Rental | | | | 1.12 | 1.12 | |
| Maint. | | | | 1.10 | 1.33 | |
| 3330-1—Purchase | $k | * | * | * | 40.47 | 32.38 |
| Rental | $/mo | | | | 1450 | 1450 |
| Maintenance | $/mo | | | | 170 | 170 |
| Ratios/Purchane | | | | | .780 | .624 |
| Rental | | | | | 1.12 | 1.12 |
| Maint. | | | | | 1.00 | 1.00 |
| 3340-B1—Purchase | $k | | 19.8+ | 19.8 | 19.8 | |
| Rental | $/mo | | 592+ | 615 | 615 | |
| Maintenance | $/mo | | 43+ | 43 | 49 | |
| Ratios-Purchase | | | 1.00 | 1.00 | 1.00 | |
| Rental | | | 1.00 | 1.04 | 1.04 | |
| Maint. | | | 1.00 | 1.00 | 1.14 | |
| 3350-B2—Purchase | $k | | | 49.5+ | 49.5 | 31.68 |
| Rental | $/mo | | | 1351+ | 1351 | 1034 |
| Maintenance | $/mo | | | 150+ | 150 | 128 |

**TABLE II.2.11.4a IBM PRODUCT PRICE TRENDS II (continued)**

| | Units | 1971 | 1973 | 1975 | 1978 | 1979 |
|---|---|---|---|---|---|---|
| Ratios-Purchase | | | | 1.00 | 1.00 | .640 |
| Rental | | | | 1.00 | 1.00 | .765 |
| Maint. | | | | 1.00 | 1.00 | .853 |
| **Punched Card Units** | | | | | | |
| 2540-1—Purchase | $k | * | * | * | 36.92 | |
| Rental | $/mo | | | | 877 | |
| Maintenance | $/mo | | | | 196 | |
| Ratios-Purchase | | | | | 1.09 | |
| Rental | | | | | 1.33 | |
| Maint. | | | | | 1.70 | |
| 3525-P1—Purchase | $k | 20.0 | 20.4 | 21.21 | 21.21 | |
| Rental | $/mo | 400 | 408 | 448 | 493 | |
| Maintenance | $/mo | 60 | 61 | 66 | 91.5 | |
| Ratios-Purchase | | 1.00 | 1.02 | 1.06 | 1.06 | |
| Rental | | 1.00 | 1.02 | 1.12 | 1.23 | |
| Maint. | | 1.00 | 1.02 | 1.10 | 1.53 | |
| **Line Printers** | | | | | | |
| 1403-1—Purchase | $k | | * | * | 21.3 | |
| Rental | $/mo | | | | 869 | |
| Maintenance | $/mo | | | | 256 | |
| Ratios-Purchase | | | | | .703 | |
| Rental | | | | | 1.20 | |
| Maint. | | | | | 1.49 | |
| 1403-N1—Purchase | $k | * | * | * | 38.14 | |
| Rental | $/mo | | | | 1081 | |
| Maintenance | $/mo | | | | 341 | |
| Ratios-Purchase | | | | | .926 | |
| Rental | | | | | 1.20 | |
| Maint. | | | | | 2.47 | |
| 3203-2—Purchase | $k | | 44.1+ | 44.1 | 44.1 | |
| Rental | $/mo | | 1310+ | 1357 | 1357 | |
| Maintenance | $/mo | | 259+ | 282 | 310 | |
| Ratios-Purchase | | | 1.0 | 1.0 | 1.0 | |
| Rental | | | 1.0 | 1.04 | 1.04 | |
| Maint. | | | 1.0 | 1.09 | 1.20 | |
| **Head-Per-Track Files** | | | | | | |
| 2305-1—Purchase | $k | 195.76 | 199.0 | 179.1 | 179.1 | |
| Rental | $/mo | 4900 | 4990 | 5495 | 5495 | |
| Maintenance | $/mo | 495 | 504 | 592 | 480 | |
| Ratios-Purchase | | 1.0 | 1.02 | .915 | .915 | |
| Rental | | 1.0 | 1.02 | 1.12 | 1.12 | |
| Maintenance | | 1.0 | 1.02 | 1.20 | 0.97 | |

*See TABLE II.2.11.4 of DPT&E. +Prices thus marked are for a year later than that given at the top of the column. Sources: See Notes to Table II.2.11.4 in DPT&E. 1978 data is from *IBM Consultants Manual*

### TABLE II.2.11.6a PROCESSOR PERFORMANCE RATIOS

| | IDC | Knight Index | | Weighted | Rental | Ratios to 360/50 or 370/135 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Com. | Com.(MP) | Speed | | IDC | | Knight Index | | Weighted | Rental |
| | (Rel) | kOp/Sec | kOp/Sec | kOp/Sec | $k/mo | | Sci. | Com. | Com.(MP) | Speed | |
| 360/20 | | 4.50 | | 1.5 | 2.8 | | 0.01 | 0.03 | | 0.01 | 0.16 |
| 360/30 | 2.3 | 17.10 | 17.5 | 24.8 | 8.8 | 0.25 | 0.04 | 0.11 | 0.10 | 0.13 | 0.50 |
| 360/40 | 4.1 | 50.07 | | 64.1 | 16.8 | 0.45 | 0.18 | 0.34 | | 0.34 | 0.96 |
| 360/50 | 9.0 | 148.97 | | 190.9 | 32.0 | 1.00 | 1.00 | 1.00 | | 1.01 | 1.83 |
| 360/65 | 31.5 | 809.7 | | 636.9 | 60.0 | 3.50 | 7.39 | 5.44 | | 3.36 | 3.43 |
| 370/115 | 2.3 | | 38.9 | 39.9 | 8.4 | 0.25 | | | 0.23 | 0.21 | 0.48 |
| 370/115-2 | 4.0 | | | (61.3) | 9.5 | 0.44 | | | | | 0.54 |
| 370/125 | 4.5 | | 70.4 | 63.0 | 11.3 | 0.50 | | | 0.41 | 0.33 | 0.64 |
| 370/125-2 | 6.3 | | | (110.0) | 11.8 | 0.70 | | | | | 0.67 |
| 370/135 | 9.0 | | 172.2 | 189.6 | 17.5 | 1.00 | | | 1.00 | 1.00 | 1.00 |
| 370/135-3 | 11.7 | | | (239.9) | 20.1 | 1.30 | | | | | 1.15 |
| 370/138 | 11.7 | | 495.5 | 265.4 | 21.0 | 1.30 | | | 2.88 | 1.40 | 1.20 |
| 370/145 | 18.0 | | 445.8 | 329.3 | 27.8 | 2.00 | | | 2.59 | 1.74 | 1.59 |
| 370/148 | 24.0 | | 1013.7 | 506.0 | 34.5 | 2.67 | | | 5.89 | 2.67 | 1.97 |
| 370/155 | 31.0 | | 1203. | 702.1 | 53.4 | 3.44 | | | 6.99 | 3.70 | 3.05 |
| 370/158 | 41.0 | | | (1163.3) | 67.5 | 4.56 | | | | | 3.86 |
| 370/158-3 | 45.0 | | 2423 | 1014.3 | 70.5 | 5.00 | | | 14.07 | 5.35 | 4.03 |
| 370/165 | 89.0 | | 3515. | 5235.6 | 95.0 | 9.89 | 106.9 | | 20.41 | 27.61 | 5.43 |
| 370/168 | 109.0 | | | (3983. ) | 126.0 | 12.11 | | | | | 7.20 |
| 370/168-3 | 124.0 | | 6008 | (5236. ) | 133.5 | 13.78 | | | 35.5 | | 7.63 |
| 370/195 | 168.0 | | | (6868. ) | 194.6 | 18.67 | | | | | 11.12 |
| 3031 | 54.0 | | 2317. | (1600. ) | 61.0 | 6.00 | | | 13.5 | | 3.49 |
| 3032 | 124.0 | | 6921. | (4728. ) | 114.0 | 13.78 | | | 40.2 | | 6.51 |
| 3033 | 223.0 | | 19019. | (9900. ) | 180.0 | 24.78 | | | 110. | | 10.29 |
| 4331 | 11.0 | | 562. | 289.4 | 7.6 | 1.23 | | | 3.26 | 1.53 | 0.43 |
| 4341 | 37.0 | | 2142. | (1022. ) | 18.9 | 4.11 | | | 12.44 | | 1.08 |

Source: See Notes on page 595. (MP) means the index was computed by Phister rather than by Knight.

### TABLE II.2.120.2a SUMMARY OF REPRESENTATIVE MEMORY TECHNOLOGIES

| | Units | 1977 | 1979 | | Units | 1977 | 1979 |
|---|---|---|---|---|---|---|---|
| **Flip-Flops** | | | | Av. Access Time | sec. | | 5.0 |
| Representative Unit | | | DEC Module | Maximum Capacity | Bby | | 11.259 |
| Price per Byte | $/by | | 27 | **Moving-Head Files** | | | |
| Access Time | μsec. | | 0.1 | Representative Unit | | IBM 3350 | IBM 3370 |
| Capacity mer Module | Bytes | | 1 | Price per Byte | cents/by | .0156 | .0061 |
| **Core Memory** | | | | Access Time | msec. | 33.3 | 30.1 |
| Processor | | BGH 6805 | | Maximum Capacity | Mbytes | 317.5 | 571.3 |
| Incr. Price per Byte | $/by | .183 | | **Magnetic Tape Units** | | | |
| Access Time | μsec. | .325 | | Representative Unit | | | IBM 3420-8 |
| Maximum Capacity | kbytes | 3072 | | Purchase Price | $k | | 28.44 |
| **IC Memory** | | | | Maximum Capacity | Mby | | 62.61 |
| Processor | | IBM 370/148 | IBM 4341 | Price per Byte | cents/by | | .045 |
| Incr. Price per Byte | $/by | .162 | .0143 | Rewind Time | sec. | | 45 |
| Access Time | μsec | .405 | .900 | **Mass Storage** | | | |
| Maximum Capacity | kbytes | 2048 | 4096 | Representative Unit | | IBM 3850 | IBM 3850 |
| **Head-Per-Track File** | | | | Price per Byte | cents/by | .00034 | .00035 |
| Representative Unit | | | IBM 2305-2 | Av. Access Time | sec. | 15 | 15 |
| Price per Byte | cents/by | | .88 | Maximum Capacity | Bby | 236.0 | 236.0 |

### TABLE II.2.12.1a MOVING HEAD FILES

| | Manufacturers: | | IBM | IBM | IBM | IBM | IBM | IBM | BGH | BGH |
|---|---|---|---|---|---|---|---|---|---|---|
| | Model Number: | | 3344-B2 | 3350-B2 | 8101-A13 | 3310-B1 | 3370-B1 | 62 PC | 9484 | 59494 2 |
| 1. | **Date lst Installed** | mo/yr | /76 | /76 | /79 | /79 | /79 | 1/79 | 7/77 | 1/79 |
| 3. | Medium—No. Surfaces | | 15 | 15 | 11 | 11 | | 11 | 5 | 8 |
| 4. | Disk Pack Model No. | | fixed | fixed | fixed | fixed | fixed | - | 9974- | |
| 5. | Diameter | in. | | | 8 | 8 | | 8 | 14 | 14 |
| 6. | Recording—No. of Tracks | | | 555 | 358 | 358 | | 358 | 815 | 1564 |
| 7. | Track Density | tr/in | 480 | 480 | 450 | 450 | | 450 | 370 | 714 |
| 8. | Recording Density | b/in | 5636 | 6350 | 8530 | 8530 | | 8530 | 6039 | 6551 |

## TABLE II.2.12.1a MOVING HEAD FILES (continued)

| | Manufacturers: Model Number: | | IBM 3344-B2 | IBM 3350-B2 | IBM 8101-A13 | IBM 3310-B1 | IBM 3370-B1 | IBM 62 PC | BGH 9484 | BGH 59494 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 8a. | Area Density | bpsi | 2.71M | 3.05M | 3.84M | 3.84M | 7.5M | 3.84M | 2.23M | 4.68M |
| 9. | Records Per Track | | | 2 | 1 | 32 | | 32 | 90 | 90 |
| 10. | Bytes Per Record | | | 19069 | 16384 | 512 | | 512 | 180 | 180 |
| 10a | By. Lost/Addl. Record | | | 185 | | | | | | |
| 11. | Mechanism–Speed | rpm | 2970 | 3600 | 3125 | 3125 | 2970 | 3125 | 3672 | 3672 |
| 12. | Av. Latency | ms | 10.1 | 8.3 | 9.6 | 9.6 | 10.1 | 9.6 | 8.17 | 8.17 |
| 13. | Seek Time–Av. | ms | 25 | 25 | 27 | 27 | 20 | 27 | 25 | 28 |
| 14. | Maximum | ms | 50 | 50 | 46 | 46 | 40 | 46 | 48 | 52 |
| 15. | Minimum | ms | 10 | 10 | 9 | 9 | 5 | 9 | 5 | 5 |
| 17. | Transfer Rate–Max. | kbps | | 288 | 853 | 853 | | 853 | 991 | 991 |
| 17c. | Specified | kby/sec | 885 | 1198 | 1031 | 1031 | 1859 | 1031 | 1210 | 1300 |
| 18. | Max. Unit Capacity | Mby | 279.6 | 317.5 | 64.52 | 64.52 | 571.3 | 64.5 | 65.2 | 201.0 |
| 19. | Av. Access Time | ms | 35.1 | 33.3 | 36.6 | 36.6 | 30.1 | 36.6 | 33.2 | 36.2 |
| | **Prices** | | | | | | | | | |
| 21. | Typ. Controller Mod. No. | | 3340 | 3830-2 | Incl. | 3310-A1 | 3880 | | 9484 | |
| 22. | Systems | | 370 | 370 | 8100 | 43x1 | 43x1 | S/34 | B1700 | |
| 23. | Price–Purchase | $k | | | 6.5 | 2.7 | 62.35 | | 10.85 | |
| 24. | Rental | $k/mo. | | | .201 | .088 | 1.704 | | .280 | |
| 25. | Maintenance | $/mo. | | | 17 | 13 | 1450 | | 36.6 | |
| 26. | Unit Price | $k | 24.75 | 24.75 | 9.91 | 10.26 | 23.4 | 8.57 | 15.58 | 16.0 |
| 27. | Rental | $k/mo. | .676 | .676 | .323 | .335 | .705 | .280 | .385 | .444 |
| 28. | Maintenance | $/mo. | 75 | 75 | 46.5 | 40 | 90 | 40 | 70.2 | 65 |
| 29. | Price Per 1000 Bytes | $/kby | .089 | .078 | .154 | .159 | .041 | 0.13 | 0.24 | 0.08 |
| 30. | Maint. Cost Per $100k | $/mo. | 303.0 | 303.0 | 469.2 | 389.9 | 384.8 | 466.7 | 450.7 | 406.3 |
| 31. | Price: Rent Ratio | | 36.61 | 36.61 | 30.68 | 30.63 | 33.19 | 30.61 | 40.45 | 36.04 |
| 32. | Accesses Per $ | k | 26.3 | 27.7 | 52.8 | 50.9 | 29.4 | 60.89 | 48.82 | 38.82 |
| 33. | **Physical Char.–Wt.** | lbs. | 375 | 500 | 450 | | 375 | | 325 | 380 |
| 34. | Floor Space | sq. ft. | 4.89 | 5.23 | 6.40 | | 4.67 | | 5.15 | 5.15 |
| 35. | Volume | cu. ft. | 18.93 | 20.28 | 21.02 | | 15.36 | | 18.88 | 18.88 |
| 36. | Electrical Load | kva | .85 | 1.15 | 1.4 | | 0.7 | | | |
| 37. | Heat Dissipation | kb/hr. | 2.5 | 3.6 | 4.1 | | 1.71 | | | |
| 38. | Density–Wt. | $lbs/ft.^3$ | 19.81 | 24.65 | 21.41 | | 24.41 | | 17.21 | 20.12 |
| 39. | Heat Per Cu. Ft. | kb/hr. | .13 | .18 | .20 | | .11 | | | |
| 40. | Capy. Per Floor Sp. | mbpsf. | 57.18 | 60.71 | 10.08 | | 122.33 | | 12.66 | 39.03 |
| 41. | Capy. Per Vol. | mbpcf. | 14.77 | 15.67 | 3.07 | | 37.19 | | 3.45 | 10.65 |
| 42. | Price Per Pound | $/lb. | 66.0 | 49.5 | 22.0 | | 93.6 | | 47.92 | |

| | Manufacturers: Model Number: | | DEC RK05 | DEC RK06 | DEC RK07 | DEC RL01 | DEC RM03 | HIS MSU330 | HIS MSU390 | Wang 2260BC |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date lst Installed** | mo/yr | /72 | 3/77 | /78 | 4/78 | 11/77 | ? | ? | |
| 3. | Medium–No. Surfaces | | 2 | 3 | 3 | 2 | 5 | 5 | 19 | |
| 4. | Disk Pack Model No. | | Cart. | Cart. | Cart. | Cart. | 9877 | 4130 | 4190 | |
| 5. | Diameter | in. | | 14 | 14 | 15 | 14 | | | |
| 6. | Recording–No. of Tracks | | 200 | 411 | 815 | 256 | 823 | 808 | 808 | |
| 7. | Track Density | tr/in | | 192.3 | 384.6 | 125 | | 400 | 384 | |
| 8. | Recording Density | B/in | 2040 | 4040 | 4040 | 3725 | | 6060 | 6038 | |
| 8a. | Area Density | bpsi | | .777M | 1.553M | .466M | | 2.424M | 2.319M | |
| 9. | Records Per Track | | 12 | 22 | 22 | 40 | 32 | 1 | 1 | |
| 10. | Bytes Per Record | | 512 | 512 | 512 | 256 | 512 | 19800 | 20160 | |
| 11. | Mechanism–Speed | rpm | 1500 | 2400 | 2400 | 2400 | 3600 | 3600 | 3600 | 2400 |
| 12. | Av. Latency | ms | 20 | 12.5 | 12.5 | 12.5 | 8.3 | 8.3 | 8.3 | 12.5 |
| 13. | Seek Time–Av. | ms | 50 | 38 | 36.5 | 55 | 30 | 30 | 30 | 40 |
| 14. | Maximum | ms | 85 | 71 | 71 | 100 | 55 | 55 | 55 | 80 |
| 15. | Minimum | ms | 10 | 8 | 6.5 | 15 | 6 | 6 | 6 | 4.5 |
| 17. | Transfer Rate–Max. | kbps | 153.6 | 450.6 | 450.6 | 409.6 | 983.0 | 1188 | 1210 | |
| 17c. | Specified | kby/sec | 180 | 465 | 465 | 513 | 1210 | 1200 | 1200 | |
| 18. | Max. Unit Capacity | Mby | 2.46 | 13.89 | 27.54 | 5.24 | 67 | 80.0 | 300 | 10.03 |
| 19. | Av. Access Time | ms | 70 | 50.5 | 49.0 | 67.5 | 38.3 | 38.3 | 38.3 | 52.5 |
| | **Prices** | | | | | | | | | |
| 21. | Typ. Controller Mod. No. | | | | | | | | | 22C12 |
| 22. | Systems | | PDP-11 | PDP-11 | PDP-11 | PDP-11 | PDP-11 | Level 62 | Level 62 | |
| 23. | Price–Purchase | $k | 5.6 | | 3.95 | 1.3 | 6.0 | 8.32 | 8.32 | 4.0 |
| 24. | Rental | $k/mo. | | | | | | .152 | .152 | |
| 25. | Maintenance | $/mo. | 42 | | 30 | 8 | 30 | 10 | 10 | 60 |

**TABLE II.2.12.1a MOVING HEAD FILES (continued)**

| | Manufacturers: Model Number: | | DEC RK05 | DEC RK06 | DEC RK07 | DEC RL01 | DEC RM03 | HIS MSU330 | HIS MSU390 | Wang 2260BC |
|---|---|---|---|---|---|---|---|---|---|---|
| 26. | Unit Price | $k | 5.1 | 9.66 | 10.5 | 3.8 | 19.0 | 15.7 | 34.5 | 7.0 |
| 27. | Rental | $k | | | | | | .448 | 1.071 | |
| 28. | Maintenance | $/mo. | 54 | 99 | 115 | 50 | 140 | 77 | 180 | 60 |
| 29. | Price Per 1000 Bytes | $/kby | 2.07 | 0.70 | 0.38 | 0.73 | 0.28 | .20 | .12 | .70 |
| 30. | Maint. Cost Per $100k | $/mo. | 1059 | 1025 | 1095 | 1319 | 737 | 490.4 | 521.7 | 857.1 |
| 31. | Price: Rent Ratio | | | | | | | 35.04 | 32.21 | |
| 32. | Accesses Per $ | k | | | | | | 36.37 | 15.21 | |
| 33. | **Physical Char.—Wt.** | lbs | 110 | 326 | 326 | 75 | 430 | 340 | | |
| 34. | Floor Space | sq. ft. | 3.50 | 4.53 | 4.53 | 3.30 | 4.74 | 5.50 | | |
| 35. | Volume | cu. ft. | 3.06 | 14.73 | 14.73 | 2.87 | 15.39 | 16.59 | | |
| 36. | Electrical Load | kva | .212 | .480 | .480 | .188 | 1.400 | 1.706 | 1.664 | |
| 37. | Heat Dissipation | kb/hr. | .616 | 1.637 | 1.500 | .600 | 4.128 | | | |
| 38. | Density—Wt. | lbs/ft.$^3$ | 35.95 | 22.13 | 22.13 | 26.13 | 27.94 | 20.49 | | |
| 39. | Heat Per Cu. Ft. | kb/hr. | .201 | .111 | .102 | .209 | .268 | | | |
| 40. | Capy. Per Floor Sp. | mbpsf. | .70 | 3.06 | 6.08 | 1.59 | 14.14 | 14.55 | | |
| 41. | Capy. Per Vol. | mbpcf. | .80 | .94 | 1.87 | 1.83 | 4.35 | 4.82 | | |
| 42. | Price Per Pound | $/lb. | 46.36 | 29.63 | 32.21 | 50.67 | 44.19 | 46.18 | | |

**TABLE II.2.12.3a MAGNETIC TAPE UNITS**

| | Manufacturer: Model Number: | | IBM 8809-3 | BGH 9495-7 | BGH 9495-24 | DEC TE-16 | DEC TU-77 |
|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /79 | /75 | 5/79 | 4/77 | 8/79 |
| | Unit Characteristics | | | | | | |
| 3. | Medium—Material | | Mylar | Mylar | Mylar | Mylar | Mylar |
| 4. | Width | in. | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 5. | Reel Length | ft. | 731 | 2400 | 2400 | 2400 | 2400 |
| 6. | Recording—No. of Tracks | | 9 | 9 | 9 | 9 | 9 |
| 7. | Density 1 | b/in. | 1600 | 800 | 1600 | 800 | 800 |
| 8. | Density 2 | b/in. | | 1600 | 6250 | 1600 | 1600 |
| 10. | Inter-Block Gap | in. | 0.6 | 0.6 | 0.3 | 0.6 | 0.6 |
| 11. | Transport—Start Time | ms | 42 | | 0.95 | | |
| 13. | R/W Speed | ips | 12.5-100 | 25 | 200 | 45 | 125 |
| 14. | Rewind Speed | ips | 185 | 480 | 640 | 150 | 440 |
| 15. | Drive Mechanism | | | Vac. | Vac. | | |
| 16. | Buffer Mechanism | | | Vac. | Vac. | Vac. | |
| | Performance | | | | | | |
| 18. | Max. Character Rate | kcps | 20-160 | 40 | 1250 | 72 | 200 |
| 19. | Max. Reel Capacity | Mby | 23.51 | 23.51 | 62.61 | 23.51 | 23.51 |
| 20. | Rewind Time | min. | 2.6 | 1 | 0.75 | 3 | 1 |
| | **Prices** | | | | | | |
| | Typ. Controller Mod. No. | | | | | | |
| 23. | System | | 8100 | | | | |
| 24. | Price—Purchase | $k | | | | 6.85 | 8.5 |
| 26. | Maintenance | $/mo. | | | | 60 | 60 |
| 27. | Tape Unit Price | $k | 10.44 | 9.0 | 34.0 | 12.0 | 19.5 |
| 28. | Rental | $k/mo. | .341 | .320 | .915 | | |
| 29. | Maintenance | $/mo. | 48 | 85 | 150 | 72 | 175 |
| 30. | Price Per 1000 Bytes | $/kby | .44 | .38 | .54 | .51 | .83 |
| 31. | Maint. Cost Per $100k | $/mo. | 459.8 | 944.4 | 441.2 | 600 | 897.4 |
| 32. | Price: Rent Ratio | | 30.61 | 28.13 | 37.16 | | |
| 34. | **Physical Char.—Wt.** | lbs. | 285 | 500 | | 110 | 630 |
| 35. | Floor Space | Sq. Ft. | 4.67 | 4.5 | | 4.34 | 5.73 |
| 36. | Volume | Cu. Ft. | 15.56 | 25.9 | | 9.40 | 28.88 |
| 37. | Electrical Load | kva | .66 | 1.4 | | .85 | |
| 38. | Heat Dissipation | kb/hr. | 1.45 | 4.5 | | 2.47 | |
| 39. | Density—Weight | lbs/ft.$^3$ | 18.32 | 19.31 | | 11.70 | 21.81 |
| 40. | Heat Per Cu. Ft. | kb/hr. | .093 | .173 | | .26 | |
| 41. | Price Per Pound | $/lb. | 36.6 | 18.0 | | 109 | 31.0 |

## TABLE II.2.12.4a LINE PRINTERS

| | Manufacturers: Model Numbers: | | IBM 3203-5 | IBM 3289-4 | IBM 3262 | BGH 9246-2 | BGH 9247-15 | DEC LP 11-R | DEC LA 180 | Wang 2231W6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | **Date 1st Installed** | mo/yr. | /79 | /79 | /79 | /75 | 1/78 | ? | 7/77 | |
| | **Unit Characteristics** | | Line | Line | Line | Line | Line | Line | Char. | Char. |
| 2. | Print Positions | | 132 | 132 | 132 | 132 | 132 | 132 | 132 | 132 |
| 3. | Character Set | | 48 | 48 | 48 | 64 | 96 | 96 | 128 | 96 |
| 4. | Spacing—Horizontal | ch/in. | 10 | 10 | 10 | 10 | 10 | 10 | | 10-12 |
| 5. | Vertical | li/in. | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | | | 6 |
| 6. | Mechanism | | Train | Belt | Belt | Drum | Train | Drum | Matrix | Matrix |
| | Performance | | | | | | | | | |
| 7. | Rated Print Speed—Alpha | lpm | 1200 | 400 | 650 | 1250 | 850 | 925 | - | |
| 8. | In Char. Per Sec. | kcps | 2.64 | 0.88 | 1.43 | 2.75 | 1.87 | 2.04 | .180 | .070 |
| 9. | Numeric Only | lpm | | | | 1800 | 1500 | 1250 | | |
| 10. | Slewing Speed | ips | 24-55 | None | 20 | 36 | 90 | 35 | | |
| 12. | System | | 43x1 | 4331 | 4331 | | | PDP-11 | PDP-11 | |
| 16. | Printer Price | $k | 38.32 | 13.25 | 14.00 | 67.275 | 58.4 | | 3.77 | 3.30 |
| 17. | Rental | $k/mo. | 1.475 | .556 | .411 | 1.96 | 1.915 | | .094e | |
| 18. | Maintenance | $/mo. | 340 | 179 | 150 | 413 | 470 | | 55 | 28 |
| 19. | Maint. Cost Per $100k | $/mo. | 887.3 | 1350.9 | 1071.4 | 613.9 | 804.8 | | 1459 | 848.5 |
| 20. | Price: Rent Ratio | | 25.98 | 23.83 | 34.06 | 34.32 | 30.50 | | | |
| 21. | Output Char. Per $ | M | 1.117 | .988 | 2.171 | .875 | .609 | | 1.19 | |
| 22. | **Physical Char.**—Wt. | lbs. | | | 530 | 800 | 980 | 800 | 102 | 70 |
| 23. | Floor Space | Sq. Ft. | | | 7.78 | 8.25 | 8.60 | 12.29 | 4.58 | 3.00 |
| 24. | Volume | Cu. Ft. | | | 25.62 | 31.63 | 31.55 | 47.12 | 12.80 | 2.50 |
| 25. | Electrical Load | kva | | | 1.6 | | | 1.44 | .312 | .144 |
| 26. | Heat Dissipation | kb/hr. | | | 5.5 | | | | .905 | |
| 27. | Density—Wt. | $lbs/ft.^3$ | | | 20.7 | 25.3 | 31.4 | | 7.97 | 28.0 |
| 28. | Heat Per Cu. Ft. | kb/hr. | | | 0.215 | | | | 0.71 | |
| 29. | Price Per Pound | $/lb. | | | 26.8 | 84.1 | 59.6 | | 37.0 | 47.1 |

## NOTES TO THE TABLES

Continued from page 596

**TABLE II.4.13.3a Integrated Circuit Memory System Manufacturing Costs.** To estimate IC memory cost in a system, we begin with the one-cabinet systems discussed in Section 4.11, compute the per-module costs there, and then modify those costs to take into account the differences between the "average" system module and a memory module.

1-4. The module count and power requirements are from Tables II.4.11.2 and II.4.11.2a. The costs are found by dividing total Power, Packaging, Interconnect, and Assumbly/Test costs from Tables II.4.11.6 and 7a by the module count on line 1.

5-8. IC costs are from Table II.4.11.1c. The cost of the "support" circuits for 1978 are taken using the same assumption as that used in deriving Table II.4.11.7a—namely that a mixture of standard and low-power Schottky circuits were used to reduce power requirements.

9-13. Each of four IC memory systems will be analyzed. Each will contain 64 memory IC's (and thus a variable number of bits, depending on the IC used) and 41 "support" IC's—the ratio 41/64 comes from a analysis of seven commercially-available IC memory boards containing 36 to 192 memory IC's and averaging 0.647 support IC's per RAM. A similar study of the same modules led to the conclusion that on the average, module power is around 200 mw per IC. Module power is thus taken as .2 x 105 = 21 watts.

14-22. These lines show the derivation of the cost of a module made using 1K RAM chips. Line 15 is the product of lines 9 and 5, line 16 the product of lines 10 and 8. Line 17 is line 3 multiplied by the ratio of line 13 to line 2. (Note the implicit assumption that the average cabinet power will be line 2 times the number of modules, so that there must be some lower-than-average-power modules to compensate for the 21-watt memory modules. If this assumption is incorrect, the power, packaging, and interconnect costs will all have to be revised, for a higher average power requirement per module will require larger power and cooling units, and thus fewer modules per cabinet). Line 18 is the same as line 4. Line 19 is the sum of lines 16-18, except that the 1976 figure is added as an interpolation between the 1974 and 1978 figures. It is repeated on lines 25 and 31 below. Line 20 is the sum of lines 19 and 15. Line 21 is the quotient of line 20 and line 14 (with K = 1024 bits), and line 22 is found by dividing line 5 by 1024 bits per chip.

23-34. These lines are derived in the same way as were lines 14-22.

Continued on page 650.

## TABLE II.2.14.1a DATA TRANSMISSION FACILITIES I—LEASED LINES

| Column | | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplier | | AT&T | AT&T | AT&T | AT&T | AT&T | AT&T | AT&T | AT&T | AT&T | AT&T |
| Effective Date | Mo/yr | 6/77 | 6/77 | 5/78 | 5/78 | 5/78 | 7/78 | 7/78 | 7/78 | 7/78 | 7/78 |
| Tariff | | 260 | 260 | 260 | 260 | 260 | 267 | 267 | 267 | 267 | 267 |
| Service | | 1005 | 1006 | 3002 | 3002 | 3002 | DDS | DDS | DDS | DDS | DDS |
| Line | | | | Voice Grade | Voice Grade | Voice Grade | | | | | |
| Speed—Bits | bps | 75 | 150 | 9600 | 9600 | 9600 | 2400 | 4800 | 9600 | 56k | 1544k |
| Characters | cps | 10 | 15 | | | | | | | | |
| Line Costs/mi | | | | A-A | A-B | B-B | | | | | |
| Duplex | | Full | Full | Full | Full | Full | | | | | |
| 1st 25 mi | $/mo | 1.25 | 1.55 | 3.648 | 5.168 | 6.104 | 3.648 | 3.648 | 3.648 | 18.24 | 144.0 |
| Next 75 mi | $/mo | 1.25 | 1.55 | 1.12 | 1.48 | 1.907 | 1.12 | 1.12 | 1.12 | 5.60 | 64.00 |
| Next 150 mi | $/mo | 1.00 | 1.25 | 0.66 | 0.66 | 0.68 | 0.66 | 0.66 | 0.66 | 3.30 | 64.00 |
| Next 250 mi | $/mo | 0.60 | 0.80 | 0.66 | 0.66 | 0.68 | 0.66 | 0.66 | 0.66 | 3.30 | 50.00 |
| Next 500 mi | $/mo | 0.40 | 0.50 | 0.66 | 0.66 | 0.68 | 0.66 | 0.60 | 0.66 | 3.30 | 40.00 |
| Next 500 mi | $/mo | 0.25 | 0.30 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 2.00 | 40.00 |
| Add'l. Miles | $/mo | 0.25 | 0.30 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 2.00 | 40.00 |
| Line Cost/Mo. | | | | | | | | | | | |
| 30 Miles | $/mo | 37.5 | 46.5 | 96.8 | 136.6 | 162.1 | 96.8 | 96.8 | 96.8 | 484 | 3920 |
| 300 Miles | $/mo | 305.0 | 382.5 | 307.2 | 372.2 | 431.6 | 307.2 | 307.2 | 307.2 | 1536 | 19800 |
| 3000 Miles | $/mo | 1125 | 1393 | 1569 | 1634 | 1708 | 1569 | 1569 | 1569 | 7846 | 130k |
| Termin. Cost | $/mo | 74.0 | 96.0 | 25 | 25 | 25 | 84.55 | 160 | 281.33 | 650 | 900 |
| Installation Cost | $ | 52.6 | 52.6 | 54.2 | 54.2 | 54.2 | 128.8 | 128.8 | 128.78 | 180.8 | 350 |
| Term/In—Amort 12 Mo. | $/mo | 156.8 | 200.8 | 59.0 | 59.0 | 59 | 190.6 | 341.5 | 584.1 | 1330 | 1858 |
| Tot—1 yr.—30 Mi. | $/mo | 194.3 | 247.3 | 155.8 | 195.6 | 221.1 | 287.4 | 438.3 | 680.9 | 1814 | 5778 |
| 300 Mi. | $/mo | 461.8 | 583.3 | 366.2 | 431.2 | 490.6 | 497.8 | 648.7 | 891.3 | 2866 | 21658 |
| 3000 Mi | $/mo | 1282 | 1593 | 1628 | 1693 | 1767 | 1760 | 1910 | 2153 | 9176 | 132k |

## TABLE II.2.14.2a DATA TRANSMISSION FACILITIES—DIALED LINES (1977-)

| Column | | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Service | | | Direct Dial (DD) 1977- | | | (1) | | | WATS 1975- | (2) | |
| Speed | bps | 9.6k | 9.6k | 9.6k | 9.6k | 9.6k | 9.6k | 9.6k | 9.6k | 9.6k | 9.6k |
| Time | | Days | | Evenings | | Nights/ Weekends | | Full Time | | Meas'd. Time | |
| Minimum Period | | 1 Minute | | 1 Minute | | 1 Minute | | 1 Month | | 10 Hrs. | |
| Line Costs Per: | | Min. | Add'l Min. | Min. | Add'l. Min. | Min. | Add'l Min. | Month Min. | Month Max. | Hour | Add'l Hr. |
| 1-10 Miles | $ | .19 | .09 | .13 | .06 | .08 | .04 | 900 | 1150 | 19.6 | 14.7 |
| 11-16 Miles | $ | .23 | .12 | .15 | .08 | .10 | .05 | 900 | 1150 | 19.6 | 14.7 |
| 17-22 Miles | $ | .27 | .14 | .18 | .10 | .11 | .06 | 900 | 1150 | 19.6 | 14.7 |
| 23-30 Miles | $ | .31 | .18 | .21 | .12 | .13 | .08 | 900 | 1150 | 19.6 | 14.7 |
| 31-40 Miles | $ | .35 | .21 | .23 | .14 | .14 | .09 | 900 | 1315 | 19.6 | 14.7 |
| 41-55 Miles | $ | .39 | .25 | .26 | .17 | .16 | .10 | 900 | 1315 | 19.6 | 14.7 |
| 56-70 Miles | $ | .41 | .27 | .27 | .18 | .17 | .11 | 900 | 1315 | 19.6 | 14.7 |
| 71-124 Miles | $ | .43 | .29 | .28 | .19 | .18 | .12 | 900 | 1500 | 21.4 | 16.1 |
| 125-196 Miles | $ | .44 | .30 | .29 | .20 | .18 | .12 | 900 | 1570 | 21.4 | 16.1 |
| 197-292 Miles | $ | .46 | .32 | .30 | .21 | .19 | .13 | 900 | 1630 | 22.6 | 17.0 |
| 293-430 Miles | $ | .48 | .34 | .32 | .23 | .20 | .14 | 1150 | 1630 | 23.4 | 17.6 |
| 431-925 Miles | $ | .50 | .34 | .33 | .23 | .20 | .14 | 1610 | 1660 | 23.6 | 17.7 |
| 926-1910 Miles | $ | .52 | .36 | .34 | .24 | .21 | .15 | 1670 | 1675 | 24.4 | 18.3 |
| 1911-3000 Miles | $ | .54 | .38 | .36 | .25 | .22 | .16 | 1675 | 1675 | 24.5 | 18.3 |

Notes:

1. For D = Distance in Miles *K* 70, Cost per Additional minute, for Days, is given by Cost = 15.81 + 6.61 log D, where the log is to the base 10. Evening rates are .65 times day rates, and night rates .40 times day rates.
2. Current "Full Time" WATS service covers only 240 hours. Greater usage per month incurs additional charges not shown here.

## TABLE II.2.14.2b PACKET SWITCHING DATA SERVICES—TYMNET, INC.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Tymnet Processor** | | | | | | | | | |
| System | | CP-8A | CP-8A | CP-30A | CP-30A | CP-96A | CP-64S | CP-256S | |
| Speed | bps | 300 | 1200 | 300 | 1200 | 1200 | 4800 | 4800 | |
| Max. No. of Users | | 8 | 8 | 30 | 30 | 96 | 64 | 256 | |
| Processor Cost | $/mo | 1000 | 1250 | 2150 | 2450 | 3170 | 1400 | 2150 | |
| Installation Cost | $ | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | |
| Amort.. 12 Mos. | $/mo | 83.3 | 83.3 | 83.3 | 83.3 | 83.3 | 83.3 | 83.3 | |
| Total Cost | $/mo | 1083 | 1333 | 2233 | 2533 | 3253 | 1483 | 2233 | |
| **Terminal Access** | | | | | | | | | |
| 1. Dial-In Line | | Hi-Dens. City | | Lo-Dens. City | | Other City | | WATS | |
| Speed | bps | 300 | 1200 | 300 | 1200 | 300 | 1200 | 300 | 1200 |
| Minimum Connect Time | min. | 6 | 6 | 2 | 2 | 2 | 2 | 1 | 1 |
| Hourly charge | $/hr. | 1 | 2 | | | 5 | 6 | 14 | 15 |
| 1-500 hr. | $/hr. | | | 4 | 5 | | | | |
| 500-1000 hr. | $/hr. | | | 2 | 3 | | | | |
| Over 1000 hr. | $/hr. | | | 1 | 2 | | | | |
| 2. Leased Line | | Hi-Dens. City | | Lo-Dens. City | | | | | |
| Speed | bps | 300 | 1200 | 300 | 1200 | | | | |
| Cost | $/mo | 125 | 175 | 175 | 225 | | | | |
| Installation Cost | $ | 200 | 200 | 200 | 200 | | | | |
| Amort. 12 mos. | $/mo. | 17 | 17 | 17 | 17 | | | | |
| Total Cost | | 142 | 192 | 192 | 242 | | | | |
| 1 or 2. Character Cost: Speed | bps | 300 | 1200 | | | | | | |
| 1-40M Bytes/Mo | $/kby | 0.10 | 0.03 | | | | | | |
| 40M-80M Bytes/Mo. | $/kby | 0.08 | 0.03 | | | | | | |
| Over 80M Bytes/Mo. | $/kby | 0.05 | 0.03 | | | | | | |
| 3. Dedicated Host Port: Speed | bps | 300 | 1200 | | | | | | |
| Cost | $/mo. | 475 | 650 | | | | | | |
| **Message Switching** | | Hi-Dens. City | | Low-Dens.City | | Other City | | WATS | |
| Speed | bps | 300 | 1200 | 300 | 1200 | 300 | 1200 | 300 | 1200 |
| Connect Cost | $/min. | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.14 | 0.25 | 0.25 |
| Minimum Connect Time | min. | 2.5 | 2.5 | 2.0 | 2.0 | 1.5 | 1.5 | 1.0 | 1.0 |
| Packet Cost | $/Kby | 0.12 | 0.05 | 0.12 | 0.05 | 0.12 | 0.05 | 0.12 | 0.05 |
| Message Cost | $ | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Service Charge | $/mo. | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

## TABLE II.2.14.3a DIRECT DIAL AVERAGE COST PER MINUTE (1977-)

| | Distance (Miles) | | | | Distance (Miles) | | |
|---|---|---|---|---|---|---|---|
| | 30 | 300 | 3000 | | 30 | 300 | 3000 |
| **Days** | | | | 5 Minutes | .14 | .25 | .28 |
| One-Half Minute | .62 | .96 | 1.08 | 10 Minutes | .13 | .24 | .27 |
| 1 Minute | .31 | .48 | .54 | Long Call | .12 | .23 | .25 |
| 2 Minutes | .25 | .41 | .46 | **Nights/Weekends** | | | |
| 5 Minutes | .21 | .37 | .42 | One-Half Minute | .26 | .40 | .44 |
| 10 Minutes | .20 | .36 | .40 | 1 Minute | .13 | .20 | .22 |
| Long Call | .18 | .34 | .38 | 2 Minutes | .11 | .17 | .19 |
| **Evenings** | | | | 5 Minutes | .09 | .16 | .18 |
| One-Half Minute | .42 | .64 | .72 | 10 Minutes | .09 | .15 | .17 |
| 1 Minute | .21 | .32 | .36 | Long Call | .08 | .14 | .16 |
| 2 Minutes | .17 | .28 | .31 | | | | |

## TABLE II.2.14.4a (See Next Page)

## TABLE II.2.14.5a LINE CONDITIONING PRICES (1979)

| **Designation** | | **C1** | **C2** | **D1** |
|---|---|---|---|---|
| **Tariff** | | **260** | **260** | **260** |
| **Effective Date** | | **5/78** | **5/78** | **5/78** |
| Installation | $ | | | 163 |
| Monthly Charge | $/Mo. | 5.4 | 20.6 | 14.7 |
| For DD | $/Mo. | 10.8 | 30.4 | |

## TABLE II.2.14.4a DATA SET PRICES (1979)

| Column<br>Supplier<br>Effective Date<br>Model No.<br>Speed (bps) | 30<br>AT&T<br>4/78<br>103F<br>300 | 31<br>AT&T<br>4/78<br>103J<br>300 | 32<br>AT&T<br>4/78<br>202T<br>1200 | 33<br>AT&T<br>4/78<br>202S<br>1200 | 34<br>AT&T<br><br>212A<br>1200 | 35<br>AT&T<br>9/77<br>201C<br>2400 | 36<br>AT&T<br>6/77<br>208A<br>4800 | 37<br>AT&T<br>6/77<br>209<br>9600 | 38<br>AJ<br>/70<br>142<br>300 | 39<br>BGH<br>/76<br>2401<br>2400 | 40<br>Codex<br>/71<br>9600<br>9600 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PL/DD | PL | DD | PL | DD | DD | PL,DD | | PL | DD | DD | PL |
| Conditioning | | | | | | | | D1 | | | C2 |
| Prices | | | | | | | | | | | |
| Send-Rec. ($/mo.) | 21.7 | 21.7 | 25.0 | 29.5 | 41.5 | 59.6 | 135.0 | 249 | 18 | 57 | 185.0 |
| Installation ($) | 27.1 | 27.1 | 100.0 | 110.0 | 120.0 | 81.2 | 163.0 | 216 | 35 | 50 | 152.0 |
| System Prices ($/mo) | | | | | | | | | | | |
| Two Sets | 43.4 | 43.4 | 50.0 | 59.0 | 83.0 | 118.2 | 270.0 | 498.0 | 36 | 114 | 370.0 |
| Two Condit. | | | | | | | | 29.4 | | | 41.2 |
| Installation-12 Mo. | | | | | | | | | | | |
| Data Sets | 2.3 | 2.3 | 16.7 | 18.3 | 20.0 | 13.5 | 27.2 | 36.0 | 5.8 | 8.3 | 25.3 |
| Condit. | | | | | | | | 27.2 | | | |
| Total Cost | 47.9 | 47.9 | 66.7 | 77.3 | 103.0 | 131.7 | 297.2 | 590.6 | 41.8 | 122.3 | 436.5 |

TABLE II.2.14.5a (See Preceding Page)

## TABLE II.2.14.6a SYSTEM PRICES FOR DATA TRANSMISSION I

| Date<br>Speed<br>DD/PL<br>Line<br>Cities | bps | 6/77<br>300<br>DD<br>Days | 6/77<br>300<br>DD<br>Nites | 5/78<br>300<br>PL<br>3002<br>A-A | 5/78<br>300<br>PL<br>3002<br>A-B | 5/78<br>300<br>PL<br>3002<br>B-B | 5/78<br>2400<br>DD<br>Days | 5/78<br>2400<br>PL<br>3002<br>A-A |
|---|---|---|---|---|---|---|---|---|
| 1. Data Set | | 103J | 103J | 103F | 103F | 103F | 201C | 201C |
| 2. Price | $/mo | 47.9 | 47.9 | 47.9 | 47.9 | 47.9 | 131.7 | 131.7 |
| **System Prices** | | | | | | | | |
| **30 Miles** | | | | | | | | |
| 3. Full Month—Cost | $/mo | | | 201.5 | 241.3 | 266.8 | | 287.5 |
| 4. Bits Transmitted | Mb/Mo. | | | 788.4 | 788.4 | 788.4 | | 6307 |
| 5. 1 M Bits—Cost | $/mo | 57.9 | 52.3 | | | | 132.9 | |
| 6. Time to Transmit | Min. | 55.6 | 55.6 | | | | 6.94 | |
| 7. 4 M Bits—Cost | $/mo | 87.9 | 65.7 | | | | 136.7 | |
| 8. Time to Transmit | Min. | 222.2 | 222.2 | | | | 27.78 | |
| 9. 16 M Bits—Cost | $/mo | 207.9 | 119.0 | | | | 151.7 | |
| 10. Time to Transmit | Min. | 888.8 | 888.8 | | | | 111.1 | |
| 11. 64 M Bits—Cost | $/mo | 687.9 | 332.1 | | | | 211.7 | |
| 12. Time to Transmit | Min. | 3556 | 3556 | | | | 444.4 | |
| 13. 256 M Bits—Cost | $/mo | 2607.9 | 1186 | | | | 451.7 | |
| 14. Time to Transmit | Min. | 14222 | 14222 | | | | 1778 | |
| **300 Miles** | | | | | | | | |
| 15. Cost—Full Month | $/mo | | | 411.9 | 476.9 | 536.3 | | 497.9 |
| 16. 1 M Bits | $/mo | 66.8 | 55.7 | | | | 134.1 | |
| 17. 4 M Bits | $/mo | 123.4 | 79.0 | | | | 141.1 | |
| 18. 16 M Bits | $/mo | 350.1 | 172.3 | | | | 169.5 | |
| 19. 64 M Bits | $/mo | 1257 | 545.7 | | | | 282.8 | |
| 20. 256 M Bits | $/mo | 4883 | 2039 | | | | 736.2 | |
| **3000 Miles** | | | | | | | | |
| 21. Cost—Full Month | $/mo | | | 1674 | 1739 | 1812 | | 1759.9 |
| 22. 1 M Bits | $/mo | 69.0 | 56.8 | | | | 134.3 | |
| 23. 4 M Bits | $/mo | 132.3 | 83.5 | | | | 142.3 | |
| 24. 16 M Bits | $/mo | 385.6 | 190.1 | | | | 173.9 | |
| 25. 64 M Bits | $/mo | 1399 | 616.8 | | | | 300.6 | |
| 26. 256 M Bits | $/mo | 5452 | 2324 | | | | 807.3 | |
| **Price Per MBits** | | | | | | | | |
| 27. **30 Miles—1MBits** | $ | 57.9 | 52.3 | | | | 132.9 | |
| 28. 4 M Bits | $ | 22.0 | 16.4 | | | | 34.2 | |
| 29. 16 M Bits | $ | 13.0 | 7.4 | | | | 9.5 | |
| 30. 64 M Bits | $ | 10.7 | 5.2 | | | | 3.3 | |
| 31. 256 M Bits | $ | 10.2 | 4.6 | | | | 1.8 | |
| 32. Full Month | $ | | | 0.256 | 0.306 | 0.338 | | .046 |
| 33. **300 Mi—1 M Bits** | $ | 66.8 | 55.7 | | | | 134.1 | |
| 34. 4 M Bits | $ | 30.9 | 19.8 | | | | 35.3 | |

**TABLE II.2.14.6a SYSTEM PRICES FOR DATA TRANSMISSION I (continued)**

| Date<br>Speed<br>DD/PL<br>Line<br>Cities | bps | 6/77<br>300<br>DD<br>Days | 6/77<br>300<br>DD<br>Nites | 5/78<br>300<br>PL<br>3002<br>A-A | 5/78<br>300<br>PL<br>3002<br>A-B | 5/78<br>300<br>PL<br>3002<br>B-B | 5/78<br>2400<br>DD<br>Days | 5/78<br>2400<br>PL<br>3002<br>A-A |
|---|---|---|---|---|---|---|---|---|
| 35. 16 M Bits | $ | 21.9 | 10.8 | | | | 10.6 | |
| 36. 64 M Bits | $ | 19.6 | 8.5 | | | | 4.4 | |
| 37. 256 M Bits | $ | 19.1 | 8.0 | | | | 2.9 | |
| 38. Full Month | $ | | | 0.522 | 0.605 | 0.680 | | .079 |
| 39. **3000 Mi**—1 M Bits | $ | 69.0 | 56.8 | | | | 134.3 | |
| 40. 4 M Bits | $ | 33.1 | 20.9 | | | | 35.6 | |
| 41. 16 M Bits | $ | 24.1 | 11.9 | | | | 10.9 | |
| 42. 64 M Bits | $ | 21.9 | 9.6 | | | | 4.7 | |
| 43. 256 M Bits | $ | 21.3 | 9.1 | | | | 3.2 | |
| 44. Full Month | $ | | | 2.123 | 2.206 | 2.299 | | .279 |
| **Total Prices** | | | | | | | | |
| 45. Fixed | $/mo | 47.9 | 47.9 | | | | 131.7 | |
| 46. Per M Bit—30 Miles | $/MBit | 10.0 | 4.44 | | | | 1.25 | |
| 47. 300 Miles | $/MBit | 18.9 | 7.77 | | | | 2.36 | |
| 48. 3000 Miles | $/MBit | 21.1 | 8.88 | | | | 2.64 | |

**TABLE II.2.14.6a SYSTEM PRICES FOR DATA TRANSMISSION I**

| Date<br>Speed<br>DD/PL<br>Line<br>Cities | | 5/78<br>9600<br>DD<br>Days | 5/78<br>9600<br>DD<br>Nites | 5/78<br>9600<br>PL<br>3002<br>A-A | 5/78<br>9600<br>PL<br>3002<br>A-B | 5/78<br>9600<br>PL<br>3002<br>B-B | 7/78<br>2400<br>PL<br>DDS | 7/78<br>9600<br>PL<br>DDS | 7/78<br>56k<br>PL<br>DDS | 7/78<br>1544k<br>PL<br>DDS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Data Set | | Codex | Codex | 209 | 209 | 209 | | | | |
| 2. Price | $/mo | 436.5 | 436.5 | 590.6 | 590.6 | 590.6 | | | | |
| **System Prices** | | | | | | | | | | |
| **30 Miles** | | | | | | | | | | |
| 3. Full Month—Cost | $/mo | | | 746.4 | 786.2 | 811.2 | 287.4 | 680.9 | 1814 | 5778 |
| 4. Bits Transmitted | Mb/Mo. | | | 25229 | 25229 | 25229 | 6307 | 25229 | 147k | 40.6M |
| 5. 1 M Bits—Cost | $/mo | 436.8 | 436.6 | | | | | | | |
| 6. Time to Transmit | Min. | 1.736 | 1.736 | | | | | | | |
| 7. 4 M Bits—Cost | $/mo | 437.7 | 437.1 | | | | | | | |
| 8. Time to Transmit | Min. | 6.944 | 6.944 | | | | | | | |
| 9. 16 M Birs—Cost | $/mo | 441.5 | 438.7 | | | | | | | |
| 10. Time to Transmit | Min. | 27.78 | 27.78 | | | | | | | |
| 11. 64 M Bits—Cost | $/mo | 456.5 | 445.4 | | | | | | | |
| 12. Time to Transmit | Min. | 111.1 | 111.1 | | | | | | | |
| 13. 256 M Bits—Cost | $/mo | 516.5 | 472.1 | | | | | | | |
| 14. Time to Transmit | Min. | 444.4 | 444.4 | | | | | | | |
| **300 Miles** | | | | | | | | | | |
| 15. Cost—Full Month | $/mo | | | 956.8 | 1022 | 1081 | 497.8 | 891.3 | 2866 | 21658 |
| 16. 1 M Bits | $/mo | 437.1 | 436.7 | | | | | | | |
| 17. 4 M Bits | $/mo | 438.9 | 437.5 | | | | | | | |
| 18. 16 M Bits | $/mo | 445.9 | 440.4 | | | | | | | |
| 19. 64 M Bits | $/mo | 474.3 | 452.1 | | | | | | | |
| 20. 256 M Bits | $/mo | 587.6 | 498.7 | | | | | | | |
| **3000 Miles** | | | | | | | | | | |
| 21. Cost—Full Month | $/mo | | | 2219 | 2284 | 2357 | 1769 | 2153 | 9176 | 132k |
| 22. 1 M Bits | $/mo | 437.2 | 436.8 | | | | | | | |
| 23. 4 M Bits | $/mo | 439.1 | 437.6 | | | | | | | |
| 24. 16 M Bits | $/mo | 447.1 | 440.9 | | | | | | | |
| 25. 64 M Bits | $/mo | 478.8 | 454.3 | | | | | | | |
| 26. 256 M Bits | mo/mo | 605.4 | 507.6 | | | | | | | |
| **Price Per MBits** | | | | | | | | | | |
| 27. **30 Miles**—1MBits | $ | 436.8 | 436.6 | | | | | | | |
| 28. 4 M Bits | $ | 109.4 | 109.3 | | | | | | | |
| 29. 16 M Bits | $ | 27.6 | 27.4 | | | | | | | |
| 30. 64 M Bits | $ | 7.1 | 7.0 | | | | | | | |
| 31. 256 M Bits | $ | 2.0 | 1.8 | | | | | | | |
| 32. Full Month | $ | | | .030 | .031 | .032 | .046 | .0270 | .0123 | .0001 |

### TABLE II.2.14.6a SYSTEM PRICES FOR DATA TRANSMISSION I (continued)

| Date<br>Speed<br>DD/PL<br>Line<br>Cities | | 5/78<br>9600<br>DD<br>Days | 5/78<br>9600<br>DD<br>Nites | 5/78<br>9600<br>PL<br>3002<br>A-A | 5/78<br>9600<br>PL<br>3002<br>A-B | 5/78<br>9600<br>PL<br>3002<br>B-B | 7/78<br>2400<br>PL<br>DDS | 7/78<br>9600<br>PL<br>DDS | 7/78<br>56k<br>PL<br>DDS | 7/78<br>1544k<br>PL<br>DDS |
|---|---|---|---|---|---|---|---|---|---|---|
| 33. **300 Mi**–1 M Bits | $ | 437.1 | 436.7 | | | | | | | |
| 34. 4 M Bits | $ | 109.7 | 109.4 | | | | | | | |
| 35. 16 M Bits | $ | 27.9 | 27.5 | | | | | | | |
| 36. 64 M Bits | $ | 7.4 | 7.1 | | | | | | | |
| 37. 256 M Bits | $ | 2.3 | 1.9 | | | | | | | |
| 38. Full Month | $ | | | .038 | .041 | .043 | .079 | .0353 | .0195 | .0005 |
| 39. **3000 Mi**–1 M Bits | $ | 437.2 | 436.8 | | | | | | | |
| 40. 4 M Bits | $ | 109.8 | 109.4 | | | | | | | |
| 41. 16 M Bits | $ | 27.9 | 27.6 | | | | | | | |
| 42. 64 M Bits | $ | 7.5 | 7.1 | | | | | | | |
| 43. 256 M Bits | $ | 2.4 | 2.0 | | | | | | | |
| 44. Full Month | $ | | | .088 | .091 | .093 | .279 | .0854 | .0624 | .0032 |
| **Total Prices** | | | | | | | | | | |
| 45. Fixed | $/mo | 436.5 | 436.5 | | | | | | | |
| 46. Per M Bit–30 Miles | $/MBit | .312 | .139 | | | | | | | |
| 47. 300 Miles | $/MBit | .590 | .243 | | | | | | | |
| 48. 3000 Miles | $/MBit | .660 | .278 | | | | | | | |

### TABLE II.2.14.6a SYSTEM PRICES FOR DATA TRANSMISSION—TYMNET AND AT&T

| | | | | | Tymnet | | | | | AT&T<br>DD or PL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dial-In | | | Ded.Port | Message | Switch | | | |
| Distance<br>City | Miles | Any<br>Hi-Dens | Any<br>Other | Any<br>Hi-Dens | Any<br>Hi-Dens | Any<br>Any | Any<br>Hi-Dens | Any<br>Other | 30<br>Any | 300<br>Any | 3000<br>Any |
| Tymnet Processor | | CP-30A | CP-30A | CP-8A | CP-64S | CP-30A | | | | | |
| Bit Rate | kbps | 7.2 | 7.2 | 1.8 | 4.8 | 7.2 | 3.0 | 3.0 | .3 | .3 | .3 |
| Total Cost | $/mo. | 2233 | 2233 | 1083 | 1483 | 2233 | | | | | |
| Data Set Price | $/mo. | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 47.9 | 47.9 | 47.9 | 47.9 | 47.9 |
| Hourly Charge | $/hr. | 1.0 | 5.0 | 1.0 | 1.0 | 0 | 2.40 | 6.20 | 10.80 | 20.40 | 22.80 |
| Packet Cost–0-40Mch | $/MBits | 10.0 | 10.0 | 10.0 | 10.0 | 0 | 12.0 | 12.00 | | | |
| Port Cost | $/mo. | | | | | 300 | | | | | |
| Service Charge | $/mo. | | | | | | 100 | 100 | | | |
| Number of Users | | 24 | 24 | 6 | 50 | 24 | 10 | 10 | 1 | 1 | 1 |
| System Costs | | | | | | | | | | | |
| Fixed | $/mo. | 117.0 | 117.0 | 204.5 | 53.66 | 417 | 57.9 | 57.9 | 47.9 | 47.9 | 47.9 |
| Incr. — 3.75 ch/sec. | $/MBits | 17.41 | 47.04 | 17.41 | 17.41 | 0 | 29.78 | 65.33 | 80.00 | 151.1 | 168.9 |
| 7.78 ch/sec. | $/MBits | 13.58 | 27.88 | 13.58 | 13.58 | 0 | 20.58 | 37.74 | 38.61 | 72.93 | 81.51 |
| 15 ch/sec. | $/MBits | 11.85 | 19.26 | 11.85 | 11.85 | 0 | 16.44 | 25.33 | 20.00 | 37.78 | 42.22 |
| 30 ch/sec. | $/MBits | 10.93 | 14.63 | 10.93 | | | 14.22 | 18.67 | 10.00 | 18.89 | 21.11 |
| Private Line — Cities | | | | | | | | | A-B | A-B | A-B |
| Monthly Cost | $/mo. | | | | | | | | 241.3 | 476.9 | 1739 |

### TABLE II.2.15.1a THE USE OF VARIOUS PROGRAMMING AIDS (Percentage "Usage" of Aids)

| Year:<br>Sample:<br><br><br><br>Basis | 1976<br>309<br>Computer users<br>in over 25<br>countries<br>"Languages used" | 1977<br>69<br>Organizations<br>Surveyed<br>(U.S.)<br>Source code |
|---|---|---|
| Assembly | 25 | 18.5 |
| FORTRAN | 17 | 2.6 |
| COBOL | 50 | 58.1 |
| RPG | | 10.2 |
| PL-I | 25 | 3.1 |
| Algol | | 1.5 |
| Other | 17 | 6.0 |
| Source | HugoI77 | LienB78 |

### TABLE II.2.15.1b THE USE OF VARIOUS PROGRAMMING AIDS

| | No. of<br>Sites | Lang.<br>per Site | 1977<br>Average<br>% Use | Total<br>Hours<br>per Lang. | Percent<br>of Total<br>Hours |
|---|---|---|---|---|---|
| COBOL | 119 | .90 | 70 | 83.3 | 63.2 |
| FORTRAN | 45 | .34 | 9 | 4.1 | 3.1 |
| Assembler | 97 | .74 | 22 | 21.3 | 16.2 |
| PL-I | 26 | .20 | 32 | 8.3 | 6.3 |
| RPG | 23 | .17 | 25 | 5.8 | 4.4 |
| Basic | 11 | .08 | 15 | 1.7 | 1.3 |
| APL | 4 | .03 | 14 | .6 | 0.5 |
| Other | 42 | .32 | 16 | 6.7 | 5.1 |
| Total | 367 | 2.78 | | 131.8 | 100.1 |

Source: PhilA77. See Notes on p. 406 of DPT&E.

## TABLE II.2.16.1a PRICE AND CAPACITY OF VARIOUS MEDIA

| | | 1970 | 1974 | 1978 |
|---|---|---|---|---|
| **Punched Cards** | | | | |
| Price Per Million Cards | $k/M | 0.95 | 1.30 | 2.30 |
| Card Capacity | Bytes | 80 | 80 | 80 |
| Price Per Million Bytes | $/MBytes | 11.9 | 16.3 | 28.8 |
| Price Per Million Cards | $k/M | .050 | .080 | 1.35 |
| Card Capacity | Bytes | 96 | 96 | 96 |
| Price Per Million Bytes | $/MBytes | 5.2 | 8.3 | 14.1 |
| **Magnetic Tape** | | | | |
| Price Per Reel | $ | 13.6 | 10.5 | 9.8 |
| Reel Capacity | MBy | 23.5 | 62.6 | 62.6 |
| Price Per Million Bytes | $/MBytes | 0.58 | 0.17 | 0.16 |
| **Disk Pack** | | | | |
| IBM Model Number | | 3336-1 | 3336-11 | 3336-11 |
| Price Per Pack | $ | 1000 | 700 | 500 |
| Pack Capacity | MBy | 100 | 200 | 200 |
| Price Per Million Bytes | $/MBytes | 10.0 | 3.5 | 2.5 |

| | | 1970 | 1974 | 1978 |
|---|---|---|---|---|
| **Continuous Forms** | | | | |
| Price per 1000 Sheets | $ | 4.62 | 5.50 | 4.70 |
| Bytes per sheet | kBytes | 7.8 | 7.8 | 7.8 |
| Price Per Million Bytes | $/MBytes | 0.59 | 0.71 | 0.60 |
| **Microfilm (16mm)** | | | | |
| Price Per 100-ft. roll | | | | |
| Pages Per Roll | k | 3 | 3 | 3 |
| Bytes Per Page | k | 6.5 | 6.5 | 6.5 |
| Price Per Million Bytes | $/MBytes | 0.15 | 0.18 | 0.18 |
| **Diskette** | | | | |
| Price Per Diskette | $ | | 7.2 | 2.9 |
| Bytes Per Diskette | k | | 243 | 500 |
| Price Per Million Bytes | $/MBytes | | 29.6 | 5.8 |
| **IBM 3850 Cartridge** | | | | |
| Price Per Cartridge | $ | | | 20 |
| Cartridge Capacity | MBy | | | 50.4 |
| Price Per Million Bytes | $/MBytes | | | $0.40 |

Sources: Table II.1.27a. For microfilm, BroeC78

## TABLE II.2.23.3a SYSTEM UTILIZATION AND RESPONSE TIME

| | | Numbers of Input Channels (I) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $s/s_C$ | J | 1 | | 2 | | 3 | | 4 | | 8 | |
| | | Util. | Resp. | Util. | Resp. | Util. | Resp. | Util. | Resp. | Util. | Resp. |
| .05 | 1 | .952 | 1.05 | .488 | 2.05 | .328 | 3.05 | .247 | 4.05 | .124 | 8.05 |
| | 2 | .998 | 2.00 | .661 | 3.03 | .496 | 4.03 | .397 | 5.04 | .221 | 9.04 |
| | 5 | 1.000 | 5.00 | .832 | 6.01 | .712 | 7.02 | .623 | 8.02 | .415 | 12.03 |
| | 10 | 1.000 | 10.00 | .909 | 11.01 | .833 | 12.01 | .768 | 13.01 | .587 | 17.02 |
| | 20 | 1.000 | 20.00 | .952 | 21.00 | .909 | 22.01 | .869 | 23.01 | .740 | 27.01 |
| .1 | 1 | .909 | 1.10 | .476 | 2.10 | .323 | 3.10 | .244 | 4.10 | .123 | 8.10 |
| | 2 | .991 | 2.02 | .654 | 3.06 | .491 | 4.07 | .394 | 5.08 | .220 | 9.09 |
| | 5 | 1.000 | 5.00 | .830 | 6.02 | .711 | 7.04 | .621 | 8.05 | .414 | 12.07 |
| | 10 | 1.000 | 10.00 | .908 | 11.01 | .832 | 12.02 | .768 | 13.03 | .587 | 17.05 |
| | 20 | 1.000 | 20.00 | .952 | 21.00 | .909 | 22.01 | .869 | 23.01 | .740 | 27.03 |
| .25 | 1 | .800 | 1.25 | .444 | 2.25 | .308 | 3.25 | .235 | 4.25 | .121 | 8.25 |
| | 2 | .952 | 2.10 | .632 | 3.17 | .477 | 4.19 | .384 | 5.21 | .217 | 9.23 |
| | 5 | .99 | 5.00 | .824 | 6.07 | .703 | 7.11 | .615 | 8.13 | .411 | 12.18 |
| | 10 | 1.000 | 10.00 | .906 | 11.03 | .829 | 12.06 | .765 | 13.08 | .584 | 17.13 |
| | 20 | 1.000 | 20.00 | .952 | 21.02 | .908 | 22.03 | .868 | 23.04 | .738 | 27.08 |
| .50 | 1 | .667 | 1.50 | .400 | 2.50 | .286 | 3.50 | .222 | 4.50 | .118 | 8.50 |
| | 2 | .857 | 2.33 | .588 | 3.40 | .452 | 4.43 | .367 | 5.44 | .211 | 9.47 |
| | 5 | .984 | 5.08 | .804 | 6.22 | .686 | 7.29 | .601 | 8.33 | .403 | 12.40 |
| | 10 | .999 | 10.00 | .900 | 11.11 | .821 | 12.17 | .757 | 13.22 | .578 | 17.32 |
| | 20 | 1.000 | 20.00 | .950 | 21.05 | .905 | 22.09 | .865 | 23.13 | .735 | 27.22 |
| .75 | 1 | .571 | .175 | .364 | 2.75 | .267 | 3.75 | .211 | 4.75 | .114 | 8.75 |
| | 2 | .757 | 2.64 | .543 | 3.68 | .426 | 4.70 | .350 | 5.71 | .206 | 9.73 |
| | 5 | .928 | 5.39 | .767 | 6.52 | .660 | 7.57 | .581 | 8.61 | .395 | 12.67 |
| | 10 | .985 | 10.15 | .882 | 11.34 | .805 | 12.43 | .742 | 13.48 | .569 | 17.59 |
| | 20 | .999 | 20.02 | .945 | 21.17 | .898 | 22.27 | .857 | 23.33 | .728 | 27.47 |
| 1.00 | 1 | .500 | 2.00 | .333 | 3.00 | .250 | 4.00 | .200 | 5.00 | .111 | 9.00 |
| | 2 | .667 | 3.00 | .500 | 4.00 | .400 | 5.00 | .333 | 6.00 | .200 | 10.00 |
| | 5 | .833 | 6.00 | .714 | 7.00 | .625 | 8.00 | .556 | 9.00 | .385 | 13.00 |
| | 10 | .909 | 11.00 | .833 | 12.00 | .769 | 13.00 | .714 | 14.00 | .555 | 18.00 |
| | 20 | .952 | 21.00 | .909 | 22.00 | .870 | 23.00 | .833 | 24.00 | .714 | 28.00 |
| 1.5 | 1 | .400 | 2.50 | .286 | 3.50 | .222 | 4.50 | .182 | 5.50 | .105 | 9.50 |
| | 2 | .526 | 3.80 | .424 | 4.71 | .353 | 5.67 | .301 | 6.64 | .189 | 10.58 |
| | 5 | .635 | 7.88 | .587 | 8.52 | .538 | 9.29 | .493 | 10.14 | .361 | 13.86 |
| | 10 | .663 | 15.09 | .652 | 15.34 | .634 | 15.78 | .611 | 16.36 | .513 | 19.49 |
| | 20 | .667 | 30.00 | .666 | 30.02 | .655 | 30.08 | .662 | 30.20 | .631 | 31.69 |
| 2.0 | 1 | .333 | 3.00 | .250 | 4.00 | .200 | 5.00 | .167 | 6.00 | .100 | 10.00 |
| | 2 | .429 | 4.67 | .364 | 5.50 | .313 | 6.40 | .273 | 7.33 | .179 | 11.20 |
| | 5 | .492 | 10.16 | .475 | 10.53 | .452 | 11.06 | .427 | 11.72 | .334 | 14.99 |
| | 10 | .500 | 20.01 | .499 | 20.05 | .496 | 20.16 | .491 | 20.37 | .451 | 22.16 |
| | 20 | .500 | 40.00 | .500 | 40.00 | .500 | 40.00 | .500 | 40.00 | .498 | 40.13 |
| 2.5 | 1 | .286 | 3.50 | .222 | 4.50 | .182 | 5.50 | .154 | 6.50 | .095 | 10.50 |

## TABLE II.2.23.3a SYSTEM UTILIZATION AND RESPONSE TIME (continued)

| $s/s_C$ | J | Numbers of Input Channels (I) 1 Util. | 1 Resp. | 2 Util. | 2 Resp. | 3 Util. | 3 Resp. | 4 Util. | 4 Resp. | 8 Util. | 8 Resp. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | .359 | 5.57 | .316 | 6.33 | .278 | 7.18 | .248 | 8.08 | .169 | 11.86 |
| | 5 | .398 | 12.58 | .391 | 12.79 | .380 | 13.14 | .367 | 13.62 | .305 | 16.39 |
| | 10 | .400 | 25.00 | .400 | 25.01 | .399 | 25.04 | .398 | 25.10 | .385 | 25.94 |
| | 20 | .400 | 50.00 | .400 | 50.00 | .400 | 50.00 | .400 | 50.00 | .400 | 50.00 |
| 3.0 | 1 | .250 | 4.00 | .200 | 5.00 | .167 | 6.00 | .143 | 7.00 | .091 | 11.00 |
| | 2 | .308 | 6.50 | .278 | 7.20 | .250 | 8.00 | .226 | 8.86 | .159 | 12.55 |
| | 5 | .332 | 15.04 | .330 | 15.17 | .325 | 15.40 | .317 | 15.75 | .277 | 18.02 |
| | 10 | .333 | 30.00 | .333 | 30.00 | .333 | 30.01 | .333 | 30.03 | .329 | 30.40 |
| | 20 | .333 | 60.00 | .333 | 60.00 | .333 | 60.00 | .333 | 60.00 | .333 | 60.00 |
| 4.0 | 1 | .200 | 5.00 | .167 | 6.00 | .143 | 7.00 | .125 | 8.00 | .083 | 12.00 |
| | 2 | .238 | 8.40 | .222 | 9.00 | .206 | 9.71 | .190 | 10.50 | .143 | 14.00 |
| | 5 | .250 | 20.02 | .249 | 20.07 | .248 | 20.18 | .246 | 20.36 | .229 | 21.84 |
| | 10 | .250 | 40.00 | .250 | 40.00 | .250 | 40.00 | .250 | 40.00 | .250 | 40.07 |
| | 20 | .250 | 80.00 | .250 | 80.00 | .250 | 80.00 | .250 | 80.00 | .250 | 80.00 |
| 6.0 | 1 | .143 | 7.00 | .125 | 8.00 | .111 | 9.00 | .100 | 10.00 | .071 | 14.00 |
| | 2 | .163 | 12.29 | .157 | 12.75 | .150 | 13.33 | .143 | 14.00 | .117 | 17.14 |
| | 5 | .167 | 30.00 | .167 | 30.02 | .166 | 30.05 | .166 | 30.11 | .163 | 30.74 |
| | 10 | .167 | 60.00 | .167 | 60.00 | .167 | 60.00 | .167 | 60.00 | .167 | 60.00 |
| | 20 | .167 | 120.00 | .167 | 120.0 | .167 | 120.0 | .167 | 120.0 | .167 | 120.0 |
| 10.0 | 1 | .091 | 11.00 | .083 | 12.00 | .077 | 13.00 | .071 | 14.00 | .056 | 18.00 |
| | 2 | .099 | 20.18 | .098 | 20.50 | .096 | 20.92 | .093 | 21.43 | .083 | 24.00 |
| | 5 | .100 | 50.00 | .100 | 50.00 | .100 | 50.00 | .100 | 50.02 | .100 | 50.17 |
| | 10 | .100 | 100.0 | .100 | 100.0 | .100 | 100.0 | .100 | 100.0 | .100 | 100.0 |
| | 20 | .100 | 200.0 | .100 | 200.0 | .100 | 200.0 | .100 | 200.0 | .100 | 200.0 |

Figure II.2.23.a supplies the formulas used in preparing this table.

## NOTES TO THE TABLES

Continued from page 643

**TABLE II.4.22.7 Programmer Productivity.** The 16 programs from JohnJ77 are all generalized and well-documented commercial application programs written between 1970 and 1977. Statements counted are all source statements, including comments and job control statements. Man-months were found by multiplying the number of people assigned to the projects times their duration in days, and then multiplying the result by 21.67 (5-day weeks, 52/12 weeks per month). Systems analysts as well as programmers were counted. The 910K COBOL program was an Employee Information system which included Payroll, Benefits, and Personnel subsystems.

The 12 programs from DoneW76 are modules having the functions described at the right. Average statements per module were given along with an average programming rate. (Standard deviation was also given for both figures.) Donelson indicated that the programming effort required for a system could be estimated by breaking the system into modules, and summing the time required for the modules. Hence, I infer that system integration time is included. Donelson also indicated that the programming rates he gave were for programmers only, and that in addition an average of 1.1 system analysts were required for every programmer. In deriving this table, I have therefore divided his productivity figures by 2.1.

**TABLE II.4.22.9a Akiyama Project Error Data.** This data is from AkiyF71. It was collected in the course of development of a program written in assembly language–for the FACOM 230-60 computer. The programmers were characterized as "mostly inexperienced." The schedule information, at the bottom of the table, shows the cumulative number of faults (Akiyama calls them "bugs") discovered. The time scale shown was read from a figure given in the paper and does not agree well with other data in the paper. Note that 53 of the 146 faults in module MC were discovered using pre-test, and are not included in the cumulative counting. Module MC was the only one for which such pre-test information is given.

Given a system with (I + 1) service facilities and a fixed number of jobs J. Assume that:

[1] The system is in equilibrium. [2] The number of jobs J does not change. [3] The service time of a job at a facility is given by an exponentially distributed random variable.

$S_i$ = Mean service time at the $i^{th}$ facility, when there are $n_i$ jobs at that facility
$p_{ij}$ = Probability that a job will proceed to the $j^{th}$ facility after completing a service request at the $i^{th}$ facility

Then it can be shown that
$Q_i(n)$ = Proportion of the time the queue at the $i^{th}$ device contains n or more jobs

$$= (X_i)^n \frac{g(J-n,\ I+1)}{g(J,\ I+1)}$$

Where $X_j$, j = 1, 2, 3, ...(I+1) is the solution to

$$\frac{X_j}{S_j} = \sum_{i=1}^{I+1} \frac{X_i}{S_i} p_{ij} \qquad j = 1, 2, 3, \ldots (I+1)$$

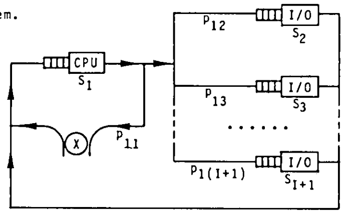
And

$$\begin{aligned} g(n,m) &= g(n,m-1) + X_m g(n-1,m) \\ g(n,0) &= 0 \\ g(0,m) &= 1 \end{aligned} \qquad (1)$$

$Q_i(1)$ = Proportion of the time the queue at the $i^{th}$ device contains at least one job

$$\triangleq U_i = \text{Utilization of device } i = X_i \frac{g(J-1,I+1)}{g(J,\ I+1)} \qquad (2)$$

For example, consider this system.




We assume that, each time a job is completed and exits the system at (X), another new job enters, so that the total number of jobs in the system remains constant at J.

(Note that $p_{21} = p_{31} = \ldots = p_{(I+1)1} = 1$

$p_{jk} = 0$ for j and k greater than one)

The (I+1) equations in X are then

$$\frac{X_1}{S_1} = \frac{X_1}{S_1} p_{11} + \frac{X_2}{S_2} p_{21} + \frac{X_3}{S_3} p_{31} + \ldots + \frac{X_{I+1}}{S_{I+1}} p_{(I+1)1}$$

$$= \frac{X_1}{S_1} p_{11} + \sum_{i=2}^{I+1} \frac{X_i}{S_i} \qquad (3)$$

$$\frac{X_2}{S_2} = \frac{X_1}{S_1} p_{12} + \frac{X_2}{S_2} p_{22} + \frac{X_3}{S_3} p_{32} + \ldots + \frac{X_{I+1}}{S_{I+1}} p_{(I+1)2} = \frac{X_1}{S_1} p_{12}$$

$$\frac{X_i}{S_i} = \frac{X_1}{S_1} p_{1i} \qquad i = 2,3,\ldots(I+1) \qquad (4)$$

Substituting (4) into (3), we find

$$1 = p_{11} + \sum_{i=2}^{I+1} p_{1i}$$

which is a tautology. Thus (4) gives the various $X_i$ in terms of an arbitrary $X_1$. If, for a particular system, we substitute (4) into (2), we find the $X_1$ cancels out and the $U_i$ can be computed.

Knowing utilization for each facility, we can compute system throughput and turnaround time as follows.

Throughput:

Since $S_i$ is the time required for facility i to service a portion of a job, then $(1/S_i)$ is the maximum rate at which that facility can handle portions, and $(U_i/S_i)$ is the actual rate. Furthermore, we see from the figure that job completions occur at a rate $p_{11}$ times the rate the CPU handles job portions. Then

W = Rate at which system completes jobs
= Throughput

$$= p_{11} \frac{U_1}{S_1} \qquad (5)$$

Furthermore, the job segment flows must balance, so

$$\frac{U_i}{S_i} = p_{1i} \frac{U_1}{S_1} \qquad i = 2,3,\ldots(I\ 1) \qquad (6)$$

And

$$\frac{U_1}{S_1} = W + \frac{U_2}{S_2} + \frac{U_3}{S_3} + \ldots + \frac{U_{I+1}}{S_{I+1}} \qquad (7)$$

Now let's define
$V_i$ = Average number of times a job visits facility i before the job is completed

$$= \frac{\text{Job segment rate at facility } i}{\text{Throughput}} = \frac{(U_i/S_i)}{W} \qquad (8)$$

Substituting (8) into (5), (6), and (7) we get

$$p_{11} = 1/V_1 \qquad (9)$$

$$p_{1i} = V_i/V_1 \quad i = 2,3,\ldots(I + 1) \qquad (10)$$

$$V_1 = 1 + V_2 + V_3 + \ldots + V_{I+1} \qquad (11)$$

where (11) may be derived from (9) and (10) knowing that

$$\sum_{i=1}^{I+1} p_i = 1$$

Substituting (9) and (10) into (4) and (5), we get

$$X_i = X_1 \frac{S_i}{S_1} \frac{V_i}{V_1} \qquad (12) \qquad\qquad W = \frac{U_1}{S_1 V_1} \qquad (13)$$

Now let's define

$Y_i$ = Total time a job spends at facility i $= V_i S_i$

then from (12) $\quad X_i = \frac{X_1}{Y_1} Y_i$

and remembering that $X_1$ can be arbitrary, we set $X_1 = Y_1$ and find

$$X_i = Y_i \qquad i = 1, 2, \ldots (I+1) \qquad (14)$$

Note that, from (8) and the definition of $Y_i$, we have

$$W = \frac{U_i}{S_i V_i} = \frac{U_i}{Y_i} \qquad i = 1, 2, 3, \ldots(I+1) \qquad (15)$$

Thus throughput, in jobs per unit time, is the same for all facilities. Generally some facility is the bottleneck, and for it (assuming there is always at least one job in that facility's queue)

$$U_b = 1 \quad \text{and} \quad W = \frac{1}{Y_b} = \frac{1}{V_b S_b} \qquad (16)$$

Substituting (14) into (2) we find

$$U_i = Y_i \frac{g(J-1,I+1)}{g(J,I+1)} \qquad (17) \qquad \text{and} \qquad W = \frac{U_i}{Y_i} = \frac{g(J-1,I+1)}{g(J,I+1)} \qquad (18)$$

The ratio of system throughput to job throughput for some particular facility is of interest. We can take

$$\frac{W}{(1/Y_2)} = WY_2 = Y_2 \frac{g(J-1,I+1)}{g(J,\ I+1)} \qquad (19)$$

Where from (1) and (14)

$$g(n,m) = g(n,\ m-1) + Y_m\ g(n-1,m)$$

$$g(n,0) = 0 \qquad g(0,m) = 1 \qquad (20)$$

Then

$$WY_2 = \frac{g(J-1,I+1)/Y_2^{J-1}}{g(J,\ I+1)/Y_2^{J}} \qquad (21)$$

And we can use (20) to find

$$\frac{g(J,\ I+1)}{Y_2^J} = \frac{g(J,I)}{Y_2^J} + \left(\frac{Y_{I+1}}{Y_2}\right) \frac{g(J-1,\ I+1)}{Y_2^{J-1}}$$

And thus define a new G such that

$$G(J,\ I+1) = \frac{g(J,I+1)}{Y_2^J} \qquad \text{And} \quad \begin{cases} G(n,m) = G(n,m-1) + \frac{Y_m}{Y_2} G(n-1,m) & (22) \\ G(n,0) = 0, \quad G(0,m) = 1 & (23) \end{cases}$$

Thus the ratio of System throughput to maximum throughput of I/O unit number 2 is

$$\frac{W}{(1/Y_2)} = \frac{G(J-1,\ I+1)}{G(J,\ I+1)} \qquad (24)$$

and from (17) and (22),

$$U_i = Y_i \frac{G(J-1,I+1)Y_2^{J-1}}{G(J,I+1)Y_2^{J}} = \frac{Y_i}{Y_2} \frac{G(J-1,I+1)}{G(J,I+1)}, \qquad (25) \qquad U_2 = \frac{G(J-1,\ I+1)}{G(J,\ I+1)} = \frac{W}{(1/Y_2)} \qquad (26)$$

Turnaround Time:

A job must visit facility i $V_i$ times, and must spend an average time $S_i/U_i$ each time it visits. Suppose the average number of jobs waiting at the $i^{th}$ facility is $\overline{n_i}$. Then the average delay a job encounters at the $i^{th}$ facility is

$$\frac{\overline{n_i} V_i S_i}{U_i} = \overline{n_i} \frac{Y_i}{U_i} = \frac{\overline{n_i}}{W}$$

And the total delay from the time a job is fed into the system until the time it leaves is

$$R = \text{Turnaround time} = \sum_{i=1}^{I+1} \frac{\overline{n_i}}{W} = \frac{1}{W} \sum_{i=1}^{I+1} \overline{n_i}$$

But at any time the total number of jobs in the system is J. Therefore

$$R = \frac{J}{W} \qquad (27)$$

Job-Related Parameters

Suppose a job requires I/O of kD characters, and that D characters each require s operations by a CPU of speed C' operations per second. Let's also assume each job visits the CPU I times, processing D/I characters each time. Then

$$Y_1 = S_1 V_1 = \frac{s(D/I)}{C'} \times I = \frac{sD}{C'}$$

The I I/O devices each has a data rate D'/I, and each handles D/I bytes of data. Then

$$S_i = \frac{kD/I}{D'/I} = \frac{kD}{D'} \quad i = 2,3,\ldots I+1$$

With a job visiting each I/O device once, $V_i = 1$ and

$$Y_i = S_i V_i = \frac{kD}{D'} \quad i = 2,3,\ldots I+1$$

Therefore

$$\frac{Y_1}{Y_2} = \frac{sD}{C'} \frac{D'}{kD} = s \frac{D'}{kC'} = s/s_c \qquad \text{where} \quad s_c = \frac{kC'}{D'} \qquad (28)$$

Using (28) and the fact that $Y_m/Y_2 = 1$ for $m > 1$, we can use (23) to compute G, and then use (26) and (27) to compute $W/(1/Y_2) = U_2$ and $R/Y_2$ as a function of $s/s_c$, J, and I. The results are shown in Table II.2.23.3a.

FIGURE II.2.23a THROUGHPUT AND RESPONSE TIME FOR QUEUEING SYSTEMS

## TABLE II.3.11.1a COMPUTER INSTALLATIONS BY SIC CODE PERCENT OF GP SYSTEMS IN USE IN U.S., BY VALUE

| SIC Code | Industry | 1973 | 1974 | 1975 | 1976* | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| 01-17 | Agriculture, Mining, Constr. | 2.0 | 2.0 | 2.0 | 1.0 | 2.0 | 2.1 | 2.1 |
| 20-29 | Non-Durables Mfg. | | | 8.8 | | 8.9 | 8.3 | 8.3 |
| 19,3x | Durables Mfg. | | | 16.3 | | 16.1 | 15.8 | 15.4 |
| | Subtotal Mfg. | 26.4 | 26.0 | 25.1 | 31.0 | 25.0 | 24.1 | 23.7 |
| 40-47 | Transportation | 3.3 | 3.3 | 3.3 | 2.9 | 3.3 | 3.3 | 3.3 |
| 48-49 | Utilities | 5.2 | 5.1 | 5.0 | 3.5 | 5.1 | 5.4 | 5.7 |
| | Subtotal Transp., etc. | 8.5 | 8.4 | 8.3 | | 8.4 | 8.7 | 9.0 |
| 50-51 | Wholesale Trade | 3.9 | 4.4 | 4.3 | | 4.6 | 4.6 | 4.6 |
| 52-59 | Retail Trade | 2.8 | 2.9 | 3.1 | | 3.2 | 3.1 | 3.2 |
| | Subtotal Trade | 6.7 | 7.3 | 7.4 | 13.1 | 7.8 | 7.7 | 7.8 |
| 60 | Banking | | | 7.6 | | 7.4 | 7.7 | 7.9 |
| 63 | Insurance | 6.5 | 6.2 | 6.5 | | 6.7 | 7.0 | 7.2 |
| 6x | Other Financial | | | 3.6 | | 3.7 | 3.7 | 3.7 |
| | Subtotal Financial | 17.8 | 16.8 | 17.7 | 13.4 | 17.8 | 18.4 | 18.8 |
| 73,89 | Service Bureaus | 13.9 | 15.1 | 15.6 | | 16.1 | 16.1 | 16.4 |
| 80 | Medical & Health Services | 1.6 | 1.6 | 1.7 | 2.7 | 1.8 | 1.8 | 1.8 |
| 82 | Education | 6.4 | 6.4 | 6.3 | 5.7 | 6.2 | 5.6 | 5.5 |
| 7x, 8x | Other Services | 1.0 | 1.1 | 1.3 | | 1.3 | 1.3 | 1.3 |
| | Subtotal Services | 22.9 | 24.2 | 24.9 | 26.0 | 25.4 | 24.8 | 25.0 |
| 91 | Federal Government | 10.3 | 9.5 | 8.7 | 3.4 | 7.2 | 7.7 | 7.4 |
| 92-93 | State & Local Gov't. | 5.4 | 5.8 | 5.9 | 5.7 | 6.4 | 6.5 | 6.2 |
| | Subtotal Government | 15.7 | 15.3 | 14.6 | | 13.6 | 14.2 | 13.6 |
| | Installed Base | $27.28B | $30.20B | $33.58B | | $37.36B | $42.95B | $48.66B |

Source: Various IDC Annual Briefing Session reports, 1974-1979, except for 1976 column marked with *. This data is from Scie77, page 1100, and is percent *by number*. All other columns are percent by value.

## TABLE II.3.11.3b PROPRIETORSHIPS, PARTNERSHIPS, AND CORPORATIONS IN THE U.S. 1974-1975

| | Units | No Receipts | Under $5000 | $5k -$10k | $10k -$25k | Under $25k | $25k -$50k | $50k -$.1M | $.1M -$.5M | $.5M -$1M | $1M -$5M |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Partnerships** | | | | | | | | | | | |
| Number | k | 73.1 | 282.0 | 101.6 | 166.1 | 549.7 | 141.0 | 133.7 | 204.6 | 25.5 | 16.5 |
| Receipts | $B | | .430 | .747 | 2.781 | 3.958 | 5.115 | 9.571 | 43.91 | 17.44 | 31.94 |
| **Proprietorships** | | | | | | | | | | | |
| Number | k | | 4800 | 1456 | 1831 | 8087 | 1192 | 852.4 | 696.2 | 39.2 | 14.5 |
| Receipts | $B | | 8.258 | 10.65 | 29.61 | 48.52 | 42.56 | 59.83 | 131.6 | 26.35 | 24.68 |
| **Corporations** | | | | | | | | | | | |
| Number | k | | 240e | 85e | 140e | 466.7 | 181.8 | 257.7 | 639.3 | 178.8 | 192.9 |
| Receipts | $B | | .5e | .9e | 3.3e | 4.713 | 6.922 | 19.43 | 155.1 | 127.5 | 406.0 |
| **Total** | | | | | | | | | | | |
| Number | k | 73.1 | 5322 | 1643 | 2137 | 9103 | 1515 | 1244 | 1540 | 243.5 | 223.9 |
| Receipts | $B | | 9.188 | 12.297 | 35.69 | 57.19 | 54.60 | 88.83 | 330.6 | 171.3 | 462.6 |

| | Units | $5M -$10M | Over $10M | $10M -$50M | $50M -$.1B | $.1B -$.5B | $.5B -$1B | Over $1B | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Partnerships** | | | | | | | | | |
| Number | k | 1.30 | .76 | | | | | | 1073 |
| Receipts | $B | 8.868 | 25.21 | | | | | | 146 |
| **Proprietorships** | | | | | | | | | |
| Number | k | .48 | .17 | | | | | | 10882 |
| Receipts | $B | 3.207 | 2.768 | | | | | | 340 |
| **Corporations** | | | | | | | | | |
| Number | k | 26.0 | 21.79 | 17.4 | 2.0 | 1.8 | .26 | .33 | 1965 |
| Receipts | $B | 187.9 | 2182 | 342.6 | 144.7 | 385.2 | 193.3 | 1116 | 3090 |
| **Total** | | | | | | | | | |
| Number | k | 27.78 | 22.72 | 17.4 | 2.0 | 1.8 | .26 | .33 | 13920 |
| Receipts | $B | 200.0 | 2210 | 342.6 | 144.7 | 385.2 | 193.3 | 1116 | 3576 |

Sources: See Notes on page 596.
The Proprietorship-Partnership data in this table is for the year 1975, the Corporation data for 1974. e = estimated.

## TABLE II.3.11.3c POTENTIAL CUSTOMERS FOR DP EQUIPMENT AND SERVICES

| Line | Item | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Reporting Units, U.S. | | | | | | | | | | | | | | | | | | | |
| 1a. | Total Establishments | M | | | | | | | | | | | | | | | 4.103 | 4.110 | 4.114 | 4.143 |
| 1b. | Total Reporting Units | M | 3.303 | | | 3.348 | | 3.458 | 3.521 | 3.542 | 3.510 | 3.503 | 3.534 | 3.521 | 3.511 | 3.541 | 3.653 | | | |
| 2. | Having 1-3 Employees | M | 1.916 | | | 1.936 | | 1.957 | 1.971 | 1.936 | 1.884 | 1.815 | 1.798 | 1.762 | 1.747 | 1.699 | 1.722 | 2.411 | 2.428 | 2.413 |
| 3. | Having 4-7 Employees | M | .623 | | | .628 | | .657 | .672 | .686 | .685 | .709 | .720 | .723 | .731 | .764 | .801 | .739 | .749 | .767 |
| 4. | Having 8-19 Employees | M | .461 | | | .463 | | .503 | .521 | .541 | .548 | .569 | .586 | .593 | .596 | .619 | .645 | .462 | .460 | .469 |
| 5. | Having 20-49 Employees | M | .187 | | | .199 | | .211 | .220 | .233 | .241 | .252 | .265 | .273 | .271 | .287 | .298 | .309 | .299 | .308 |
| 6. | Having 50-99 Employees | k | 61.42 | | | 64.78 | | 68.99 | 73.73 | 77.45 | 81.01 | 84.44 | 86.87 | 90.10 | 88.39 | 92.21 | 98.69 | 102.9 | 98.28 | 103.28 |
| 7. | Having 100-249 Employees | k | 35.22 | | | 36.85 | | 39.19 | 41.31 | 44.15 | 46.04 | 48.10 | 49.53 | 51.57 | 50.40 | 53.06 | 57.08 | 55.86 | 52.43 | 54.96 |
| 8. | Having 250-499 Employees | k | 11.15 | | | 11.82 | | 12.46 | 12.97 | 14.07 | 14.96 | 15.34 | 16.05 | 16.60 | 16.15 | 16.78 | 18.20 | 17.49 | 16.26 | 16.94 |
| 9. | Having Over 500 Employees | k | 7.99 | | | 8.526 | | 8.803 | 9.247 | 10.103 | 10.70 | 10.94 | 11.50 | 11.63 | 11.15 | 11.51 | 12.17 | 12.00 | 11.73 | 11.97 |
| 10. | 500-999 Employees | k | | | | 5.330 | | 5.589 | | 6.308 | 6.626 | 6.81 | 7.15 | | 6.997 | | 7.682 | 7.607 | 7.06 | 7.30 |
| 11. | 1000-1500 Employees | k | | | | 1.419 | | 1.467 | | 1.729 | 1.861 | 1.89 | 2.04 | | 1.959 | | 2.125 | 2.071 | | |
| 12. | 1500-2500 Employees | k | | | | .954 | | .910 | | 1.067 | 1.136 | 1.158 | 1.216 | | 1.169 | | 1.285 | 1.308 | 4.67 | 4.67 |
| 13. | 2500-5000 Employees | k | | | | .580 | | .594 | | .688 | .754 | .745 | .756 | | .716 | | .701 | .712 | | |
| 14. | Over 5000 Employees | k | | | | .243 | | .243 | | .311 | .327 | .335 | .342 | | .310 | | .316 | .302 | | |
| | Number of Proprietorships, Partnerships & Corporations, U.S. | | | | | | | | | | | | | | | | | | | |
| 15. | Total | M | 11.165 | 11.172 | 11.371 | 11.383 | 11.383 | 11.489 | 11.416 | 11.479 | 11.566 | 11.672 | 12.010 | 12.001 | 12.437 | 12.978 | 13.592 | 13.902 | 13.979 | |
| | Having Receipts | | | | | | | | | | | | | | | | | | | |
| 16. | Less Than $10k | M | | | | | | | | | 6.136 | | | | | | | | | |
| 17. | $10k to $25k | M | | | | | | | 8.190 | | 1.989 | | | 8.200 | | | | 9.141 | | |
| 18. | $25k to $50k | M | | | | | | | 1.209 | | 1.232 | | | 1.302 | | | | 1.506 | | |
| 19. | $50k to $100k | M | | | | | | | .845 | | .921 | | | 1.000 | | | | 1.228 | | |
| 20. | $100k to 200k | M | | | | | | | .535 | | | | | .661 | | | | | | |
| 21. | $200k to 500k | M | | | | | | | .359 | | .985 | | | .474 | | | | 1.512 | | |
| 22. | $500k to $1M | M | | | | | | | .138 | | | | | .181 | | | | .241 | | |
| 23. | Over $1M | M | | | | | | | .139 | | .303 | | | .182 | | | | .273 | | |
| | Number Operating in Indicated Industry | | | | | | | | | | | | | | | | | | | |
| 24. | Agric., Forest, Fish. | M | 3.646 | | | | | | 3.381 | | 3.353 | | | 3.363 | | | | 3.561 | 3.546 | |
| 25. | Mining | M | .065 | | | | | | .064 | | .073 | | | .079 | | | | .087 | .086 | |
| 26. | Construction | M | .726 | | | | | | .876 | | .856 | | | 1.020 | | | | 1.145 | 1.144 | |
| 27. | Manufacturing | M | .382 | | | | | | .409 | | .402 | | | .436 | | | | .456 | .468 | |
| 28. | Trans., Common, Util. | M | .345 | | | | | | .375 | | .359 | | | .431 | | | | .454 | .453 | |
| 29. | Trade | M | 2.509 | | | | | | 2.529 | | 2.528 | | | 2.937 | | | | 2.998 | 3.001 | |
| 30. | Finance | M | .899 | | | | | | 1.176 | | 1.223 | | | 1.467 | | | | 1.594 | 1.590 | |
| 31. | Services | M | 2.086 | | | | | | 2.565 | | 2.714 | | | 3.181 | | | | 3.524 | 3.669 | |

## TABLE II.3.11.6a COMPUTER USAGE DATA FOR SOME SPECIFIC ORGANIZATIONS

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | **Federal Government** | | | | | | | |
| 1. | Total Computers | 3.11.20 | k | 7.149 | 7.830 | 8.649 | 9.648 | 11.124 |
| 2. | Genl. Management | | k | | 3.487 | 3.622 | 3.829 | 4.408 |
| 2a. | Percent of Total | 3.11.20 | % | | 44.5 | 41.9 | 39.7 | 39.6 |
| 3. | Special | | k | | 4.343 | 5.027 | 5.819 | 6.716 |
| 4. | Computers Owned–Number | | k | | 6.614 | 7.500 | 8.639 | 10.068 |
| 5. | Percent of Total | 3.11.21 | % | | 84.5 | 86.7 | 89.5 | 90.5 |
| 6. | Genl. Management | | k | | 2.481 | 2.670 | 2.995 | 3.568 |
| 7. | Percent of All G.M. | 3.11.21 | % | | 71.1 | 73.7 | 78.2 | 80.9 |
| 8. | Special | | k | | 4.133 | 4.830 | 5.644 | 6.500 |

## TABLE II.3.11.6a COMPUTER USAGE DATA FOR SOME SPECIFIC ORGANIZATIONS (continued)

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| 9. | Pct. of All Special | 3.11.21 | % | | 95.2 | 96.1 | 97.0 | 96.8 |
| 10. | Number Manufactured by—BGH | | | 295 | 339 | 315 | 304 | 287 |
| 11. | CDC | | | 499 | 530 | 541 | 519 | 515 |
| 12. | DEC | | | 1156 | 1393 | 1699 | 2095 | 2593 |
| 12a. | Data General | | | | | 372 | 526 | 724 |
| 13. | HIS | | | 589 | 681 | 706 | 752 | 886 |
| 13a. | Hewlett-Packard | | | | | 361 | 499 | 641 |
| 14. | IBM | | | 1422 | 1363 | 1320 | 1202 | 1225 |
| 15. | NCR | | | | | | | |
| 16. | RCA | | | | | | | |
| 17. | Uni | | | 1422 | 1400 | 1368 | 1345 | 1617 |
| 18. | XDS | | | 339 | 354 | 360 | 351 | 320 |
| 19. | Other | | | 1427 | 1770 | 1607 | 2055 | 2316 |
| 20. | Percent of Tot.—BGH | 3.11.22 | % | 4.1 | 4.3 | 3.6 | 3.2 | 2.6 |
| 21. | CDC | 3.11.22 | % | 7.0 | 6.8 | 6.3 | 5.4 | 4.6 |
| 22. | DEC | 3.11.22 | % | 16.2 | 17.8 | 19.6 | 21.7 | 23.3 |
| 22a. | Data General | | % | | | 4.3 | 5.5 | 6.5 |
| 23. | HIS | | % | 8.2 | 8.7 | 8.2 | 7.8 | 8.0 |
| 23a. | Hewlett-Packard | | % | | | 4.2 | 5.2 | 5.8 |

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| 24. | IBM | 3.11.22 | % | 19.9 | 17.4 | 15.3 | 12.5 | 11.0 |
| 25. | NCR | | % | | | | | |
| 26. | RCA | | % | | | | | |
| 27. | Uni | 3.11.22 | % | 19.9 | 17.9 | 15.8 | 13.9 | 14.5 |
| 28. | XDS | | % | 4.7 | 4.5 | 4.2 | 3.6 | 2.9 |
| 29. | Other | | % | 20.0 | 22.6 | 18.6 | 21.3 | 20.8 |
| 30. | Value in Use—All Systems | | $B | | 3.80 | 4.04 | 4.12 | |
| 31. | Genl. Management | | $B | | 2.70 | 2.89 | 2.95 | |
| 32. | Special | | $B | | 1.10 | 1.15 | 1.17 | |
| 33. | Average Value—All Systems | | $k | | 485 | 467 | 427 | |
| | Ann. Costs—Genl. Mgnt. Comp. | | | | | | | |
| 34. | Capital Costs—Eq. Purch. | | $M | | 186 | 246 | 279 | 377 |
| 35. | Site Preparation | | $M | | 30 | 22 | 18 | 24 |
| 36. | Oper. Costs—Eq. Rent | 3.11.23 | $M | | 428 | 466 | 403 | 425 |
| 37. | Salaries | 3.11.23 | $M | | 1372 | 1504 | 1666 | 1747 |
| 38. | Contractual Services | | $M | | 415 | 482 | 506 | 629 |
| 39. | Supplies | | $M | | 98 | 123 | 114 | 128 |
| 40. | Other | | $M | | 133 | 257 | 202 | 218 |
| 41. | Grand Total | 3.11.23 | $M | 2651 | 2662 | 3100 | 3188 | 3548 |

## TABLE II.3.25.5a CHRONOLOGY OF SYSTEM OPERATING COSTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Overhead Rates** | | | | | | | | | | | | | | | | | | | | | | |
| 2. | Basic Programmer/SA | 3.25.1 | % | 50 | 50 | 51 | 51 | 51 | 52 | 52 | 52 | 53 | 53 | 53 | 54 | 54 | 54 | 55 | 57 | 57 | 58 | 58 | 59 |
| 5. | Complete—Office Worker | 3.25.1 | % | 85 | 85 | 86 | 86 | 86 | 87 | 87 | 87 | 88 | 88 | 88 | 89 | 89 | 89 | 90 | 92 | 92 | 93 | 93 | 94 |
| | **Computer Facilities** | | | | | | | | | | | | | | | | | | | | | | |
| 6. | Av. U.S. GP System Value | | $k | 430.8 | 423.9 | 423.6 | 430.2 | 388.9 | 359.3 | 361.1 | 346.9 | 400.0 | 424.3 | 477.5 | 510.7 | 517.8 | 492.0 | 468.3 | 491.0 | 544.3 | 635.9 | 737.1 | 839.7 |
| 12. | Operating Time/Mo. | | hr | 300 | 300 | 305 | 310 | 315 | 320 | 325 | 330 | 335 | 340 | 345 | 350 | 355 | 360 | 365 | 370 | 373 | 376 | 378 | 380 |
| 19. | Tot. Facilities Costs | 3.25.9 | $k/mo | .37 | .34 | .28 | .24 | .23 | .22 | .22 | .21 | .23 | .24 | .27 | .29 | .30 | .30 | .30 | .34 | .40 | .49 | .60 | .71 |
| | **Cost Summary** | | | | | | | | | | | | | | | | | | | | | | |
| | U.S. GP Users | | | | | | | | | | | | | | | | | | | | | | |
| 21. | In Use—Processors | | $B | .549 | .630 | .884 | 1.307 | 1.367 | 1.321 | 1.661 | 1.511 | 2.651 | 3.533 | 4.997 | 5.364 | 5.304 | 4.317 | 4.034 | 4.798 | 6.477 | 7.952 | 10.172 | 11.621 |
| 22. | Internal Memory | | $B | .259 | .400 | .548 | .626 | 1.018 | 1.450 | 1.749 | 2.074 | 2.748 | 3.657 | 4.130 | 4.719 | 5.137 | 5.741 | 5.832 | 5.805 | 5.960 | 6.623 | 6.666 | 7.185 |
| 23. | Peripherals & Controllers | | $B | .532 | .835 | 1.163 | 1.482 | 2.060 | 3.079 | 4.140 | 5.435 | 6.376 | 7.572 | 8.663 | 9.607 | 10.739 | 12.052 | 13.914 | 15.007 | 15.370 | 15.839 | 16.471 | 17.741 |
| 24. | CPU System | | $B | 1.340 | 1.865 | 2.595 | 3.415 | 4.445 | 5.850 | 7.550 | 9.020 | 11.775 | 14.762 | 17.790 | 19.690 | 21.180 | 22.110 | 23.780 | 25.610 | 27.807 | 30.414 | 33.309 | 36.547 |
| 25. | Keyboard DE | | $B | .067 | .095 | .136 | .179 | .258 | .374 | .483 | .637 | .811 | .975 | 1.193 | 1.445 | 1.775 | 2.045 | 2.365 | 2.489 | 2.461 | 2.515 | 2.515 | 2.454 |
| 26. | OCR & MICR | | $B | | | .010 | .030 | .050 | .070 | .110 | .150 | .215 | .308 | .410 | .490 | .570 | .650 | .720 | .825 | .868 | .895 | 1.050 | 1.325 |
| 27. | Data Entry Tot. | | $B | .067 | .095 | .146 | .209 | .308 | .444 | .593 | .787 | 1.026 | 1.283 | 1.603 | 1.935 | 2.345 | 2.695 | 3.085 | 3.314 | 3.329 | 3.410 | 3.565 | 3.779 |
| 28. | Terminals | | $B | | | | .040 | .055 | .080 | .140 | .230 | .410 | .630 | .900 | 1.220 | 1.400 | 1.760 | 2.500 | 3.335 | 4.600 | 5.750 | 7.600 | 9.150 |
| 29. | Annual Rev.—Data Sets | | $B | | .001 | .001 | .003 | .004 | .006 | .011 | .016 | .026 | .040 | .061 | .089 | .115 | .139 | .156 | .163 | .164 | .156 | .144 | .125 |
| 30. | Data Transmission | | $B | | | .004 | .009 | .014 | .023 | .035 | .053 | .085 | .135 | .200 | .280 | .369 | .414 | .431 | .429 | .413 | .391 | .397 | .374 |
| 31. | Software—Standard | | $B | | | | | | | | | .010 | .025 | .050 | .060 | .075 | .110 | .220 | .410 | .635 | .875 | 1.155 | 1.480 |
| 32. | Supplies | | $B | .067 | .109 | .163 | .213 | .300 | .373 | .457 | .530 | .637 | .705 | .817 | .863 | .875 | .956 | 1.135 | 1.403 | 1.446 | 1.455 | 1.574 | 1.684 |
| 33. | Services—Batch DP | | $B | .090 | .125 | .180 | .220 | .260 | .285 | .340 | .410 | .480 | .600 | .740 | .945 | 1.075 | 1.235 | 1.405 | 1.580 | 1.740 | 1.860 | 1.935 | 2.100 |
| 34. | Other | | $B | | | | | | .002 | .005 | .010 | .030 | .050 | .080 | .110 | .145 | .190 | .255 | .335 | .415 | .495 | .575 | .660 |
| 35. | Annual Salaries—SA | | $M | 48.0 | 71.8 | 107.2 | 151.5 | 214.0 | 299.5 | 410.6 | 581.3 | 830.8 | 1114 | 1475 | 1794 | 1968 | 2180 | 2434 | 2508 | 2863 | 3432 | 4179 | 5000 |
| 36. | Programmers | | $M | 51.3 | 76.3 | 110.5 | 159.6 | 217.3 | 298.8 | 422.4 | 609.2 | 846.5 | 1150 | 1537 | 1860 | 2096 | 2345 | 2520 | 2752 | 3188 | 3832 | 4548 | 5417 |
| 37. | SA & P | | $M | 99.3 | 148.1 | 217.7 | 311.1 | 431.3 | 598.3 | 833.0 | 1190.5 | 1677.3 | 2264 | 3012 | 3654 | 4064 | 4525 | 4954 | 5260 | 6051 | 7264 | 8727 | 10417 |

## TABLE II.3.25.5a CHRONOLOGY OF SYSTEM OPERATING COSTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38. | Comp. Operators | | $M | 27.3 | 41.8 | 62.9 | 89.7 | 122.7 | 170.3 | 236.7 | 331.1 | 457.6 | 612.3 | 813.8 | 1036 | 1251 | 1459 | 1690 | 1861 | 2170 | 2574 | 3049 | 3631 |
| 39. | Keypunch Op. | | $M | 71.6 | 106.4 | 155.6 | 216.0 | 308.3 | 456.8 | 642.4 | 867.8 | 1165 | 1443 | 1742 | 2108 | 2467 | 3023 | 3658 | 4157 | 4574 | 4976 | 5310 | 5577 |
| 40. | Total Salaries | | $M | 198.2 | 296.3 | 436.2 | 616.8 | 862.3 | 1225.4 | 1712.1 | 2389.4 | 3300 | 4319 | 5568 | 6798 | 7782 | 9007 | 10302 | 11278 | 12795 | 14814 | 17086 | 19625 |
| | Monthly Sal. incl. OH | | | | | | | | | | | | | | | | | | | | | | |
| 41. | SA & P | | $M/mo | 15.3 | 22.8 | 33.7 | 48.2 | 66.9 | 93.2 | 129.8 | 185.5 | 262.8 | 354.7 | 471.9 | 575.5 | 640.1 | 712.7 | 784.4 | 841.6 | 968.2 | 1168.3 | 1403.6 | 1684.1 |
| 42. | Comp. Operators | | $M/mo | 4.2 | 6.4 | 9.7 | 13.9 | 19.0 | 26.5 | 36.9 | 51.6 | 71.7 | 95.9 | 127.5 | 163.2 | 197.0 | 229.8 | 267.6 | 297.8 | 347.2 | 414.0 | 490.4 | 587.0 |
| 43. | Keypunch Operators | | $M/mo | 11.0 | 16.4 | 24.1 | 33.5 | 47.8 | 71.2 | 100.1 | 135.2 | 182.5 | 226.1 | 272.9 | 332.0 | 388.6 | 476.1 | 579.2 | 665.1 | 731.8 | 800.3 | 854.0 | 901.6 |
| 44. | Total | | $M/mo | 30.5 | 45.6 | 67.5 | 95.6 | 133.7 | 190.9 | 266.8 | 372.3 | 517.0 | 676.7 | 872.3 | 1070.7 | 1225.7 | 1418.6 | 1631.2 | 1804.5 | 2047.2 | 2382.6 | 2748.0 | 3172.7 |
| | Monthly Hardware Cost | | | | | | | | | | | | | | | | | | | | | | |
| 45. | Processors | | $M/mo | 12.5 | 14.3 | 20.1 | 29.7 | 31.1 | 30.0 | 37.8 | 34.3 | 60.3 | 80.3 | 113.6 | 121.9 | 120.5 | 98.1 | 91.7 | 109.0 | 147.2 | 180.7 | 231.2 | 264.1 |
| 46. | Internal Memory | | $M/mo | 5.9 | 9.1 | 12.5 | 14.2 | 23.1 | 33.0 | 39.8 | 47.1 | 62.5 | 83.1 | 93.9 | 107.3 | 116.8 | 130.5 | 132.5 | 131.9 | 135.5 | 150.5 | 151.5 | 163.3 |
| 47. | Peripherals & Controllers | | $M/mo | 12.1 | 19.0 | 26.4 | 33.7 | 46.8 | 70.0 | 94.1 | 123.5 | 144.9 | 172.1 | 196.9 | 218.3 | 244.1 | 273.9 | 316.2 | 341.1 | 349.3 | 360.0 | 374.3 | 403.2 |
| 48. | CPU Systems | | $M/mo | 30.5 | 42.4 | 59.0 | 77.6 | 101.0 | 133.0 | 171.6 | 205.0 | 267.6 | 335.5 | 404.3 | 447.5 | 481.4 | 502.5 | 540.5 | 582.0 | 632.0 | 691.2 | 757.0 | 830.6 |
| 49. | Keyboard Data Entry | | $M/mo | 1.2 | 1.7 | 2.4 | 3.2 | 4.6 | 6.6 | 8.5 | 11.2 | 14.4 | 17.4 | 21.5 | 26.2 | 32.4 | 37.5 | 43.7 | 46.7 | 46.9 | 48.6 | 49.1 | 48.4 |
| 50. | OCR & MICR | | $M/mo | | | 0.2 | 0.7 | 1.1 | 1.6 | 2.5 | 3.4 | 4.9 | 7.0 | 9.3 | 11.1 | 13.0 | 14.8 | 16.4 | 18.8 | 19.7 | 20.3 | 23.9 | 30.1 |
| 51. | Total Data Entry | | $M/mo | 1.2 | 1.7 | 2.6 | 3.9 | 5.7 | 8.2 | 11.0 | 14.6 | 19.3 | 24.4 | 30.8 | 37.3 | 45.4 | 52.3 | 60.1 | 65.5 | 66.6 | 68.9 | 73.0 | 78.5 |
| 52. | Terminals | | $M/mo | | | | 0.9 | 1.3 | 1.8 | 3.2 | 5.2 | 9.3 | 14.3 | 20.5 | 27.7 | 31.8 | 40.0 | 56.8 | 75.8 | 104.5 | 130.7 | 172.7 | 208.0 |
| | Monthly Expenses | | | | | | | | | | | | | | | | | | | | | | |
| 53. | Data Sets | | $M/mo | | 0.1 | 0.1 | 0.3 | 0.3 | 0.5 | 0.9 | 1.3 | 2.2 | 3.3 | 5.1 | 7.4 | 9.6 | 11.6 | 13.0 | 13.6 | 13.6 | 13.0 | 12.0 | 10.4 |
| 54. | Data Transmission | | $M/mo | | | 0.3 | 0.8 | 1.2 | 1.9 | 2.9 | 4.4 | 7.1 | 11.3 | 16.7 | 23.3 | 30.8 | 34.5 | 35.9 | 35.8 | 34.4 | 32.6 | 33.1 | 31.2 |
| 55. | Software–Standard | | $M/mo | | | | | | | | | 0.8 | 2.1 | 4.2 | 5.0 | 6.3 | 9.2 | 18.3 | 34.2 | 52.9 | 72.9 | 96.3 | 123.3 |
| 56. | Supplies | | $M/mo | 5.6 | 9.1 | 13.6 | 17.8 | 25.0 | 31.1 | 38.1 | 44.2 | 53.1 | 58.8 | 68.1 | 71.9 | 72.9 | 79.7 | 94.6 | 116.9 | 120.5 | 121.3 | 131.2 | 140.3 |
| 57. | Services–Batch DP | | $M/mo | 0.8 | 1.0 | 1.5 | 1.8 | 2.2 | 2.4 | 2.8 | 3.5 | 4.0 | 5.0 | 6.2 | 7.9 | 9.0 | 10.3 | 11.7 | 13.2 | 14.5 | 15.5 | 16.1 | 17.5 |
| 58. | Other | | $M/mo | | | | | | 0.2 | 0.4 | 0.8 | 2.5 | 4.2 | 6.7 | 9.2 | 12.1 | 15.8 | 21.3 | 27.9 | 34.6 | 41.3 | 47.9 | 55.0 |
| 59. | Total | | $M/mo | 0.8 | 1.0 | 1.5 | 1.8 | 2.2 | 2.6 | 3.2 | 4.3 | 6.5 | 9.2 | 12.9 | 17.1 | 21.1 | 26.1 | 33.0 | 41.1 | 49.1 | 56.8 | 64.0 | 72.5 |
| 59a. | Facilities | | $M/mo | 1.2 | 1.5 | 1.7 | 1.9 | 2.7 | 3.7 | 4.8 | 5.7 | 7.1 | 8.9 | 10.8 | 12.2 | 13.5 | 15.1 | 17.5 | 20.9 | 24.8 | 29.2 | 34.9 | 41.2 |
| | **Summary** | | | | | | | | | | | | | | | | | | | | | | |
| 60. | Total User Costs | | $M/mo | 69.8 | 101.4 | 146.3 | 200.6 | 273.1 | 373.7 | 502.5 | 657.0 | 890.0 | 1144.5 | 1445.7 | 1720.1 | 1938.5 | 2189.6 | 2500.9 | 2790.3 | 3145.6 | 3599.2 | 4122.2 | 4708.7 |
| 61. | Number of GP Systems | | k | 3.110 | 4.400 | 6.150 | 8.100 | 11.700 | 16.700 | 21.600 | 27.100 | 31.000 | 37.000 | 40.000 | 41.900 | 45.000 | 50.200 | 58.300 | 61.500 | 62.100 | 59.600 | 58.200 | 58.000 |
| 62. | Cost per System | | $k/mo | 22.44 | 23.05 | 23.79 | 24.77 | 23.34 | 22.38 | 23.26 | 24.24 | 28.71 | 30.93 | 36.14 | 41.05 | 43.07 | 43.62 | 42.90 | 45.37 | 50.65 | 60.39 | 70.83 | 81.18 |
| | Cost Breakdown I | | | | | | | | | | | | | | | | | | | | | | |
| 63. | Hardware–CPU Syst. | | % | 43.7 | 41.8 | 40.3 | 38.7 | 37.0 | 35.6 | 34.1 | 31.2 | 30.1 | 29.3 | 28.0 | 26.0 | 24.8 | 23.0 | 21.6 | 20.9 | 20.1 | 19.2 | 18.4 | 17.6 |
| 64. | Data Entry | | % | 1.7 | 1.7 | 1.8 | 1.9 | 2.1 | 2.2 | 2.2 | 2.2 | 2.2 | 2.1 | 2.1 | 2.2 | 2.3 | 2.4 | 2.4 | 2.3 | 2.1 | 1.9 | 1.8 | 1.7 |
| 65. | Terminals & Data Sets | | % | | 0.1 | 0.1 | 0.6 | 0.6 | 0.6 | 0.8 | 1.0 | 1.3 | 1.5 | 1.8 | 2.0 | 2.1 | 2.4 | 2.8 | 3.2 | 3.8 | 4.0 | 4.5 | 4.6 |
| 66. | Total Hardware | 3.25.11 | % | 45.4 | 43.6 | 42.2 | 41.2 | 39.7 | 38.4 | 37.1 | 34.4 | 33.6 | 32.9 | 31.9 | 30.2 | 29.2 | 27.8 | 26.8 | 26.4 | 26.0 | 25.1 | 24.7 | 23.9 |
| 67. | Data Transmission | | % | | | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.6 | 1.4 | 1.3 | 1.1 | 0.9 | 0.8 | 0.7 |
| 68. | Software | | % | | | | | | | | | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.7 | 1.2 | 1.7 | 2.0 | 2.3 | 2.6 |
| 69. | Supplies | 3.25.11 | % | 8.0 | 8.9 | 9.3 | 8.9 | 9.2 | 8.3 | 7.6 | 6.7 | 6.0 | 5.1 | 4.7 | 4.2 | 3.8 | 3.6 | 3.8 | 4.2 | 3.8 | 3.4 | 3.2 | 3.0 |
| 70. | Services | | % | 1.1 | 1.0 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.7 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.5 | 1.6 | 1.6 | 1.6 | 1.5 |
| 71. | Personnel–Total | 3.25.11 | % | 43.7 | 45.0 | 46.1 | 47.7 | 49.0 | 51.1 | 53.1 | 56.7 | 58.1 | 59.1 | 60.3 | 62.2 | 63.2 | 64.8 | 65.2 | 64.7 | 65.1 | 66.2 | 66.7 | 67.4 |
| 72. | Salaries | | % | 23.6 | 24.3 | 24.8 | 25.6 | 26.3 | 27.3 | 28.4 | 30.3 | 30.9 | 31.5 | 32.1 | 32.9 | 33.4 | 34.3 | 34.3 | 33.7 | 33.9 | 34.3 | 34.5 | 34.7' |
| 73. | Overhead | | % | 20.1 | 20.7 | 21.3 | 22.1 | 22.7 | 23.8 | 24.7 | 26.4 | 27.2 | 27.6 | 28.2 | 29.3 | 29.8 | 30.5 | 30.9 | 31.0 | 31.2 | 31.9 | 32.2 | 32.7 |
| 74. | Personnel–SA & P | | % | 21.9 | 22.5 | 23.0 | 24.0 | 24.5 | 24.9 | 25.8 | 28.2 | 29.5 | 31.0 | 32.6 | 33.5 | 33.0 | 32.6 | 31.4 | 30.2 | 30.8 | 32.5 | 34.0 | 35.8 |
| 75. | Computer Oper. | | % | 6.0 | 6.3 | 6.6 | 6.9 | 7.0 | 7.1 | 7.3 | 7.9 | 8.1 | 8.4 | 8.8 | 9.5 | 10.2 | 10.5 | 10.7 | 10.7 | 11.0 | 11.5 | 11.9 | 12.5 |
| 76. | Keyboard Op. | | % | 15.8 | 16.2 | 16.5 | 16.7 | 17.5 | 19.1 | 19.9 | 20.6 | 20.5 | 19.8 | 18.9 | 19.3 | 20.1 | 21.7 | 23.2 | 23.8 | 23.3 | 22.2 | 20.7 | 19.1 |
| 77. | Facilities | | % | 1.7 | 1.5 | 1.2 | 0.9 | 1.0 | 1.0 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.9 |
| | Cost Breakdown II | | | | | | | | | | | | | | | | | | | | | | |
| 78. | Operations–CPU Syst. | | % | 43.7 | 41.8 | 40.3 | 38.7 | 37.0 | 35.6 | 34.1 | 31.2 | 30.1 | 29.3 | 28.0 | 26.0 | 24.8 | 23.0 | 21.6 | 20.9 | 20.1 | 19.2 | 18.4 | 17.6 |
| 79. | Supplies | | % | 8.0 | 8.9 | 9.3 | 8.9 | 9.2 | 8.3 | 7.6 | 6.7 | 6.0 | 5.1 | 4.7 | 4.2 | 3.8 | 3.6 | 3.8 | 4.2 | 3.8 | 3.4 | 3.2 | 3.0 |
| 80. | Comp. Operators | | % | 6.0 | 6.3 | 6.6 | 6.9 | 7.0 | 7.1 | 7.3 | 7.9 | 8.1 | 8.4 | 8.8 | 9.5 | 10.2 | 10.5 | 10.7 | 10.7 | 11.0 | 11.5 | 11.9 | 12.5 |
| 81. | Facilities | | % | 1.7 | 1.5 | 1.2 | 0.9 | 1.0 | 1.0 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.9 |

## TABLE II.3.25.5a CHRONOLOGY OF SYSTEM OPERATING COSTS

| Line | Item | Figure | Units | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82. | Total | 3.25.13 | % | 59.4 | 58.5 | 57.4 | 55.4 | 54.2 | 52.0 | 50.0 | 46.7 | 45.0 | 43.6 | 42.2 | 40.4 | 39.5 | 37.8 | 36.8 | 36.5 | 35.7 | 34.9 | 34.3 | 34.0 |
| 83. | Data Entry–Equipment | | % | 1.7 | 1.7 | 1.8 | 1.9 | 2.1 | 2.2 | 2.2 | 2.2 | 2.2 | 2.1 | 2.1 | 2.2 | 2.3 | 2.4 | 2.4 | 2.3 | 2.1 | 1.9 | 1.8 | 1.7 |
| 84. | Operators | | % | 15.8 | 16.2 | 16.5 | 16.7 | 17.5 | 19.1 | 19.9 | 20.6 | 20.5 | 19.8 | 18.9 | 19.3 | 20.1 | 21.7 | 23.2 | 23.8 | 23.3 | 22.2 | 20.7 | 19.1 |
| 85. | Total | 3.25.13 | % | 17.5 | 17.9 | 18.3 | 18.6 | 19.6 | 21.3 | 22.1 | 22.8 | 22.7 | 21.9 | 21.0 | 21.5 | 22.4 | 24.1 | 25.6 | 26.1 | 25.4 | 24.1 | 22.5 | 20.8 |
| 86. | Communications–Lines | | % | | | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.6 | 1.4 | 1.3 | 1.1 | 0.9 | 0.8 | 0.7 |
| 87. | Data Sets & Terminals | | % | | 0.1 | 0.1 | 0.6 | 0.6 | 0.6 | 0.8 | 1.0 | 1.3 | 1.5 | 1.8 | 2.0 | 2.1 | 2.4 | 2.8 | 3.2 | 3.8 | 4.0 | 4.5 | 4.6 |
| 89. | Total | 3.25.13 | % | | 0.1 | 0.3 | 1.0 | 1.0 | 1.1 | 1.4 | 1.7 | 2.1 | 2.5 | 3.0 | 3.4 | 3.7 | 4.0 | 4.2 | 4.5 | 4.9 | 4.9 | 5.3 | 5.3 |
| 90. | Syst Analysts & Prog. | 3.25.13 | % | 21.9 | 22.5 | 23.0 | 24.0 | 24.5 | 24.9 | 25.8 | 28.2 | 29.5 | 31.0 | 32.6 | 33.5 | 33.0 | 32.6 | 31.4 | 30.2 | 30.8 | 32.5 | 34.0 | 35.8 |
| 91. | Software & Services | | % | 1.1 | 1.0 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.7 | 0.8 | 1.0 | 1.2 | 1.3 | 1.4 | 1.6 | 2.0 | 2.7 | 3.3 | 3.F | 3.9 | 4.1 |
| | Per-System Costs | | | | | | | | | | | | | | | | | | | | | | |
| 92. | Total Cost | 3.25.10 | $k/mo | 22.44 | 23.05 | 23.79 | 24.77 | 23.34 | 22.38 | 23.26 | 24.24 | 28.71 | 30.93 | 36.14 | 41.05 | 43.07 | 43.62 | 42.90 | 45.37 | 50.65 | 60.39 | 70.83 | 81.18 |
| | Cost Breakdown I | | | | | | | | | | | | | | | | | | | | | | |
| 93. | Total Hardware | 3.25.10 | $k/mo | 10.19 | 10.05 | 10.04 | 10.21 | 9.27 | 8.59 | 8.63 | 8.34 | 9.65 | 10.18 | 11.53 | 12.40 | 12.58 | 12.13 | 11.50 | 11.98 | 13.17 | 15.16 | 17.50 | 19.40 |
| 94. | Supplies | 3.25.10 | $k/mo | 1.80 | 2.07 | 2.21 | 2.20 | 2.14 | 1.86 | 1.76 | 1.63 | 1.71 | 1.59 | 1.70 | 1.72 | 1.64 | 1.59 | 1.62 | 1.91 | 1.92 | 2.05 | 2.27 | 2.44 |
| 95. | Personnel–Total | | $k/mo | 9.81 | 10.37 | 10.98 | 11.82 | 11.43 | 11.43 | 12.35 | 13.74 | 16.68 | 18.29 | 21.79 | 25.53 | 27.22 | 28.26 | 27.98 | 29.35 | 32.97 | 39.98 | 47.24 | 54.72 |
| 96. | Salaries | 3.25.10 | $k/mo | 5.30 | 5.60 | 5.90 | 6.35 | 6.14 | 6.11 | 6.60 | 7.34 | 8.87 | 9.73 | 11.60 | 13.51 | 14.39 | 14.96 | 14.72 | 15.29 | 17.17 | 20.71 | 24.44 | 28.17 |
| 97. | Overhead | 3.25.10 | $k/mo | 4.51 | 4.77 | 5.07 | 5.47 | 5.30 | 5.33 | 5.75 | 6.40 | 7.81 | 8.54 | 10.19 | 12.03 | 12.83 | 13.30 | 13.26 | 14.06 | 15.80 | 19.26 | 22.81 | 26.55 |
| 98. | Other Costs | | $k/mo | 0.63 | 0.58 | 0.57 | 0.54 | 0.51 | 0.49 | 0.51 | 0.56 | 0.69 | 0.87 | 1.12 | 1.40 | 1.59 | 1.70 | 1.76 | 2.13 | 2.63 | 3.20 | 3.90 | 4.63 |
| | Cost Breakdown II | | | | | | | | | | | | | | | | | | | | | | |
| 99. | Operations Total | 3.25.12 | $k/mo | 13.33 | 13.48 | 13.66 | 13.72 | 12.65 | 11.64 | 11.63 | 11.32 | 12.92 | 13.49 | 15.25 | 16.58 | 17.01 | 16.49 | 15.79 | 16.56 | 18.08 | 21.08 | 24.29 | 27.60 |
| 100. | Data Entry Total | 3.25.17 | $k/mo | 3.93 | 4.13 | 4.35 | 4.61 | 4.57 | 4.77 | 5.14 | 5.53 | 6.52 | 6.77 | 7.59 | 8.83 | 9.65 | 10.51 | 10.98 | 11.84 | 12.87 | 14.55 | 15.94 | 16.89 |
| 101. | Communications Total | 3.25.12 | $k/mo | | 0.02 | 0.07 | 0.25 | 0.23 | 0.25 | 0.33 | 0.41 | 0.60 | 0.77 | 1.08 | 1.40 | 1.59 | 1.75 | 1.80 | 2.04 | 2.48 | 2.96 | 3.75 | 4.30 |
| 102. | Syst. Analysts & Prog. | 3.25.12 | $k/mo | 4.92 | 5.18 | 5.48 | 5.95 | 5.72 | 5.58 | 6.01 | 6.84 | 8.48 | 9.59 | 11.78 | 13.75 | 14.21 | 14.22 | 13.47 | 13.70 | 15.60 | 19.63 | 24.08 | 29.06 |
| 103. | Other Costs | | $k/mo | 0.25 | 0.23 | 0.24 | 0.22 | 0.19 | 0.16 | 0.14 | 0.17 | 0.23 | 0.31 | 0.43 | 0.53 | 0.60 | 0.70 | 0.86 | 1.22 | 1.67 | 2.17 | 2.76 | 3.33 |
| 104. | CPU System Costs | | $k/mo | 9.81 | 9.64 | 9.59 | 9.58 | 8.63 | 7.96 | 7.94 | 7.56 | 8.63 | 9.07 | 10.11 | 10.68 | 10.70 | 10.01 | 9.27 | 9.46 | 10.18 | 11.60 | 13.00 | 14.32 |
| | % of CPU/System Costs | | | | | | | | | | | | | | | | | | | | | | |
| 105. | Total Costs | 3.25.14 | % | 228.7 | 239.1 | 248.1 | 258.6 | 270.5 | 281.2 | 292.9 | 320.6 | 332.7 | 341.0 | 357.6 | 384.4 | 402.5 | 435.8 | 462.8 | 479.6 | 497.5 | 520.6 | 544.8 | 566.9 |
| 106. | Software Purchases | | % | | | | | | | | | 0.3 | 0.6 | 1.1 | 1.1 | 1.3 | 1.8 | 3.4 | 5.8 | 8.4 | 10.4 | 12.5 | 14.7 |
| 107. | Services | | % | 2.5 | 2.4 | 2.5 | 2.3 | 2.2 | 2.0 | 1.8 | 2.2 | 2.3 | 2.7 | 3.2 | 3.8 | 4.4 | 5.2 | 6.0 | 7.2 | 8.0 | 8.3 | 8.7 | 8.5 |
| 108. | Personnel–Total | 3.25.14 | % | 100.0 | 107.6 | 114.3 | 123.3 | 132.5 | 143.6 | 155.5 | 181.7 | 193.2 | 201.6 | 215.6 | 238.8 | 254.7 | 282.3 | 301.7 | 310.2 | 324.0 | 344.7 | 363.2 | 382.1 |
| 109. | Salaries | 3.25.14 | % | 54.0 | 58.1 | 61.5 | 66.2 | 71.1 | 76.7 | 83.2 | 97.1 | 102.8 | 107.4 | 114.8 | 126.3 | 134.6 | 149.4 | 158.7 | 161.6 | 168.7 | 178.6 | 187.9 | 196.7 |
| 110. | Overhead | | % | 46.0 | 49.5 | 52.8 | 57.1 | 61.4 | 66.9 | 72.3 | 84.6 | 90.5 | 94.1 | 100.8 | 112.5 | 120.1 | 132.9 | 143.0 | 148.6 | 155.3 | 166.1 | 175.3 | 185.4 |
| 111. | Operations–CPU Syst. | 3.25.15 | % | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 100.0 | 99.9 | 99.9 | 100.1 | 99.9 | 100.0 | 99.9 | 99.9 | 100.1 | 99.9 | 100.2 | 100.0 | 100.0 | 100.2 | 99.9 |
| 111a. | Supplies | 3.25.15 | % | 18.3 | 21.3 | 23.1 | 23.0 | 24.9 | 23.3 | 22.3 | 21.5 | 20.0 | 17.4 | 16.8 | 16.1 | 15.3 | 15.7 | 17.6 | 20.1 | 18.9 | 17.7 | 17.4 | 17.0 |
| 112. | Computer Operators | 3.25.15 | % | 13.7 | 15.1 | 16.4 | 17.8 | 18.9 | 20.0 | 21.4 | 25.3 | 26.9 | 28.7 | 31.5 | 36.5 | 41.1 | 45.7 | 49.5 | 51.3 | 54.7 | 59.9 | 64.8 | 70.9 |
| 113. | Facilities | 3.25.15 | % | 3.9 | 3.6 | 3.0 | 2.3 | 2.7 | 2.8 | 2.9 | 2.9 | 2.7 | 2.7 | 2.5 | 2.7 | 2.8 | 3.0 | 3.2 | 3.4 | 4.0 | 4.2 | 4.4 | 5.1 |
| 114. | Total | 3.25.15 | % | 136.0 | 139.9 | 142.4 | 143.2 | 146.6 | 146.1 | 146.4 | 149.7 | 149.7 | 148.7 | 150.9 | 155.1 | 159.2 | 164.7 | 170.3 | 175.0 | 177.7 | 181.7 | 186.8 | 192.8 |
| 115. | Data Entry–Equipment | 3.25.16 | % | 3.9 | 4.1 | 4.5 | 4.9 | 5.7 | 6.2 | 6.4 | 7.1 | 7.3 | 7.2 | 7.5 | 8.5 | 9.3 | 10.5 | 11.1 | 11.0 | 10.5 | 9.9 | 9.8 | 9.6 |
| 116. | Operators | 3.25.16 | % | 36.2 | 38.8 | 40.9 | 43.2 | 47.3 | 53.7 | 58.3 | 66.0 | 68.2 | 67.5 | 67.6 | 74.1 | 81.0 | 94.5 | 107.3 | 114.1 | 116.0 | 115.6 | 112.7 | 108.3 |
| 117. | Total | 3.25.16 | % | 40.1 | 42.8 | 45.4 | 48.1 | 53.0 | 59.9 | 64.7 | 73.1 | 75.5 | 74.7 | 75.1 | 82.6 | 90.3 | 105.0 | 118.4 | 125.1 | 126.5 | 125.5 | 122.5 | 117.9 |
| 118. | Communications–Lines | | % | | | 0.5 | 1.0 | 1.1 | 1.4 | 1.8 | 2.2 | 2.7 | 3.4 | 4.3 | 5.4 | 6.5 | 7.0 | 6.5 | 6.2 | 5.5 | 4.7 | 4.4 | 3.9 |
| 119. | Data Sets | | % | | 0.2 | 0.2 | 0.4 | 0.3 | 0.4 | 0.5 | 0.6 | 0.8 | 1.0 | 1.3 | 1.7 | 2.0 | 2.3 | 2.4 | 2.3 | 2.2 | 1.9 | 1.6 | 1.3 |
| 120. | Terminals | 3.25.16 | % | | | | 1.2 | 1.3 | 1.4 | 1.9 | 2.5 | 3.5 | 4.3 | 5.1 | 6.2 | 6.6 | 8.0 | 10.5 | 13.0 | 16.5 | 18.9 | 22.8 | 25.0 |
| 121. | Total | 3.25.16 | % | | 0.2 | 0.7 | 2.6 | 2.7 | 3.1 | 4.1 | 5.4 | 7.0 | 8.5 | 10.7 | 13.1 | 14.9 | 17.4 | 19.4 | 21.6 | 24.4 | 25.5 | 28.9 | 30.1 |
| | **Supplies Expenses per Peripheral** | | | | | | | | | | | | | | | | | | | | | | |
| 122. | Cont. Forms per L.P. | 3.25.17 | $k/yr | 15.6 | 15.2 | 15.0 | 14.8 | 14.6 | 11.9 | 11.4 | 10.9 | 11.4 | 10.8 | 11.8 | 11.8 | 10.7 | 10.1 | 10.1 | 11.8 | 11.4 | 12.1 | 13.5 | 14.8 |
| 123. | Cards per Punch | 3.25.17 | $k/yr | 10.8 | 12.1 | 11.0 | 9.9 | 8.3 | 6.4 | 5.8 | 5.1 | 4.8 | 4.0 | 3.8 | 3.6 | 3.3 | 2.9 | 2.5 | 2.3 | 2.3 | 2.4 | 2.5 | 2.5 |
| 124. | Tape Reels per MTU | 3.25.17 | $k/yr | 1.5 | 1.8 | 2.2 | 2.1 | 2.2 | 2.2 | 1.9 | 1.4 | 1.3 | 0.9 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| 125. | Disc Packs per Spindle | 3.25.17 | $k/yr | | | | | | | 0.1 | 0.3 | 0.8 | 1.0 | 0.7 | 0.4 | 0.3 | 0.2 | 0.3 | 0.4 | 0.6 | 0.4 | 0.3 | 0.3 |

## TABLE II.3.25.7a USERS' COSTS VS. SYSTEM RENTAL 1974-1978, AS PERCENT OF TOTAL COSTS

| Rental Range ($k) | 0-2.1 | 2.1-8.3 | 8.3-20.8 | 20.8-41.7 | 41.7-83.3 | Over 83.3 |
|---|---|---|---|---|---|---|
| CPU System | | | | | | |
| 1974 | 16.6 | 31.6 | 28.4 | 30.9 | 29.2 | 34.4 |
| 1975 | 32.2 | 32.2 | 30.5 | 32.4 | 31.2 | 32.1 |
| 1976 | 22.5 | 30.8 | 31.8 | 31.3 | 33.3 | 35.0 |
| 1978 | 20.3 | 30.0 | 35.6 | 31.5 | 35.0 | 32.4 |
| Internal Personnel | | | | | | |
| 1974 | 51.8 | 52.8 | 55.8 | 49.6 | 53.1 | 39.4 |
| 1975 | 58.5 | 49.5 | 51.7 | 50.4 | 52.6 | 48.9 |
| 1976 | 58.4 | 51.1 | 49.4 | 46.5 | 43.7 | |
| 1978 | 63.7 | 53.7 | 47.7 | 49.0 | 48.1 | 45.3 |
| Supplies | | | | | | |
| 1974 | 22.1 | 7.0 | 5.5 | 6.9 | 7.0 | 3.9 |
| 1975 | 7.4 | 9.3 | 8.5 | 6.2 | 7.1 | 5.3 |
| 1976 | 9.7 | 7.5 | 6.9 | 7.7 | 6.6 | 5.8 |
| 1978 | 10.5 | 7.5 | 5.3 | 5.5 | 4.7 | 5.5 |

"CPU System" Includes central site computer, memory, peripherals, COM, communications gear, terminals, and "other" hardware.
Source: McLaR74-2.

## TABLE II.4.10.1a U.S. DEPARTMENT OF COMMERCE MANUFACTURING COST DATA

| Line | Item | Figure | Units | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | Electronic Compt'ng Ind.(3573) | | | | | | | | |
| 6. | Shipment Value | | $M | 7,423 | 9,122 | 8,560 | 10,388 | 12,700 | 15,380 |
| 7. | Production Wages | | $M | 660 | 795 | 731 | 707 | | |
| 8. | Material Costs | | $M | 3,481 | 4,164 | 3,705 | 4,380 | | |
| 9. | Percent of Shipments—Wages | | % | 8.9 | 8.7 | 8.5 | 6.8 | | |
| 10. | Materials | | % | 46.9 | 45.6 | 43.3 | 42.2 | | |
| | Calc & Acctg Mach Ind.(3574) | | | | | | | | |
| 11. | Shipment Value | | $M | 802 | 891 | 854 | 961 | 1,000 | 1,040 |
| 12. | Production Wages | | $M | 147 | 155 | 112 | 107 | | |
| 13. | Material Costs | | $M | 352 | 491 | 425 | 492 | | |
| 14. | Percent of Shipments—Wages | | % | 18.3 | 17.4 | 13.1 | 11.1 | | |
| 15. | Materials | | % | 43.9 | 55.1 | 49.8 | 51.2 | | |
| | Shipment Value of All Equip. | | | | | | | | |
| 17. | Electronic Compt'ng (3573) | | $M | 7,085 | 8,668 | 8,443 | 10,134 | 12,558 | 15,100 |

## TABLE II.4.11.1a LOGIC TECHNOLOGY COST PARAMETERS

| | | | 1974 | 1976 | 1978 |
|---|---|---|---|---|---|
| | **Labor Costs** | | | | |
| 1. | Factory Assembly | $/hr | 4.45 | 4.91 | 5.10 |
| 2. | Overhead Rates | % | 180 | 182 | 185 |
| | Burdened Cost | | | | |
| 3. | Factory Assembly | $/hr | 12.46 | 13.85 | 14.54 |
| 4. | Module Test | $/hr | 14.95 | 16.62 | 17.44 |
| 5. | System Test | $/hr | 18.69 | 20.77 | 21.80 |
| 6. | Labor Cost Ratio | | 2.21 | 2.46 | 2.58 |
| | **Component Costs** | | | | |
| 18a. | Average IC Cost—MSI | $ | 1.40 | .93 | .91 |
| 18b. | SSI | $ | .70 | .27 | .22 |
| | **Interconnect Costs** | | | | |
| 28. | Two-Sided, 4x5 | $ | 3.30 | 2.65 | 2.16 |
| 29. | Four-Layer 8.5x11.75 | $ | 30.0 | 24.6 | 20.5 |
| 29a. | Four-Layer 8.5x11.75 | $ | 43.0 | 30.0 | 23.0 |
| 29b. | 8-Layer 8.5x11.75 | $ | | | 38.3 |
| | Labor Cost per Pin | | | | |
| 33. | Manual Wire-wrap | cents | 3.1 | 3.5 | 3.6 |
| 34. | AWW | cents | | .37 | .44 |
| 35. | Wire Cost per Pin | cents | 1 | 1 | 1 |
| 37. | AWW Deprec'n. per pin | cents | | .1 | .1 |
| | Total Cost Per Pin | | | | |
| 41. | Manual Wire-wrap | cents | | 4.5 | 4.6 |
| 42. | AWW (old machine) | cents | 2.3 | 2.4 | 2.5 |
| 42a. | (new machine) | cents | 1.5 | 1.5 | 1.5 |
| 43. | Fixed Cost | cents | 19 | 22 | 24 |
| 44. | Per Pin | cents | 1.9 | 2.2 | 2.4 |
| | **Power Costs** | | | | |
| 45. | Labor Cost Per Wire | cents | 33.2 | 36.9 | 38.8 |
| 46. | Material Cost pe Wire | cents | 3 | 3 | 3 |
| 47. | Total Cost | cents | 36.2 | 39.9 | 41.8 |
| | Linear Regulated | | | | |
| 48. | Fixed Cost | $ | 107 | 109 | 110 |
| 49. | Incremental Cost | $/watt | .54 | .68 | .75 |
| 50. | Volume Occupied | $in^3/w$ | 2.5 | 2.5 | 2.5 |
| | Switching | | | | |
| 50a. | Fixed Cost | $ | | | 200 |
| 50b. | Incremental Cost | $/watt | | | .50 |
| 50c. | Volume Occupied | $in^3/w$ | | | 1.0 |
| | **Packaging Cost** | | | | |
| | Module Mount Cost | | | | |
| 51. | Fixed Cost | $ | 13.0 | 15.5 | 17.6 |
| 52. | Incremental Cost | $\$/in^3$ | .16 | .19 | .22 |
| | Cabinet Cost | | | | |
| 53. | Fixed Cost | $ | 107 | 130 | 145 |
| 54. | Increment Cost | $\$/ft^3$ | 3.2 | 3.9 | 4.4 |
| | Cooling System | | | | |
| 55. | Cost | $/watt | .10 | .12 | .14 |
| 56. | Volume | $in^3/w$ | 2 | 2 | 2 |

## TABLE II.4.11.1b IC DENSITY ON MODULES

| Source | Modules No. | Modules Type | Area (sq.in.) | IC's No. | IC's Types | IC's per sq.in. | IC number per type |
|---|---|---|---|---|---|---|---|
| **DEC** | | | | | | | |
| LSI-11 | 1 | quad | 88.1 | 48 | 24 | .545 | 2.00 |
| 11/04 | 1 | hex | 132.2 | 138 | 40 | 1.04 | 3.45 |
| 11/10 | 2 | hex | 264.4 | 203 | 60 | .768 | 3.38 |
| 11/20 | 6 | quad | | | | | |
| | 6 | doub. | | | | | |
| | 2 | sing. | | | | | |
| | (38 | sing.) | 837.3 | 523 | 27 | .625 | 19.37 |
| 11/34 | 2 | hex | 264.4 | 231 | 54 | .874 | 4.28 |
| 11/40 | 4 | hex | | | | | |
| | 1 | quad | | | | | |
| | (28 | sing.) | 616.9 | 417 | 53 | .676 | 7.87 |
| 11/45 | 7 | hex | | 417 | 53 | .676 | 7.87 |
| | 1 | quad | | | | | |
| | (46 | sing.) | 1014 | 696 | 78 | .687 | 8.92 |
| 11/16 | 6 | hex | 793.2 | 648 | 74 | .817 | 8.76 |
| **Other** | | | | | | | |
| Intel | 1 | | 81 | 59 | | .73 | |
| Natl.Semi | 1 | | 84 | 59 | | .70 | |
| Computer Auto. | 1 | | 127 | 90 | | .71 | |
| | 1 | | 127 | 83 | | .65 | |
| | 1 | | 254 | 119 | | .47 | |
| | 1 | | 254 | 125 | | .49 | |
| | 1 | | 127 | 80 | | .63 | |
| | 1 | | 254 | 159 | | .63 | |
| | 1 | | 254 | 221 | | .87 | |

Sources: BellC78 p.107 for the DEC modules. For the others, advertisements in *Electronic News* during 1976 and 1977. For the DEC modules, approximately Area = -22.02 + (1.44 x Number of IC's) or Area = 1.40 x Number of IC's.

## TABLE II.4.11.1c. IC PRICE TRENDS

| | | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| **MOS Circuits** | | | | | | | | |
| RAM—1K dynamic | $ | 5.6 | 3.90 | 3.30 | 2.90 | 2.40 | 2.30 | 2.10 |
| 4K dynamic | $ | | | 15.00 | 8.70 | 5.00 | 3.70 | 2.00 |
| 16K dynamic | $ | | | | | 20.00 | 20.00 | 10.00 |
| RAM—1K static | $ | | | 6.00 | 2.70 | 2.30 | 1.00 | 1.00 |
| 4K static | $ | | | | | | 8.00 | 6.00 |
| Microprocessors—4004 | $ | 150.0 | 62.50 | 38.00 | 25.00 | 14.00 | 7.00 | 4.00 |
| 8080 | $ | | | 180.00 | 60.00 | 30.00 | 17.50 | 6.00 |
| **Bipolar** | | | | | | | | |
| RAM—1K | $ | | | 10.00 | 7.70 | 6.00 | 5.00 | 4.00 |
| Microprocessor | $ | | | | | | | 10.00 |
| Microprocessor Support | $ | | | | | | | 5.00 |
| **PROM's** 1K | $ | | 18.00 | 8.00 | 4.00 | 2.00 | 1.50 | 1.50 |
| 2K | $ | | 28.00 | 18.00 | 12.40 | 8.40 | 6.00 | 4.00 |
| 4K | $ | | | | | 26.00 | 12.00 | 5.00 |
| 8K | $ | | | | | 50.00 | 21.00 | 7.50 |

Sources: Technical and trade press; informal conversations with industry sources; MackI78.

## TABLE II.4.11.2a SYSTEM AND TECHNOLOGY CHARACTERISTICS

| | | Units | 1974 | 1978 | | | Units | 1974 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | **Interconnect** | | | | 48 | Total Components | | 7842 | 9000 |
| 5 | Printed Circuit Boards | | D | D | | Module Fabrication Time | | | |
| 6 | Size | in. | 8.5x11.75 | 8.5x11.75 | 52 | IC's—16-Pin DIP | min. | 1926 | 2048 |
| 7 | Spacing | in. | 0.5 | 0.5 | 53 | 24- or 40-Pin DIP | min. | 125 | 405 |
| 8 | Layers | | 4 | 4 | 54 | Total Insertion Time | min. | 2051 | 2453 |
| 9 | Line Width | in. | .015 | .012 | 55 | Soldering Time | min. | 87 | 100 |
| 10 | Pins | | 150 | 150 | 56 | Inspection/Repair Time | min. | 957 | 1100 |
| 13 | Module Test Time | hrs. | 0.3 | 0.3 | 57 | Total Assembly Time | min. | 3095 | 3653 |
| 14 | Wiring | | AWW | AWW | 58 | Test Time | min. | 1566 | 1800 |
| | **System** | | | | | Wiring Time & Cost | | | |
| | per module | | | | 62 | Total Signal Pins | | 12876 | 14800 |
| 27 | Power | mw | 10860 | 11970 | 63 | Labor Time | min. | 515 | 266 |
| 28 | Module Volume | $in^3$ | 50 | 50 | 64 | Material Cost | $ | 128.8 | 148.0 |
| 29 | Power and Cooling Volume | $in^3$ | 48.87 | 35.91 | 65 | Depreciation | $ | 70.82 | 14.8 |
| 30 | Total Volume | | 98.87 | 85.91 | 66 | Power Wiring Wires | | 174 | 200 |
| | System Power & Packaging | | | | | Assembly Time | | | |
| 31 | Cabinet Volume | $ft^3$ | 24 | 24 | 67 | Install—Connectors | min. | 29 | 33 |
| 32 | Available | $in^3$ | 8640 | 8640 | 68 | Module Mounts | min. | 14 | 16 |
| 33 | Number of Modules | | 87 | 100 | 69 | Power Supplies | min. | 10 | 10 |
| 34 | Number of Flip-flops | | 6214 | 21690 | 70 | Modules | min. | 22 | 25 |
| 35 | Total Power | kw | .945 | 1.20 | 71 | Total | min. | 75 | 84 |
| 36 | Power Density | wpcf | 39.4 | 50.0 | | Test Time | | | |
| 37 | Power Supplies—Capacity | watts | 473 | 600 | 74 | Number of Bad Comp. | | 4 | 5 |
| 38 | Number | | 2 | 2 | 76 | Time to Locate and Correct | hrs. | 1.33 | 2.08 |
| 39 | Module Mounts Volume | $in^3$ | 621 | 625 | | System Exercise Time | hrs. | 8.0 | 8.0 |
| 40 | Number | | 7 | 8 | | Total Test Time | hrs. | 9.33 | 10.08 |

## TABLE II.4.11.6a IC TECHNOLOGY COSTS III

| | | Units | Factors | 1978 | | | Units | Factors | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **Components** | $ | 9000 | 9900 | | | | | |
| | **Power** | | | | | **Assembly & Test** | | | |
| 6 | Supply | $ | 2-600 watt | 1000 | 22 | Assembly Labor | $ | 84 min. | 20 |
| 7 | Wiring | $ | 200 wires | 84 | | Test Labor | $ | 10.08 hrs. | 220 |
| 8 | Total Power | $ | | 1084 | | Total System | $ | | 240 |
| | **Packaging** | | | | | **Summary** | | | |
| 9 | Module Mounts | $ | $8\text{-}625in^3$ | 1241 | 25 | Total Costs | $ | | 17420 |
| 10 | Cabinet | $ | $1\text{-}24ft^3$ | 251 | | Distribution | | | |
| 11 | Cooling System | $ | 1200 watts | 168 | 26 | Components | % | | 56.8 |
| 12 | Total Packaging | $ | | 1660 | 27 | Power | % | | 6.2 |
| | **Interconnects** | | | | 28 | Packaging | % | | 9.5 |
| 13 | PCB's | $ | 100 | 2300 | 29 | Interconnects | % | | 26.0 |
| 14 | Mod. Assy. Labor | $ | 3653 min. | 885 | 30 | Assy. & Test | % | | 1.4 |
| 15 | Mod. Test Labor | $ | 1800 min. | 523 | 31 | Cost/Flip-flop | $ | 21690 | $0.80 |
| 16 | Subtotal Modules | $ | | 3708 | 32 | Cost per Component—Total | $ | 9000 | 1.93 |
| 17 | Connectors | $ | 100-150pin | 384 | 33 | Components | $ | | 1.10 |
| 18 | Backwiring Labor | $ | 266 min | 65 | 34 | Power | $ | | .12 |
| 19 | Matls/Depr. | $ | | 163 | 35 | Packaging | $ | | .18 |
| 20 | Cables | $ | | 216 | 36 | Interconnects | $ | | .50 |
| 21 | Total Interconn. | $ | | 4536 | 37 | Assy. & Test | $ | | .03 |

## TABLE II.4.12.1a IC TECHNOLOGY CHARACTERISTICS

| | | Units | 1972 | 1974 | 1976 | 1978 | | | 1972 | 1974 | 1976 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **IC Geometry** | | | | | | | | | | | |
| 1. | Wafer Diameter | in. | 2 | 3 | 3 | 4 | | **Compo. per Circuit** | | | | |
| | Component Area | | | | | | 10. | Per Gate | 4 | 4 | 3.8 | 3.6 |
| 5. | Bipolar—Logic | $mils^2$ | 4.5 | 4 | 3.5 | 3 | 11. | Per Flip-Flop | 30 | 30 | 30 | 30 |
| 5a. | Memory | $mils^2$ | 3 | 2 | 1.0 | 0.8 | | Per Memory | | | | |
| 6. | MOS—Logic | $mils^2$ | 2 | 1.5 | 1.1 | 0.7 | | Array Bit | | | | |
| 6a. | Memory | $mils^2$ | 2 | 1.5 | 0.7 | 0.3 | 14. | Bipolar | 4 | 4 | 4 | 4 |
| 6b. | PROM Bit | $mils^2$ | 4.5 | 2.4 | 1.9 | 1.4 | 15. | MOS—Static | 6 | 6 | 6 | 6 |
| 7. | Stacking Factor | | .4 | .4 | .4 | .4 | 16. | MOS-Dynamic | 4 | 4 | 2 | 2 |

## TABLE II.4.12.1a IC TECHNOLOGY CHARACTERISTICS (continued)

| | | Units | 1972 | 1974 | 1976 | 1978 |
|---|---|---|---|---|---|---|
| | **Circuits per Sq. In.** | | | | | |
| 17. | Gates—Bipolar | k | 22.2 | 25.0 | 30.1 | 37.0 |
| 18. | MOS | k | 50.0 | 66.7 | 95.7 | 158.7 |
| 18a. | Logic Comp.—Bip. | k | 88.9 | 100.0 | 114.3 | 133.3 |
| 18b. | MOS | k | 200.0 | 266.7 | 363.6 | 571.4 |
| 19. | Flip-Flops—Bipolar | k | 3.0 | 3.3 | 4.0 | 4.9 |
| 20. | MOS | | 6.7 | 8.9 | 12.8 | 21.2 |
| | Memory Array Bits | | | | | |
| 23. | Bipolar | k | 33.3 | 50.0 | 100.0 | 125.0 |
| 24. | Static MOS | k | 33.3 | 44.4 | 95.2 | 222.2 |
| 25. | Dynamic MOS | k | 50.0 | 66.7 | 285.7 | 666.7 |
| 25a. | Bipolar PROM | k | 88.9 | 166.7 | 210.5 | 285.7 |
| | **Costs** | | | | | |
| 26. | Wafer Cost (Cw) | $ | 30 | 45 | 45 | 60 |
| 27. | per Unit Area | $/in.$^2$ | 9.55 | 6.37 | 6.37 | 4.77 |
| 28. | Defect Density (k) | | 28 | 20 | 14.4 | 10.4 |
| 29. | Packag./Test Yields | % | 90 | 90 | 90 | 90 |
| | Package Costs | | | | | |
| 32. | Plastic DIP | | | | | |
| | 14-16 pins | cents | 4 | 4 | 3.5 | 3 |
| 33. | LSI DIP—16 pins | $ | .7 | .8 | .04 | .03 |
| 33a. | 24 pins | $ | 1.10 | 1.10 | .15 | .10 |
| 33b. | 40 pins | $ | | | .18 | .12 |
| 34. | Labor Cost—U.S. | $/hr. | 11.61 | 12.46 | | |
| 35. | Overseas | $/hr. | 1.38 | 2 | 2 | 2 |
| 36. | Die Attach Time | secs. | 30 | 30 | 25 | 20 |
| 37. | Pin Connect Time | secs. | 8 | 7 | 10 | 14.5 |
| 38. | Typ. No. of Pins | | 16 | 24 | 40 | 40 |
| 39. | Connect Cost—U.S. | cents | 51.0 | 68.5 | | |
| 40. | Overseas | cents | 6.1 | 11.0 | 23.6 | 33.3 |
| 41. | Test Cost | cents | 12 | 12 | 19 | 25 |

| | | Units | 1972 | 1974 | 1976 | 1978 |
|---|---|---|---|---|---|---|
| | Memory IC's | | | | | |
| | Bipolar | | | | | |
| 51. | 1024-Bit—Edge | mils | 175 | 143 | 101 | 91 |
| 52. | Process Yield | % | 12.4 | 28.6 | 53.0 | 62.6 |
| 53. | Cost | $ | 4.66 | 1.85 | 0.54 | 0.56 |
| 54. | 4096-Bit—Edge | mils | 350 | 286 | 202 | 181 |
| 55. | Process Yield | % | 0.91 | 4.36 | 19.9 | 33.2 |
| 56. | Cost | $ | 248 | 19.79 | 2.29 | 1.15 |
| | Dynamic MOS | | | | | |
| 60. | 1024-Bit—Edge | mils | 143 | 124 | 60 | 39 |
| 61. | Process Yield | % | 20.5 | 35.8 | 68.8 | 76.3 |
| 62. | Cost | $ | 2.46 | 0.65 | 0.42 | 0.49 |
| 63. | 4096-Bit—Edge | mils | 286 | 248 | 120 | 78 |
| 64. | Process Yield | % | 2.24 | 7.23 | 45.6 | 66.4 |
| 65. | Cost | $ | 62.5 | 9.35 | 0.67 | 0.56 |
| 65a. | 16k-Bit—Edge | mils | | 496 | 239 | 157 |
| 65b. | Process Yield | % | | 0.38 | 13.1 | 40.4 |
| 65c. | Cost | $ | | 758 | 4.69 | 0.99 |
| 65d. | 64k-Bit—Edge | mils | | | 479 | 314 |
| 65e. | Process Yield | % | | | 1.00 | 9.67 |
| 65f. | Cost | $ | | | 268 | 7.84 |
| | Static MOS | | | | | |
| 69. | 1024-Bit—Edge | mils | 175 | 152 | 104 | 68 |
| 70. | Process Yield | % | 12.4 | 25.7 | 51.9 | 69.5 |
| 71. | Cost | $ | 4.66 | 2.01 | 0.55 | 0.52 |
| 72. | 4096-Bit—Edge | mils | 350 | 304 | 207 | 136 |
| 73. | Process Yield | % | | | 18.8 | 47.3 |
| 74. | Cost | $ | | | 2.51 | 0.75 |
| 75. | 16k-Bit—Edge | mils | | | | 272 |
| 76. | Process Yield | % | | | | 14.5 |
| 77. | Cost | $ | | | | 4.11 |

## TABLE II.4.12.2a CHARACTERISTICS OF MEMORY IC'S

| Component Organization | Source of Data | No. of Bits | Mem. Device Area Total (sq. mils) | per Bit (sq. mils) | Devices per Bit | Area per Device (sq. mils) | Chip Area (sq. mils) | S.F. | Density (kbits/ sq. in.) |
|---|---|---|---|---|---|---|---|---|---|
| **MOS Static RAM** | | | | | | | | | |
| Intel | ISSCC76 p.138 | 1k | 8090 | 7.9 | 6 | 1.32 | 18080 | .447 | 56.6 |
| Amer. Micros. | IEEE JSSC 10/77 p.515 | 1k | 3072 | 3.0 | 8 | 0.38 | 10125 | .303 | 101.1 |
| IBM | IEEE JSSC 6/76 p.352 | 2k | | | | | 27234 | | 75.2 |
| Intel 2147 | EN adv. 6/27/77 | 4k | | | | | 24964 | | 164.1 |
| AMD | IEEE JSSC 10/76 p.602 | 4k | 21709 | 5.3 | 6 | 0.88 | 37824 | .574 | 108.3 |
| EMM/SEMI | IEEE JSSC 10/77 p.497 | 4k | 21299 | 5.2 | 6 | 0.87 | 32000 | .666 | 128.0 |
| EMM/SEMI | IEEE JSSC 10/77 p.497 | 4k | 17449 | 4.26 | 6 | 0.71 | 26500 | .658 | 154.6 |
| MOSTEK 4104 | ISSCC 77 | 4k | 11264 | 2.75 | 6 | 0.46 | 25024 | .450 | 163.7 |
| Intel | ISSCC 77 | 4k | 15360 | 3.75 | 6 | 0.63 | 25944 | .592 | 157.9 |
| MOSTEK 4801 | EN Adv. 10/8/78 | 8k | | | | | 18900 | | 433.4 |
| MOSTEK | ISSCC 77 | 16k | 11469 | 0.7 | | | 27694 | .414 | 591.6 |
| **MOS Dynamic RAM** | | | | | | | | | |
| Intel 1103 | LuecG 73 | 1k | 6144 | 6.0 | 3 | 2.0 | 16675 | .368 | 61.4 |
| Motorola 6605 | EN 11/25/74 | 4k | | | 3 | | 24000 | | 170.7 |
| Microsyst. | IEEE JSSC 10/75 p.255 | 4k | 7946 | 1.94 | 2 | 0.97 | 20130 | .395 | 203.5 |
| Intel 2107B | Electronics 2/19/76 | 4k | 5325 | 1.3 | | | 18690 | .285 | 219.2 |
| MOSTEK 4096 | IEEE JSSC 2/76 p.7 | 4k | 6554 | 1.6 | | | 17931 | .365 | 228.4 |
| TI 4030 | IEEE JSSC 2/76 p.7 | 4k | 8192 | 2.0 | | | 28779 | .285 | 142.3 |
| Intel 2116 | IEEE JSSC 10/76 p.570 | 16k | 11550 | 0.705 | 2 | 0.35 | 33930 | .340 | 482.9 |
| MOSTEK 4116 | Sci. Amer. 9/77 p.130 | 16k | 9454 | 0.577 | 2 | 0.29 | 21000 | .450 | 780.2 |
| Hitachi | IEEE JSSC 10/76 p.585 | 16k | 20120 | 1.228 | 2 | 0.61 | 54372 | .370 | 301.3 |
| IBM | EN 11/6/78 | 18k | | | | | 40920 | | 450.4 |
| IBM | EN 11/6/78 | 32k | | | | | 61520 | | 532.6 |
| IBM | EN 11/6/78 | 64k | 18750 | 0.286 | 2 | 0.14 | 62500 | .300 | 1048.6 |
| TI | Electronics 9/28/78 | 64k | 17826 | 0.272 | 2 | 0.14 | 33000 | .540 | 1985.9 |
| Nippon Tel | IEEE JSSC 6/78 p.333 | 64k | 21299 | 0.325 | 2 | 0.16 | 54839 | .389 | 1195.1 |

### TABLE II.4.12.2a CHARACTERISTICS OF MEMORY IC'S (continued)

| Component Organization | Source of Data | No. of Bits | Mem. Device Area Total (sq. mils) | Mem. Device Area per Bit (sq. mils) | Devices per Bit | Area per Device (sq. mils) | Chip Area (sq. mils) | S.F. | Density (kbits/ sq. in.) |
|---|---|---|---|---|---|---|---|---|---|
| **Read-only Memory** | | | | | | | | | |
| (MOS) | LuecG73 | 1k | 3308 | 3.23 | | | 12090 | .273 | 84.7 |
| (MOS) | LuecG73 | 4k | 4465 | 1.09 | | | 13098 | .341 | 312.7 |
| Intel 1702A | Electronics 3/3/77 | 2k | | | | | 17956 | | 114.1 |
| Intel 2708 | Electronics 3/3/77 | 8k | | | | | 25600 | | 320.0 |
| Intel | ISSCC 77 | 8k | 8192 | 1.00 | | | 25326 | .323 | 323.5 |
| Intel 2716 | Electronics 3/3/77 | 16k | | | | | 30625 | | 535.0 |
| AMI | IEEE JSSC 10/76 p.614 | 16k | 7340 | .448 | | | 16800 | .437 | 975.2 |
| MOSTEK | ISSCC 78 | 64k | 16384 | 0.25 | | | 34770 | .471 | 1884.8 |
| **Bipolar RAM** | | | | | | | | | |
| 7489 | LuecG73 | 64 | 3968 | 62 | 8 | 7.75 | 10479 | .379 | 6.1 |
| 74200 | LuecG73 | 256 | 9216 | 36 | | | 19116 | .482 | 13.4 |
| | LuecG73 | 1k | 11776 | 11.5 | | | 22477 | .523 | 45.6 |
| (1972) | See notes (p.596) | 1k | | 11.0 | 4 | 2.75 | 20000 | .563 | 51.2 |
| (1973) | See notes (p.596) | 1k | | 7.0 | 4 | 1.75 | 14000 | .512 | 73.1 |
| (1975) | See notes (p.596) | 1k | | 5.0 | 4 | 1.25 | 11000 | .465 | 93.1 |
| (1976) | See notes (p.596) | 1k | | 4.0 | 4 | 1.00 | 9000 | .455 | 113.8 |
| (1977) | See notes (p.596) | 4k | | 3.0 | 4 | .75 | 23650 | .520 | 173.2 |
| (1978) | See notes (p.596) | 4k | | 2.3 | 4 | .58 | 17200 | .548 | 238.1 |
| Fairchild | ISSCC 78 p.154 | 16k | 11469 | 0.7 | 2 | .35 | 26000 | .441 | 630.2 |

### TABLE II.4.12.2b CHARACTERISTICS OF MICROPROCESSOR IC'S

| Processor | Source | No. of Elements | Edges | Area Total | Area Per Element |
|---|---|---|---|---|---|
| **MOS** | | | | | |
| Signetics Microprocessor | Sci. Amer. 9/77 p.54 | 10,000 transistors | 157 x 197 | 30929 | 3.09/trans |
| Intel 8085 | Sci. Amer. 9/77 p.63 | 6,200 transistors | 164 x 222 | 36408 | 5.87/trans |
| Intel 8748 | Sci. Amer. 9/77 p.147 | 20,000 transistors | 220 x 260 | 57200 | 2.86/trans |
| (1972) Microprocessor | Spectrum 5/78 p.29 | 750 gates | | 18910 | 25.2/gate |
| (1974) Microprocessor | Spectrum 5/78 p.29 | 1500 gates | | 27900 | 18.6/gate |
| (1976) Microprocessor | Spectrum 5/78 p.29 | 3000 gates | | 33170 | 11.1/gate |
| (1978) Microprocessor | Spectrum 5/78 p.29 | 8000 gates | | 55150 | 6.9/gate |
| Hewl. Pack Microprocessor | ISSCC 77 | 9600 transistors | | 52700 | 5.49/trans |
| Intel Dual Processor | ISSCC 77 | 22,000 transistors | 218 x 244 | 53192 | 2.42/trans |
| **Bipolar** | | | | | |
| TI 9900 | Computer Design 6/78 p.170 | 6182 gates | | 76000 | 12.3/gate |
| TRW Multiplier | Sci. Amer. 9/77 p.195 | 18,000 components | 250 x 250 | 62500 | 3.5/component |
| NEC Microprocessor | ISSCC 78 | 1600 gates | 177 x 177 | 31329 | 19.6/gate |

### TABLE II.4.12.3a INTEGRATED CIRCUIT PACKAGES

| Source | Package Designations | Number of Pins | Dimensions (inches) | Area (sq. in.) | Pins per sq. in. | Remarks |
|---|---|---|---|---|---|---|
| LymaJ | Dual In-Line (DIP) | 40 | 2.0 x 0.6 | 1.20 | 33.3 | |
| | Minipak | 28 | 0.5 x 0.5 | 0.25 | 112 | Only from Genl. Instr. Corp. |
| | Ceramic Chip-carrier | 24 | 0.4 x 0.4 | 0.16 | 150 | |
| | Ceramic Chip-carrier | 40 | 0.46 x 0.43 | 0.198 | 202 | |
| | Plastic pre-molded | | | | | |
| | Chip carrier | 28 | 0.45 x 0.45 | 0.203 | 138 | From AMP, Inc. |
| | Chip carrier | 44 | 0.65 x 0.65 | 0.423 | 104 | From AMP, Inc. |
| | chip carrier | 156 | 2.05 x 2.05 | 4.20 | 37 | From AMP, Inc. |
| | Ceramic DIP | 64 | 3.2 x 0.9 | 2.88 | 22.2 | Biggest DIP (1977) |

## TABLE II.4.12.4a COMPONENTS IN A CHIP OF FIXED COST

| Year | Chip Area (sq. mils) | Chip Area (sq.1mm) | Components per Chip Logic Bip. | Components per Chip Logic MOS | Components per Chip Memory Bip. | Components per Chip Memory MOS | Bits per Chip Bipolar | Bits per Chip MOS Dyn. | Bits per Chip MOS Stat. | Chip Area (sq. mm) NoycR76 | Chip Area (sq. mm) FaggF78 | Chip Area (sq. mm) AllaR77 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1962 | 3875 | 2.50 | | 14.4 | | | 3.6 | | | 2.03 | 2.99 | 2.61 |
| 1964 | 5248 | 3.39 | | 45.0 | | | 11.2 | | | 3.04 | 4.03 | 3.83 |
| 1966 | 8928 | 5.76 | | 134 | | | 33.5 | | | 4.55 | 5.44 | 5.62 |
| 1968 | 11147 | 7.19 | 279 | 836 | | | 69.7 | 139 | 209 | 6.81 | 7.33 | 8.25 |
| 1970 | 18439 | 11.9 | 1475 | 2459 | | | 369 | 410 | 615 | 10.2 | 9.88 | 12.1 |
| 1972 | 20955 | 13.5 | 1863 | 4191 | 2794 | 4191 | 699 | 699 | 1048 | 15.3 | 13.3 | 17.8 |
| 1974 | 30832 | 19.9 | 3083 | 822 | 6166 | 8222 | 1542 | 1370 | 2055 | 22.9 | 18.0 | 26.1 |
| 1976 | 36355 | 23.5 | 4155 | 13220 | 14542 | 20774 | 3635 | 3462 | 10387 | 34.3 | 24.2 | 38.3 |
| 1978 | 49899 | 32.2 | 6653 | 28514 | 24950 | 66532 | 6237 | 11089 | 33266 | 51.3 | 32.6 | 56.2 |

## TABLE II.4.13.3a INTEGRATED CIRCUIT MEMORY SYSTEM MANUFACTURING COSTS

| | | Units | 72 | 74 | 76 | 78 |
|---|---|---|---|---|---|---|
| 1. | Modules per Cabinet | | 89 | 87 | | 100 |
| | Per Module | | | | | |
| 2. | Power | watts | 10.48 | 10.86 | | 12.0 |
| 3. | Power Cost | $ | 8.2 | 9.1 | | 10.8 |
| | Pack., Inter., | | | | | |
| 4. | Assy/Test Costs | $ | 70.6 | 70.6 | | 64.4 |
| | IC Costs | | | | | |
| 5. | Dynamic RAM–1k | $ | 5.6 | 3.3 | 2.4 | 2.1 |
| 6. | 4k | $ | | 15.0 | 5.0 | 2.0 |
| 7. | 16k | $ | | | 20.0 | 10.0 |
| 8. | MSI Support | $ | 2.0 | 1.4 | 1.0 | 1.0 |
| | System Characteristics | | | | | |
| 9. | Memory IC's | | 64 | 64 | 64 | 64 |
| 10. | Support IC's | | 41 | 41 | 41 | 41 |
| 11. | Total IC's | | 105 | 105 | 105 | 105 |
| 12. | Board Area | sq. in. | 100 | 100 | 100 | 100 |
| 13. | Module Power | watts | 21 | 21 | 21 | 21 |
| | Using 1k Chips | | | | | |
| 14. | Board Capacity | bits | 64k | 64k | 64k | 64k |
| 15. | Cost–RAM's | $ | 358.4 | 211.2 | 153.6 | 134.4 |
| 16. | Support MSI | $ | 82 | 57.4 | | 41.0 |
| 17. | Power | $ | 16.4 | 17.6 | | 18.9 |
| 18. | P., I., A/T | $ | 70.6 | | 64.4 | |
| 19. | Subtotal | $ | 169.0 | 145.6 | 135.0 | 124.3 |
| 20. | Total | $ | 527.4 | 356.8 | 288.6 | 258.7 |
| 21. | per bit | cents | .805 | .544 | .440 | .395 |
| 22. | RAM cost/bit | cents | .547 | .322 | .234 | .205 |
| | Using 4k Chips | | | | | |
| 23. | Board Capacity | bits | 256k | 256k | 256k | 256k |
| 24. | Cost–RAM's | $ | | 960.0 | 320.0 | 128.0 |
| 25. | All Others | $ | | 145.6 | 135.0 | 124.3 |
| 26. | Total | $ | | 1105.6 | 455.0 | 252.3 |
| 27. | per bit | cents | | .422 | .174 | .096 |
| 28. | RAM cost/bit | cents | | .366 | .122 | .049 |
| | Using 16k Chips | | | | | |
| 29. | Board Capacity | bits | 1024k | 1024k | 1024k | 1024k |
| 30. | Cost–RAM's | $ | | | 1280 | 640 |
| 31. | All Others | $ | | | 135 | 124.3 |
| 32. | Total | $ | | | 1415 | 764.3 |
| 33. | per bit | cents | | | .135 | .073 |
| 34. | RAM cost/bit | cents | | | .122 | .061 |

See Notes on page

## TABLE II.4.22.3a PROGRAMMING PRODUCTIVITY

| | | Units | 1974 | 1976 | 1978 |
|---|---|---|---|---|---|
| | MOL/POL Usage | | | | |
| 1. | Percent MOL | % | 14 | 13 | 14 |
| | Program Productivity | | | | |
| | Effort per 1000 Object Instr. | | | | |
| 2. | MOL Programs | MM | 4.18 | 3.69 | 2.90 |
| 3. | POL Programs | MM | 1.51 | 1.33 | 1.04 |
| 4. | Average U.S. | MM | 1.88 | 1.64 | 1.30 |
| | Instructions per Man-Month | | | | |
| 5. | MOL | | 239 | 271 | 345 |
| 6. | POL | | 662 | 750 | 960 |
| 7. | Average U.S. | | 532 | 610 | 769 |
| | Costs, Including Overhead | | | | |
| 8. | User Programmer | $k/mo. | 2.13 | 2.42 | 2.81 |
| 9. | Supplier Programmer | $k/mo. | 3.44 | 4.16 | 4.81 |
| | Cost per Object Instruction | | | | |
| 10. | User–MOL | $ | 8.91 | 8.93 | 8.15 |
| 11. | POL | $ | 3.22 | 3.22 | 2.92 |
| 12. | Average U.S. | $ | 4.00 | 3.97 | 3.65 |
| 13. | Supplier–MOL | $ | 14.38 | 15.35 | 13.95 |
| 14. | POL | $ | 5.19 | 5.53 | 5.00 |
| 15. | Average U.S. | $ | 6.47 | 6.82 | 6.25 |
| | Computer Usage | | | | |
| | Hours per 1000 Object Intr. | | | | |
| 16. | MOL Programs | hrs. | 14.76 | 12.85 | 11.19 |
| 17. | POL Programs | hrs. | 4.88 | 4.25 | 3.70 |
| 18. | Average U.S. | hrs. | 6.26 | 5.37 | 4.75 |
| | Instr. per Computer Hr. | | | | |
| 19. | MOL | | 67.75 | 77.82 | 89.37 |
| 20. | POL | | 204.9 | 235.3 | 270.3 |
| 21. | Average U.S. | | 159.7 | 186.2 | 210.5 |
| | Computer Operating Costs | | | | |
| 22. | Total Costs Excluding SA&P | $/hr. | 86.10 | 109.8 | 140.5 |
| 23. | Per Object Instruction–MOL | $ | 1.27 | 1.41 | 1.57 |
| 24. | POL | $ | 0.42 | .47 | .52 |
| 25. | Average U.S. | $ | 0.54 | .59 | .67 |
| | Cost Summary | | | | |
| | Cost Per Object Instruction | | | | |
| 26. | User–MOL | $ | 10.18 | 10.34 | 9.72 |
| 27. | POL | $ | 3.64 | 3.69 | 3.44 |
| 28. | Average U.S. | $ | 4.54 | 4.56 | 4.32 |
| 29. | Supplier–MOL | $ | 15.65 | 16.76 | 15.52 |
| 30. | POL | $ | 5.61 | 6.00 | 5.52 |
| 31. | Average U.S. | $ | 7.01 | 7.41 | 6.92 |

In establishing lines 5-6, I assumed that recent improvements in programming practice have accelerated the rate of change of programmer productivity—see Tables 4.22.4a, II.4.22.5a, II.4.22.7a.

## TABLE II.4.22.5a IBM FEDERAL SYSTEMS DIVISION PROGRAMMING EXPERIENCE

| | Completed Development Projects | | Service Projects | |
|---|---|---|---|---|
| | Median 50% | Quartiles 25%-75% | Median 50% | Quartiles 25%-75% |
| Productivity | | | | |
| Source lines per mm of total effort | 274 | 150-440 | | |
| Product | | | | |
| Source lines (k) | 20 | 10-59 | | |
| Pages of Documentation per 1000 lines of source code | 69 | 27-167 | | |
| Lines of maintained source code (k) | | | 103 | 56-474 |
| Ratio of Developed to Maintained Code | | | .04 | 0-.19 |
| Resources | | | | |
| Computer cost, as % of project cost | 18 | 10-34 | | |

| | Completed Development Projects | | Service Projects | |
|---|---|---|---|---|
| | Median 50% | Quartiles 25%-75% | Median 50% | Quartiles 25%-75% |
| Total effort (mm) | 67 | 37-186 | | |
| Average manning | 6 | 3.8-145 | 6 | 4-11 |
| Distribution of effort | | | | |
| Mgmt. and Admin. (%) | 18 | 12-20 | 15 | 10-20 |
| Analysis (%) | 18 | 6-27 | 10 | 4-30 |
| Prog. and Design (%) | 60 | 50-70 | 72 | 40-80 |
| Other (%) | 4 | 0-6 | 3 | 0-7 |
| Maintained lines of source code/man (k) | | | 15 | 5-24 |
| Duration (months) | 11 | 8-19 | | |
| Errors Detected | | | | |
| Total per 1000 source lines | 3.1 | 0.8-8.0 | 1.4 | .2-2.9 |
| Distribution | | | | |
| Incorrect function (%) | 76 | 50-86 | 73 | |
| Omitted function (%) | 8 | 0-22 | 11 | |
| Misinterpreted fn. (%) | 17 | 7-25 | 13 | |

Source: WalsC77

## TABLE II.4.22.6a TEN OF THE 29 VARIABLES FOUND BY IBM TO HAVE A MARKED AFFECT ON PROGRAMMING PRODUCTIVITY

| Variable | Response Group Mean Productivity (Delivered Source Lines per Man-Month) | | | Productivity Change DSL/mm | % |
|---|---|---|---|---|---|
| Customer Interface Complexity | <Normal 500 | Normal 295 | >Normal 124 | 376 | 75 |
| Overall Personnel Exper. & Qualifications | Low 132 | Average 257 | High 410 | 278 | 68 |
| Previous Exper. with Prog. Languages | Minimal 122 | Average 225 | Extensive 385 | 263 | 68 |
| Previous Exper. with Appln. of Similar or Greater Size & Complex. | Minimal 146 | Average 221 | Extreme 410 | 264 | 64 |
| Pct. of Programmers Doing Dev. Who Helped Design Functional Specs | <25% 153 | 25-50% 242 | >50% 391 | 61 | |
| User Partic. in the Defn. of Reqts. | None 491 | Some 267 | Much 205 | 286 | 58 |
| Use of Improved Programming Techniques: | 0-33% | 34-66% | >66% | | |
| Chief Programmer Team | 219 | | 408 | 189 | 46 |
| Structured Programming | 169 | | 301 | 132 | 43 |
| Top Down Development | 196 | 237 | 321 | 125 | 39 |
| Design & Code Insptions | 220 | 300 | 339 | 119 | 35 |

## TABLE II.4.22.7a PROGRAMMER PRODUCTIVITY

| Program Module Description | Program Size (k Statements) | Language | Productivity (State. per MM) | Man-Months |
|---|---|---|---|---|
| | Source:JohnJ77 | | | |
| | 3.1 | COBOL | 1679 | 1.85 |
| | 4.0 | COBOL | 1238 | 3.23 |
| | 5.6 | COBOL | 2167 | 2.58 |
| | 5.9 | COBOL | 1162 | 5.08 |
| | 10.0 | COBOL | 410 | 24.37 |
| | 14.0 | COBOL | 1264 | 11.08 |
| | 34.0 | PL-I | 797 | 42.65 |
| | 41.0 | COBOL | 961 | 42.65 |
| | 60.0 | COBOL | 379 | 158.4 |
| | 75.0 | COBOL | 410 | 182.8 |
| | 80.0 | COBOL | 365 | 219.3 |
| | 130.0 | PL-I | 191 | 682.3 |
| | 140.0 | COBOL | 884 | 158.4 |
| | 140.0 | COBOL | 287 | 487.4 |
| | 190.0 | COBOL | 473 | 402.1 |
| | 910.0 | COBOL | 249 | 3655.4 |
| | Source:DoneW76 | | | |
| Data Definition | .062 | COBOL | 1321 | .047 |
| Utility | .177 | COBOL | 2476 | .071 |
| Data Base Extracts | .186 | COBOL | 578 | .322 |
| Utility | .260 | COBOL | 413 | .630 |
| Minor Reports | .260 | COBOL | 743 | .350 |
| Utility | .449 | COBOL | 1981 | .227 |
| Data Base Utility | .450 | COBOL | 825 | .545 |
| Data Base Extracts | .530 | COBOL | 1238 | .428 |
| Major Reports | .907 | COBOL | 660 | 1.37 |
| Processing | 1.186 | COBOL | 660 | 1.80 |
| Data Base Update | 1.278 | COBOL | 1651 | .774 |
| Edit | 1.715 | COBOL | 1321 | 1.30 |

### TABLE II.4.22.9a AKIYAMA PROJECT ERROR DATA

| Module | MA | MB | MC | MD | ME | MF | MT | Subt. | MG | MH | MX |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Instructions | 4032 | 1329 | 5453 | 1674 | 2051 | 2513 | 2100 | 19152 | 699 | 3792 | 3412 |
| Faults | 102 | 18 | 146 | 26 | 71 | 37 | 26 | 426 | 16 | 50 | 80 |
| Faults/1000 Instr. | 25.3 | 13.5 | 26.8 | 15.5 | 34.6 | 14.7 | 12.4 | 22.2 | 22.9 | 13.2 | 23.4 |
| Schedule of Faults Found (Cumulative) | | | | | | | | | | | |
| Pre-Test | | | 53 | | | | | | | | |
| 40 Days | 58 | 9 | 78 | 21 | 54 | 21 | 14 | 255 | | | |
| 60 | 83 | 13 | 84 | 21 | 62 | 30 | 22 | 315 | | | |
| 121 | 94 | 17 | 92 | 25 | 67 | 36 | 26 | 357 | | | |
| 143 | 98 | 17 | 92 | 26 | 68 | 37 | 26 | 364 | | | |
| 179 | 102 | 18 | 93 | 26 | 71 | 37 | 26 | 373 | | | |

Source: AkiyF71

### TABLE II.4.22.10a CUMULATIVE NUMBER OF BUGS IN INDICATED TIME

| Source | MusaJ75 | AkiyF71 | ShooM75 | | | | |
|---|---|---|---|---|---|---|---|
| Time | | | | 83 | 118 | 340 | |
| (Days) | | | | 90 | | 345 | |
| 3 | | 13 | | 103 | | 351 | 27 |
| 9 | | 52 | 1 | 110 | | 354 | |
| 17 | | 89 | 9 | 121 | | 357 | 29 |
| 24 | 20 | 187 | | 131 | | 358 | |
| 33 | 28 | 231 | | 141 | | 362 | 30 |
| 42 | | 257 | 11 | 148 | | 367 | 37 |
| 49 | | 281 | | 169 | | 370 | 51 |
| 55 | 45 | 301 | 13 | 179 | | 373 | 52 |
| 61 | 65 | 317 | | 191 | | | 54 |
| 69 | 90 | 328 | | 209 | | | 59 |
| 75 | 105 | 336 | 21 | 222 | | | 61 |

### TABLE II.4.22.11a DETECTING AND CORRECTING FAULTS IN A 4000-INSTRUCTION PROGRAM

| | | | Causes of Faults | | | | | | Nature of Change to Correct Faults | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cause: | New Reqt. | Wrong Spec | Incomplete Spec | Program Bug | Support Software | Software Interface | Other | Change: | Fix Instr. | Change Constant | Structural | Others |
| Faults—No. | 1 | 2 | 3 | 33 | 5 | 3 | 5 | | 25 | 4 | 20 | 1 |
| Percent | 2 | 4 | 6 | 65 | 10 | 6 | 10 | | 50 | 8 | 40 | 2 |
| | | | Computer Runs Required to Diagnose (Av. 0.61 Runs) | | | | | | | | | |
| Number of Runs | | | 0 | 1 | 2 | 3 | 4 | | | | | |
| Faults—No. | | | 37 | 17 | 6 | 2 | 1 | | | | | |
| Percent | | | 59 | 27 | 10 | 3 | 1 | | | | | |
| | | | Computer Runs Required to Correct (Av. 1.35 Runs) | | | | | | | | | |
| Number of Runs | | | 0 | 1 | 2 | 3 | 5 | 6 | 10 | | | |
| Faults—No. | | | 4 | 41 | 2 | 1 | 1 | 1 | 1 | | | |
| Percent | | | 8 | 80 | 4 | 2 | 2 | 2 | 2 | | | |
| | | | Working Time to Diagnose (Av. 2.46 Hours) | | | | | | | | | |
| Time to Diagnose (Hrs) | | | .1-.25 | .5 | 1 | 2 | 3 | 4 | 5 | 7 | 14 | 17 |
| Faults—No. | | | 14 | 7 | 7 | 12 | 3 | 1 | 1 | 4 | 2 | 1 |
| Percent | | | 27 | 13 | 13 | 23 | 6 | 2 | 2 | 8 | 4 | 2 |
| | | | Working Time to Correct (Av. 1.98 Hours) | | | | | | | | | |
| Time to Correct (Hrs) | | | 0 | .1 | .5 | 1 | 2 | 4 | 7 | 28 | 35 | |
| Faults—No. | | | 1 | 27 | 11 | 5 | 1 | 3 | 1 | 1 | 1 | |
| Percent | | | 2 | 53 | 22 | 10 | 2 | 6 | 2 | 2 | 2 | |

Source: ShooM75

### TABLE II.4.22.12a PROGRAM MAINTENANCE FACTORS

| Source | HugoI77 | DalyE77 | ElshJ76 | PeepD78 | WalsC77 | LienB78 |
|---|---|---|---|---|---|---|
| Percent of Effort | | | | | | |
| New | 75 | | 25 | | | 46.1 |
| Maintenance | 25 | | 75 | | | 48.0 |
| Number of Instructions Maintained By One Programmer | | | | | | 15k |
| On-line Programs | | 10k-30k | | | | |
| Support Programs | | 30k-120k | | | | |
| Annual Maint. Hrs. per 1000 Lines of Code | | | | 1.86 | | |
| Errors Detected per 1000 Lines of Maintained Code | | | | | 1.4 | |
| Percent of Software Life-Cycle Cost | | | | | | |
| Maintenance | | | | 60-75 | | |
| Development | | | | 25-40 | | |

### TABLE II.4.4.3a MAINTENANCE COST EXAMPLE—1978

| | | Units | Peripheral | CPU and Memory | Terminal | System |
|---|---|---|---|---|---|---|
| | **System Parameters** | | | | | |
| 1. | Unit Value (V) | $k | 30 | 100 | 5 | |
| 2. | Number per System | | 8 | 2 | 12 | |
| 3. | Value per System | $k | 240 | 200 | 60 | 500 |
| | **Cost Factors** | | | | | |
| 4. | CE Hourly Rate (S) | $/hr | 8.00 | 8.00 | 8.00 | |
| 5. | Overhead Rate (r) | | 1.85 | 1.85 | 1.85 | |
| 6. | CE Fraction Available (f) | | 0.7 | 0.7 | 0.7 | |
| 7. | Burdened Salary | $/hr | 32.57 | 32.57 | 32.57 | |
| 8. | Inventory Cost (100C) | %/mo | 4.5 | 4.5 | 4.5 | |
| 9. | Operating Hours (H) | hrs/mo | 380 | 380 | 380 | 380 |
| 13. | Spares Inventory (I) | $ | 822 | 2750 | 50 | |
| 18. | Hourly Parts Cost (P) | $/hr | 3 | 3 | 10 | 3.8 |
| | **Preventive Maint.** | | | | | |
| 19. | Total Hourly Rate (R) | $/hr | 35.57 | 35.57 | 42.57 | 36.43 |
| 20. | Sched. PM Interval (T(p)) | hrs | 90 | | | |
| 21. | CE PM Time (T(rp)) | hrs | 0.25 | | | |
| 22. | CE PM Travel Time (T(tp)) | hrs | 0.2 | | | |
| 23. | Percent PM Time | % | 0.5 | | | |
| 24. | per $100k | % | 1.67 | | | |
| 25. | Monthly PM Cost | $/mo | 67.6 | | | 540.7 |
| 26. | per $100k | $/mo | 225.3 | | | 108.1 |
| | **Fixed Costs/$100k** | | | | | |
| 27. | PM | $/mo | 225.3 | | | 108.1 |
| 28. | Inventory | $/mo | 123.3 | 123.8 | 45.0 | 114.1 |
| 29. | Total | $/mo | 348.6 | 123.8 | 45.0 | 222.2 |
| | **Incremental Cost** | | | | | |
| 30. | Per % Downtime (.01RH) | $/mo | 135.2 | 135.2 | 161.8 | 138.4 |
| | **Typical Costs** | | | | | |
| 31. | MTBF (T(f)) | hrs | 750 | 900 | 2000 | 52.9 |
| 32. | MTTR (T(rf)) | hrs | 1.4 | 3.2 | 0.5 | 1.33 |
| 33. | CM Travel Time (T(tf)) | hrs | 1.0 | 1.0 | 1.0 | 1.0 |
| 34. | Percent CM Time | % | 0.32 | 0.47 | 0.075 | 4.4 |
| 35. | per $100k | % | 1.07 | 0.47 | 1.50 | 0.88 |
| 36. | CM Cost | $/mo | 43.3 | 63.1 | 12.1 | 617.8 |
| 37. | Per $100k | $/mo | 144.2 | 63.1 | 242.7 | 123.6 |
| 38. | Total Cost | $/mo | 147.8 | 186.8 | 14.4 | 1728.9 |
| 39. | per $100k | $/mo | 492.8 | 186.8 | 287.7 | 345.8 |

**TABLE II.4.4.3a MAINTENANCE COST EXAMPLE—1978 (continued)**

| | | Units | Peri-pheral | CPU and Memory | Ter-minal | System |
|---|---|---|---|---|---|---|
| | System Values | | | | | |
| 42. | Total Fixed Costs | $/mo | 836.6 | 247.5 | 27.0 | 1111.1 |
| 43. | Car Cost | $/mo | 346.0 | 126.2 | 145.6 | 617.8 |
| 44. | Total Cost | $/mo | 1182.6 | 373.7 | 172.6 | 1728.9 |
| 45. | Failures per Month | | 4.05 | .84 | 2.28 | 7.17 |
| 46. | Repair Time per Mo. | hr/mo | 5.67 | 2.70 | 1.14 | 9.51 |
| 47. | CE Hrs./Mo.–PM | hr/mo | 15.2 | | | 15.2 |
| 48. | CM | hr/mo | 9.7 | 3.5 | 3.4 | 16.6 |
| 49. | Total | hr/mo | 24.9 | 3.5 | 3.4 | 31.8 |
| 50. | Direct Labor Cost | $/mo | 199.4 | 28.4 | 27.4 | 255.2 |
| 51. | Indirect Labor Cost | $/mo | 85.5 | 12.2 | 11.7 | 109.4 |
| 52. | Overhead Cost | $/mo | 527.0 | 75.0 | 72.3 | 674.3 |
| 53. | Total Labor Cost | $/mo | 811.9 | 115.5 | 111.4 | 1038.8 |
| 54. | Parts Cost | $/mo | 74.8 | 10.6 | 34.2 | 119.6 |
| 55. | Inventory Cost | $/mo | 295.9 | 247.5 | 27.0 | 570.4 |
| 56. | Total Cost | $/mo | 1182.6 | 373.7 | 172.6 | 1728.9 |
| | Percent Distributor | | | | | |
| 57. | Direct Labor | % | 16.9 | 7.6 | 15.9 | 14.8 |
| 58. | Indirect Labor | % | 7.2 | 3.3 | 6.8 | 6.3 |
| 59. | Labor Overhead | % | 44.6 | 20.1 | 41.8 | 39.0 |
| 60. | Parts Cost | % | 6.3 | 2.8 | 19.8 | 6.9 |
| 61. | Inventory Cost | % | 25.0 | 66.2 | 15.6 | 33.0 |
| 62. | Total | % | 100.0 | 100.0 | 100.0 | 100.0 |
| 63. | Labor Cost | % | 78.2 | 11.1 | 10.7 | 100.0 |
| 64. | Parts Cost | % | 62.5 | 8.9 | 28.6 | 100.0 |
| 65. | Inventory Cost | % | 51.9 | 43.4 | 4.7 | 100.0 |
| 66. | Total Cost | % | 68.4 | 21.6 | 10.0 | 100.0 |

Figure II.4.22.1a PRODUCTIVITY RELATIONSHIPS DERIVED FROM 61 IBM PROGRAMMING PROJECTS

M = Total effort in man-months
P = Thousands of lines of delivered source code
D = Pages of documentation
t = Project duration in months
M/t = Average number of people on staff
$C_c$ = Computer Cost in $k

Least-square fit: minimize y-distance

$M = 5.2\ P^{0.91}$

$P = .925\ M^{0.70}$

$D = 49\ M^{1.01}$

$t = 4.1\ P^{0.36}$

$t = 2.47\ M^{0.35}$

$(M/t) = .54\ M^{0.6}$

$C_c = 1.1\ M^{0.81}$

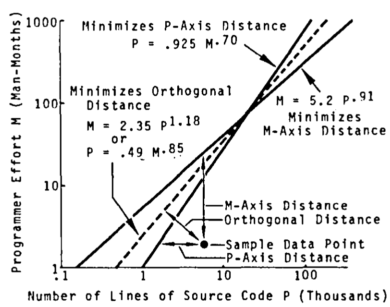
Least-square fit: minimize orthogonal distance

$M = 2.35\ P^{1.18}$

$P = .49\ M^{0.85}$

$\frac{P}{M}$ = Productivity

$= 425.5\ P^{-.18}$ Lines/mm



# Bibliography and Indexes

# Introduction

## USE OF THE BIBLIOGRAPHY

This annotated bibliography is subdivided into the same four chapters (covering the Marketplace, Products, Applications, and Costs) as is the rest of the book, and it uses the same numbering system for the subheadings within those chapters. The reader interested in references on a general subject is therefore advised to find that subject in the Table of Contents at the front of the book, and then to examine the corresponding section of the bibliography. For example, if one is interested in communications products, one would find "2.14 Data Communications" under the Products chapter in the Table of Contents, and would thus look under Section 2.14 in this bibliography.

If the reader finds a reference, in the text, to a bibliographic entry, and wants to find that entry here in the bibliography, he is advised to turn to Index D at the end of the book. There all bibliographic citations are arranged in alphabetical order, each with a number indicating that section of the bibliography which contains the entry. For example, if the reader finds a reference to KnutD71 in the text, he should turn to Index D. There he will find Section 2.15 listed opposite KnutD71; and under Section 2.15 of the bibliography he will find the complete reference.

Index D is also useful in locating all articles by a given author. Look in the index under the first four letters of the author's last name, followed by the (capitalized) initial of his first name. The index then lists the section number in the bibliography under which the reference may be found. For example, if one were interested in articles by D.G. Gibson, one would look under GibsD in Index D, and would be referred to Section 2.21 of the bibliography.

## SOURCES

As was mentioned and demonstrated in the introduction to this book, there are several sources which collect and disseminate statistical data about various aspects of the data processing industry. Before listing these sources, let me describe two useful and more general sources of data.

The first is the United States government. The U.S. Department of Commerce collects and publishes data on virtually every aspect of American business and commerce. A good starting point for an overview of that data is CenStatAb, and that reference is described in Section 1.1 below, along with other key publications available from the same source. Most university and many public libraries have these publications, and some libraries are designated as centers which maintain fairly complete files of *all* government publications.

Much economic data about U.S. business is also published from time to time in magazines and other periodicals. The accuracy of such data is quite uncertain, but the periodicals generally indicate the source o. data and thus give the reader some basis for forming a judgement about accuracy. Usually such articles are intended to evaluate the future for an industry, a company, or a type of product.

There exists an excellent source which provides a fairly complete and extremely useful index to this public data. It is called *Predicasts*, and is published by an organization named Predicasts, Inc. The material in this periodical is generally organized by SIC code, though some of the information (e.g. population, or gross national product) cannot be classified in that way. A typical line entry in *Predicasts* describes a product type (e.g. "data communications" or "magnetic tape units"), an event (e.g. "number in use at year-end" or "annual dollar shipments"), along with data measuring the event. The data covers a period of up to three specified years, typically one or two in the past, and two or one in the future. The periodical in which the data was published, along with its date and page number, are given by *Predicasts* so that the reader may look up the article to see what other data it contains, and to note the sources and the assumptions employed. An excellent subject index is included.

The following organizations are among the most important of those whose business it is to collect, analyze, and publish information about the data processing industry—though, as will be seen, some of them are also active in other areas as well.

**Arthur D. Little Corp.** ADL, of Cambridge, Mass., is primarily a consulting firm and has interests and expertise in many technical areas besides data processing. However, as an expression explicitly of its data processing interests, it has for some years produced a limited-distribution report presenting a five-year forecast of business and technical trends in data processing.

**Auerbach, Inc.** Auerbach, of Philadelphia, Penn., is the oldest of the companies which survey and summarize the products in the data processing industry. (AuerCTR, described in Section 2.0 below, is an example of one of Auerbach's most popular publications.) The company also is in the consulting business, and is a publisher of books on computers and data processing.

**Datapro Research Corp.** Datapro, of Delran, N.J., is a consultant and publisher comparable in many ways to Auerbach. (see DProEDP in Section 2.0 below.)

**The Diebold Group.** Diebold, located in New York City, are consultants and are the publishers of *Automatic Data Processing Newsletter* (*ADP/N*), which for some years printed a periodic census of U.S. computer installations.

**International Data Corporation**. IDC, of Waltham, Mass., is a consulting firm, and the publisher of the weekly newspapers *Computerworld* and *Computer Business News*, and of various newsletters including the bimonthly *EDP Industry Report* (*EDP/IR*). IDC maintains what is, in my opinion, the best set of statistics available about the data processing industry. In part, the quality of these statistics arises from the fact that IDC keeps a close watch on the industry via its publishing and consulting interests. In part, it comes from the existence of a regularly-maintained and updated file of data on over 30,000 U.S. computer sites containing more than 45,000 GP computers. The data in this file is collected from survey questionaires returned to IDC by computer users. The surveys contain data on the quantity and model numbers of hardware products at each site. And IDC periodically evaluates the accuracy of data in the returned questionaires by telephoning selected sites. Finally, the accuracy of IDC's statistics on the industry arises in part from the fact that IDC maintains a very *broad* range of statistics, with the result that the company can make cross-checks on various aspects of the business. (For example, they can compare data on the sales of magnetic tape and disk packs, included as part of their statistics on the supplies industry, with data on installations of magnetic tape units and moving-head-file spindles.)

## Citations

### INTRODUCTION

**GustG71.** Gustafson, G.A., "An Evaluation of the Automated Teacher Credentialing System," Commission for Teacher Preparation and Licensing, Sacramento, Calif. 1971. Describes a computer system intended to reduce costs of and speed processing of applications for teachers' credentials. Concludes that the computer system should be removed and that a new and much cheaper manual system should be implemented. (A subsequent follow-up in September, 1973, confirmed that the computer had been removed and the manual system implemented.)

**PhisM58.** Phister, M., Jr., *Logical Design of Digital Computers*, New York: John Wiley and Sons, 1958. "The classical work applying Boolean algebra to computers. Presented here are models which incorporate a concept of time. This is a pioneering attempt to systematize the computer art; the trouble is, it seems to add little to one's ability to design a better computer." (From an annotated bibliography in *Computer Logic* by Ivan Flores, Prentice-Hall Inc., 1960.)

**PhisM76.** Phister, M., Jr., 'A Proposed Course on Data Processing Economics," *Computer, 9,* 9, Sept. 1976, 44-48. Describes a suggested university course for computer science and engineering students, explains the purpose of such a course, and presents arguments for and against it—mostly for.

### 1.1 BACKGROUND

**CenCenMan.** U.S. Dept. of Commerce, Bureau of the Census, "Census of Manufacturers". A detailed analysis of all U.S. manufacturing industries, conducted at 10-year intervals from 1809-1899, and at 5-year intervals since then. Recent censuses in 1958, 1963, 1967, 1972. Gives more detailed data than CenSurMan (q.v.).

**CenColoTi60,65.** US Dept. of Commerce, Bureau of the Census, *Historical Statistics of the U.S.—Colonial Times to 1957*, 1960 (update 1965). A marvelous book providing a great variety of statistics about the U.S., generally over the past 200 years. The 1965 update carries the data on up to and including 1962, and adds some new data. Much of the data continues to be reported every year in CenStatAb (q.v.).

**CenCurBiz.** US Dept of Commerce, Bureau of the Census. *Survey of Current Business.* A monthly periodical which presents timely data and commentary. Annual June/July issues contain yearly data on such things as number of employees, wages and salary, sales, capital expenditures (including those for computing and office machinery), and national income analyses.

**CenLong66.** US Dept of Commerce, Bureau of the Census, *Long Term Economic Growth 1860-1965*, October 1966. A fascinating look at selected data, presented both graphically and in tables, on the U.S. and certain foreign countries. Generally covers the period since 1860, though it includes some interesting industry and regional comparisons for the period since 1950.

**CenStatAb.** US Dept of Commerce, Bureau of the Census, Statistical Abstract of the United States. An annual collection of a great variety of statistics on the U.S. Much of the data is a continuation of, and consistent with CenColoTi60 (q.v.).

**CenSurMan.** US Dept of Commerce, Bureau of the Census, *Annual Survey of Manufacturers*, almost annually since 1949. Gives establishments, employees, payroll, production workers, wages, value added, and capital expenditures for all manufacturing from 1849 to the present. Gives employees, payroll, production workers, wages, value added, material costs, shipment value, capital expenditures for 1-2 years by major SIC code—and at more detailed level also. Shows inventories, fuel use, plant expenditures. See also CenCenMan.

**ComIndOutXX.** U.S. Dept. of Commerce, "U.S. Industrial Outlook, 19XX", An annual publication of the Department of Commerce which summarizes the recent historical data on each major industry and provides comments and interpretive remarks. Must be used with care, because it is apparently produced hurriedly and often contains typographical and other errors in the numerical tables.

**EIAYrbk.** Electronic Industries Assoc *Yearbook.* An annual publication of the EIA, Washington, D.C. Subdivides the industry into consumer products, communications and industrial products, government products, and replacement components, and shows the growth of each of these sectors since 1914. Also provides some data on employment, the U.S. balance of trade, and research and development expenditures. Gives shipments and average values for electronic components in a variety of different categories.

**EIUQR.** Economist Intelligence Unit, Ltd., *Quarterly Economic Review of (Country)*, London (quarterly). Gives latest estimates of GNP, population, and other items for most countries of the world. Financial data is expressed in local currencies.

**IMFIFS.** International Monetary Fund, *International Financial Statistics*, Washington, D.C. (monthly). Gives latest estimates of GNP, population, and many other items for most countries of the world. Financial data is expressed in local currencies.

**MorgO63.** Morgenstern, Oskar, *On the Accuracy of Economic Observations*, Princeton U Press, 1963. 2nd ed. Extraordinarily readable and realistic review and warning on the difficulties inherent in presenting statistical economic data.

**PoraM76.** Porat, M.U., "The Information Economy," Report No. 27, Institute for Communications Research, Stanford University, Aug 1976. A fascinating and beautifully documented analysis of the information sectors of the U.S. ecomony—of that portion of the economy involved in transforming information from one pattern to another, as distinguished from the other portion, which is responsible for transforming matter and energy from one form to another.

**UNStYe.** United Nations, *Statistical Yearbook*, Statistical Office of the United Nations, Dept of Economic and Social Affairs. Published annually since 1948. Provides a variety of data on national product, population, and other subjects for most of the principal countries of the world.

### 1.20 OVERVIEW

**CEIR66.** American Federation of Information Processing Societies, *The State of the Information Processing Industry*, NY, 1966. Results of a study consisting of a literature search, and of interviews with authorities in the field. Discusses personnel, salaries, hardware characteristics, installation data, new products and industries, automation and job displacement, and computer applications. Includes extensive bibliography. Generally concludes that good data is not available.

**DoloT76.** Dolotta, T.A., et al, *Data Processing in 1980-1985—A Study of Potential Limitations to Progress*, John

Wiley & Sons, N.Y., 1976. Discusses the economic and societal environment expected, the characteristics of users of computer equipment, present and future applications, hardware, software, and management.

**GropA70.** Groppelli, A.A., *The Growth Process in the Computer Industry*, Dissertation presented to Faculty at the Graduate School of Arts and Sciences, NYU, in partial fulfillment of requirements for degree of Ph.D, June 1970. A fascinating and quantitative review of the industry, with particular emphasis on the role played by IBM. Relies extensively on computer censuses from *Computers and Automation.*

**GrueF62.** Gruenberger, F., "Editor's Readout–.06 Ideas/ Kiloman Year", *Datamation* 8, 1962, p.23. Identifies 30 key ideas, considered by the author to be the most significant contributions to the industry's progress.

**IDC1932.78.** IDC, *Keys to Profitability in the Independent Peripheral Market*, No. 1932, Nov., 1978. Breaks down the U.S. independent peripherals industry, by purchaser (OEM, PCM, and end-user not PCM) and by peripheral.

**IDCBrief.** In February each year, International Data Corp. holds an all-day seminar at which they present their analysis of the preceding year's results and a forecast for the coming year. A notebook containing pertinent data is given out to attendees. Content varies somewhat from year to year, but generally there is an analysis of shipments and revenues of the major GP, SBC, and mini manufacturers, a review of the service industries (including software), and of the terminals business.

**NyboP77.** Nyborg, P.S., et al., "Information Processing in the United States–A Quantitative Summary", AFIPS Press, N.Y., 1977. Provides data on suppliers of equipment and services, on users and user expenses, and on personnel and education, in the computer field, mostly in the U.S. Gives forecasts for some figures.

**OECDGaps.** Organization for Economic Cooperation and Development, *Gaps in Technology Between Member Countries.* Includes three reports: (1) General Report; (2) Sector Reports–scientific instruments, electronic components, electronic computers, plastics, pharmaceuticals, nonferrous metals; and (3) Analytical Report–education, research and development, technological innovation, and international economic exchanges. (All in one volume.)

**SharW69.** Sharpe, William F., *The Economics of Computers,* Columbia University Press, NY 1969. A pioneering and most successful attempt to study the economics of data processing, by collecting and analyzing available statistics on computers and their application. The first third of the book presents relevant economics theory. The last seven chapters cover the computer industry and include analyses of prices and pricing policy, system performance, and of the markets for equipment and services and software.

**USSen74.** U.S. Senate, Committee on the Judiciary, "The Computer Industry", *Hearings Before the Subcommittee on Antitrust and Monopoly*, July 23-26, 1974. A fascinating mish-mash of arguments, data, complaints about, and suggestions regarding, IBM's dominant position in the computer field. IBM's only part in the proceedings is an initial warning that virtually all the individuals invited to testify have an axe to grind against IBM.

## 1.22 GP SYSTEM COMPONENTS

**IDC1671.76.** International Data Corp., *Small Business Computers*, No. 1671 March, 1976. Results of an analysis of 816 survey returns covering a variety of small GP and SBC systems. Gives data on configurations, applications, and budgets.

**IDC1675.76** International Data Corp., *The Independent Memory Market*, No. 1675, March 1976. Gives data on the distribution of memory sizes among IBM 360, 370, and S/3 systems, as of 12/75, and projections back to 1973 and forward to 1977.

**IDC1728.76** International Data Corp., *IBM Fixed Media Disk Drives (3344 and 3350)*, No. 1728, August, 1976. Presents estimates of the populations of 2314/19, 3330, 3340, 3344, and 3350 disk spindles on IBM 370 Systems as of December, 1975, based on an analysis of IDC's data file. The estimates include "percent with" and "average number" data by IBM 370 CPU's and are extrapolated to 12/77.

**IDC1811.77.** International Data Corp., *Minicomputer Marketplace,*, No. 1811, August, 1977. One of a series of IDC reports on the subject. Includes revenues and shipments of the major suppliers, and a sampling of miniperipheral configurations on DEC, Hewlett-Packard, and Data General minis.

**IDC1824.77.** International Data Corp., *Line Printer Market*, No. 1824 Nov., 1977. Gives current estimates and forecasts of the number of line printers *and character printers* in use in the U.S. over the period 1976-1981, based on an analysis of IDC's data base. Breaks down the population by large, medium, small, and minicomputer sites, and then adds usage at terminals, key-to-disk systems, and word processors. The non-mini computer sites include some SBC's as well as GP's, so the results must be interpreted with care.

**IDCPeriph72.** International Data Corporation, "A Report to Management: Independent Computer Peripheral Equipment," *Business Week,* June 24, 1972. An advertising insert, prepared by *IDC*, and containing data on the market for IBM peripherals, principally tapes and moving-head files.

**MisdW71.** Misdom, W.E. and Stone, J.A., "Outlook for the Peripheral Equipment Industry", *Wall St. Transcript*, Jan 11, 1971, pp. 22860 ff. One of the few quantitative articles on the peripheral equipment industry. Authors from IDC and Quantum Sciences. Mostly concentrates on IBM 360-compatible tapes and disks.

**MoDa72.** Modern Data Services, Inc., "Market Survey: IBM Compatible Disk, Tape, and Core Storage", Framingham, Mass.:1972. Analysis of a sample of 1,215 IBM 360 and 370 users. Gives data on tape and disk model numbers and internal memory sizes for each CPU model number, based on the sample.

**NBS72.** National Bureau of Standards, "Means of Achieving Interchangeability of Computer Peripherals", Federal Information Processing Systems Report by The Center for Computer Sciences and Technology, May 1972. Recommends ways the Federal Government can effect savings in procurement of computer peripheral equipment by making it possible to interchange equipment of various manufacturers. Provides some data on the number and value of peripherals in use on government computers as of March 31, 1972.

## 1.23 DATA ENTRY EQUIPMENT

**IDC1765.76** International Data Corp., *Data Entry Site Analysis,* Waltham, Mass. 02154, Dec. 1976, No. 1765. Results of a survey of data entry practices of 939 GP computer sites spanning all sizes from System 32 to Cyber-74. Gives distribution of keypunches, key-to-tape, and key-to-disk systems, terminals, and OCR/MICR devices in each of seven computer size classes.

**IDC1905.78** International Data Corp., *Statistical Reference Book, Data Entry/Communications Equipment*, Waltham, Mass. 02154, Aug. 1978, No. 1905. One of a series of IDC reports on this subject. Each generally gives a summary of number and value, in-use and shipped, in a 6-8 year time span including some history and some forecast. Remote-batch terminals, OCR and other data entry equipment (but not MICR), and conversational, editing, and processing terminals are included.

## 1.24 DATA COMMUNICATIONS AND TERMINALS

**ZeidH69.** Zeidler, H.M. et al, "Patterns of Technology in Data Processing and Data Communications", Stanford Research Institute Report 7379B-4, Feb 2969, in Dept of Commerce Clearinghouse Document PB 183 612, vol.1. Reports on a study of the technology and costs of computers, software, terminals, and data communications. Is based partly on FCC data, partly on studies of the literature and discussions with industry representatives. Contains a great deal of data and an excellent bibliography.

## 1.25 SOFTWARE EXPENSES

**BelaL77** Belady, L.A., and Lehman, M.M. "The Characteristics of Large Systems", IBM Report RC 6785, ( 28969), Sept. 13, 1977. Provides data and arguments on the characteristics and history of some large software systems, and concludes that their complexity, and the requirement that they be continually modified and "improved", "make them costly to implement, even more costly to maintain, and could prove disasterous in certain applications."

**IDC1968.79.** International Data Corp., *The Independent Packaged Software Market,* No. 1968, March, 1979. Gives estimates of the revenues captured by independent (i.e. non-mainframe) software houses for their "packaged" products. Breaks such products down into Systems, Utility, and Applications pakages, with revenue estimates for the years 1976-1983.

**IDC1980.79.** International Data Corp., *Industry Forecast 1979*, No. 1980, May, 1979. Presents data on user spending on computers in the U.S., and on vendor revenues, as reported in various IDC Data Bases, for the years 1977-1979. Explains the reasons for apparent discrepancies.

## 1.26 THE DATA PROCESSING SERVICE INDUSTRY

**DesJServ.** DesJardins, R.H., *An Economic Analysis of the Data Processing Service Industry*, Dec 1, 1967. (See IDCServ, below.)

**IDC1781.77.** International Data Corp., *Independent Software/Facilities Management/Processing Services Statistical Reference Book*, No. 1781, May, 1977. One of a series of IDC reports on this industry. Estimates revenues from packaged and custom software, batch, interactive batch, and remote services, among other things. Covers the years 1975-1981.

**IDCServ.** IDC, *Annual Industry Survey* (of the Data Processing Service Industry). Since 1966, the Association of Data Processing Service Organizations (ADAPSO) has sponsored an annual industry-wide survey. The versions published from 1967-1970, inclusive, were carried out by R.B. DesJardins (See DesJServ, above). From 1971 to 1973, they were published by IDC. The 1974 study was carried out by Quantum Sciences Corp. Each study describes the industry in general, under the sector headings of batch-data processing, on-line processing, software, and other (including key punch services, OCR, COM, training, and facilities management). In general, however, the reports concentrate on performance of the service bureaus, which comprise the biggest part of today's service industry.

**INPUTServ78.** INPUT, *Twelfth Annual Survey of the Computer Services Industry*, Menlo Park, CA, July, 1978. Since 1976, INPUT has published a survey of the computer services marketplace, including software products and facilities management. This is their first ADAPSO Report (The Eleventh ADAPSO survey was conducted by IDC).

**MacDN58.** Macdonald, N. "Computing Services Survey," *Computers and Automation, 7,* 7, July, 1958, 9-12. Reports the results of a survey of firms which provide computer services. Gives data on firm size, age, and computers used, along with a listing of organizations which replied.

## 1.27 DATA PROCESSING SUPPLIES

**BroeC78-1.** Broemel, C.A. "A Study on the World Magnetic Tape Industry." Plastics Division, ICI Petrochemicals and Plastics Co., Wilmington, Del. March 1978. Estimates production and consumption, in units and dollars, of magnetic media used in the computer, audio, video, instrumentation, and cinematic industries. Includes reel tape, floppy disks, cassettes, 1/4-inch cartridges, and magnetic cards in the computer media portion.

**IDC1554.75** International Data Corp., *The Media Marketplace*, No. 1554, Jan. 1975. Estimates the number of disk packs and modules, and tape reels, in use at year-end 1973. (See also IDC1740.76)

**IDC1740.76** IDC, *The Media Marketplace*, No. 1740, September, 1976. September, 1976. Gives detailed estimates and projections of the number of disk packs, cartridges, floppy disketts, tape reels, and cassettes/cartridges in use, based on estimates of the number of devices using the media. Is particularly interesting in that it shows estimates of disk spindles per 370 system, by spindle type.

## 1.28 WORLDWIDE COMPUTER INSTALLATIONS

**BarqR74.** Barquin, R.C., "Computation in Latin America", *Datamation, 20*, 3, March 1974, pp.73-78. Provides data on number of computers in use in each South and Central American country, along with calculations of computers per million people and per $B GNP. Data was collected by the author on field trips in 1972 and 1973.

**BruiW66.** Bruijn, W.N. de, *Computers in Europe 1966*, Amsterdam, Neth. Automatic Information Processing Research Center, 1966. An *excellent* review of installations in Europe 1955-65, by country.

**BruiW67.** Bruijn, W., "Recent Developments in the European Market," *Datamation, 13,* 12, Dec. 1967, 25-26. Shows computers in use in Europe, by country, for the years 1965-1967. Gives some data showing installations by industry in 1965.

**BDCommMo/Yr.** Business and Defense Services Administration, *Overseas Business Reports,* U.S. Department of Commerce, Mo./Yr. The Department of Commerce has periodically published reports on the computer industry outside the United States. The number and value of equipments imported, exported, and in use is often given, by country.

**CompC68.** Computer Consultants, Ltd., *European Computer Survey*, Pergamon Press, 1968. An excellent survey of various aspects of the data processing business in Europe.

**DataCens62.** *Datamation,* Magazine, "*Datamation's* International Computer Census,"*8,*, 8, Aug., 1962, 46-48. Shows computers in use in the U.S., Benelux, France, Germany, Great Britain, Italy, Scandanavia, and 'others' as of July, 1962, by manufacturer and model number.

**EmOff72.** Department of Employment, "Computers in Offices 1972", Manpower Study 12, London: HMSO, 1972. Provides data on applications, on installations, and on office and computer personnel. Concludes that the advent of electronic data processing "has not caused widespread, major repercussions in office personnel".

**HarmA71.** Harman, A.J., *The International Computer Industry,* Harvard University Press, Cambridge, Mass., 1971. Reviews the history of the industry in the U.S., Europe, and Japan.

**JCUsag70.** Japan Computer Usage Development Institute, *Computer White Paper—1970 Edition.* Summary of highlights compiled from the Japanese original and published by Japan Computer Usage Development Institute. Provides data on computer inventories, on the relative value of Japanese- and foreign-made computers, on computer operating costs, on computer peripheral equipment and data communication facilities, on computer personnel, and on present and potential problems.

**LeeW71.** Lee, Wayne J., "The International Computer Industry", Applied Library Resources, Inc., Wasnington, D.C., 1971. Presents a melange of information about computer use in many nations, mostly culled from U.S. Government reports.

**LeviG67.** Levine, G.B., "Computers in Japan," *Datamation, 13,* 12, Dec., 1967, 22-24. Describes Japanese computer manufacturers, and gives a history of computers in use in Japan from 1958 to 1967.

**OECDGapCtrs69.** OECD, *Gaps in Technology—Electronic Computers*, Paris, 1969. Describes the computer industry from a variety of points of view. Argues that the industry is a key factor in the structure of any country. Points out that a small group of American companies dominate the world computer industry, and that IBM has a particularly strong position, both in the US and abroad. Finds that "the most important gap between the United States and other industrial advanced member countries lies in the capacity to bring inventions swiftly and successfully to the market." (p.10)

**PantA76** Pantages, A. "The International Computer Industry," *Datamation, 22* 9, Sept 1976. One of five articles on the subject, covering the U.S. Multinational corporations, and the industries in Western Europe, Japan, and the Soviet Bloc.

**PeteR76** Peters, R.A. & Bunn, H.F. "Economy Dips, Terminal Forecast Climbs." *Datamation, 22*, 12, December, 1976, 102B-102H. Summarizes the results of a study by PA International Management Consultants for the 17 communications authorities of Western Europe. Shows that terminal shipments exceeded forecasts during a time when the economies in general were in trouble.

**SelCom70.** Select Committee on Science and Technology. Session 1969-70, *United Kingdom Computer Industry*, London: HMSO, 1970. 2 vols. Report by a House of Commons committee on science and technology, and a subcommittee established to examine "the prospects for the UK computer industry in the 1970's, including the possibilities of an international collaboration and the functions of government in this field both as policy maker and user."

**SelCom71.** Select Committee on Science and Technology, *The Prospects for the UK Computer Industry in the 1970's*, Fourth report, Session 1970-71, London: HMSO, 1971. 3 vols. A continuation and conclusion of the 1969-70 session of the Select Committee referred to above.

**SzupB78.** Szuprowicz, B.O. "The world's Top 50 Computer Import Markets". *Datamation 24* 3, March 1978, 153-168. An analysis and discussion of international trade statistics, compiled by the U.N. and analyzed by the author's company, 21st Century Research. Gives a breakdown of imports by country for the years 1972-1975, and imports and exports by region.

**ThorB75.** Thornton, B.S., "Factors Affecting the Economics and Use of E.D.P. Resources in Australia", Sydney, Australia: Foundation for Australian Resources, July, 1975. Reviews history of computer use in Australia. Gives data on installations, personnel, software, industry usage, and other matters.

## 1.3 COMPANIES

**AR.** Annual Report. A report to the stockholders, published once a year by a company, describing its activities during that year and supplying financial data on its operations, including at least a statement of revenue and profits, and of assets and liabilities.

**Data/50** *Datamation*, "The Top 50 Companies in the DP Industry" June, 1976; June, 1977; June, 1978; May 25, 1979. An Annual survey of the fifty U.S. companies whose revenue from data processing (programming, equipment, or services,) puts them in the first fifty. For each company, gives DP revenues, total revenues, net income from the total revenues, number of employees, and estimated breakdown of revenues between mainframes, minis, peripherals and terminals, media and supplies, and software and services. Also gives brief corporate history and discussion.

**MoodI.** Moody's Investors Service, Inc., *Industrial Manual,* New York, N.Y. Summarizes the financial data for most U.S. industrial corporations and enterprises of any importance. Includes a summary of the history, background, business, and products of each organization.

**Pros.** Prospectus. When a company issues stock, it is required to provide a detailed description of its operations over the past several years, along with a statement as to how it proposes to use the issued stock or the proceeds from selling the stock. Prospectuses often contain data not available in AR's or 10K's.

**S&PCR.** Standard and Poor's Corp., *Standard Corporation Descriptions,* New York, N.Y. Like MoodI, this periodical summarizes the financial status and history of most U.S. corporations.

**10K.** One of a series of reports submitted by each company listed on a stock exchange, to the Securities and Exchange Commission. The 10K report is an annual report, and generally contains all of the information in AR together with additional data as required by the SEC. 10K reports are available in some libraries. Furthermore, any stock exchange which trades in a stock must have on file the 10K reports for each company for the past five years.

### 1.311 IBM

**BrocG75.** Brock, G.W., *The U.S. Computer Industry: A Study of Market Power,* Ballinger Publishing Co., Cambridge, Mass., 1975. A fascinating account of the history of the industry and of the companies which have participated in its growth. Analyzes pricing and product actions, and recommends that changes be made—specifically, that IBM be split into a maintenance company, a peripheral company, a marketing company, and a CPU company. Much of the data behind the analysis comes from IBM documents made public in the course of legal procedings.

**CounEur71.** Council of Europe, *The Computer Industry in Europe: Hardware Manufacturing.* Document 2893, January 15, 1971. Describes the European computer scene and concludes that IBM dominates it. Reviews the steps taken by the governments of the United Kingdom, France, and West Germany to encourage and support their national industries. Suggests that a European pooling of development, manufacturing, and marketing resources might be necessary to end the domination.

### 1.4 PERSONNEL

**BusAuSal.** *Management and Business Automation Magazine,* "EDP Jobs and Salaries". Published annually, at midyear, starting in 1959. Gives job descriptions and salaries for many jobs, including system analysts, programmers, computer operators, keypunch operators, and their managers and supervisors.

**CvSrvOccu.** US Civil Service Commission, "Occupations of Federal White Collar Workers", Bureau of Manpower Information Systems. Published various dates since 1954. Gives manpower count and average salaries in all government white-collar jobs. Under "General Administrative, Clerical, and Office Services" gives 40 or more classifications. The 1968 edition summarizes data processing occupations including operators, programmers, card punch, and electric accounting-machine operators for period 1958-1968.

**GilcB69.** Gilchrist B., "Manpower Statistics in the Information Processing Field", *Computers and Automation* Sept 1969, pp.24-27. Survey of the very sparse statistics on data processing employment. Cites sources. Summarizes estimates of programmer, system analyst, and operator counts, from US Dept of Labor sources.

**GilcB72-1.** Gilchrist, B. and Weber, R.E., "Sources of Trained Computer Personnel—A Quantitative Survey", *AFIPS Conf. Proc., 40,* 1972, pp.633-679. This surveys the public schools, private EDP schools, and universities as sources of computer employees. Estimates how many potential and actual employees have been supplied from various sources annually since about 1965.

**GilcB72-2.** Gilchrist, B. and Weber, R.E., "Employment of Trained Computer Personnel—A Quantitative Survey", *AFIPS Conf. Proc., 40,* 1972, pp.641-647. Reviews a variety of sources of data to come up with an estimate of the number of system analysts, programmers, computer operators, and keypunch operators employed in the United States at the end of 1970. Reviews data from federal government sources, local government sources, and business. The latter data covers the largest number of employees, and is derived from area wage surveys conducted by the Federal Bureau of Labor Statistics.

**GilcB72-3.** Gilchrist, B., "The US Data Processing Industry", *Proceedings of the US-Japan Computer Conference,* Oct 1, 1972. Estimates the number of companies involved, dollar revenues, shipments and installed base, use of computers by various industry groups, imports and exports of computing equipment, and data processing personnel in the US, mostly for the period 1971-1972.

**GilcB74-2.** Gilchrist, B., and Kapor, R., "Computer Industry Employment", *American Federation of Information Processing Societies, Inc.,* Montvale, N.J., July 1974. Derives estimates of the total number of employees in Standard Industrial Classification 3573 (Electronic Computing Equipment) for the years 1967 and 1970-1972, in four major categories: manufacturing, auxiliary, (R&D and administrative employees), wholesale (sales and marketing employees), and services (maintenance, repair, and programming employees who provide services to other companies). The data sources are various government reports.

**GilcB74-1.** Gilchrist, B., and Weber, R.E., "Numerical Bias in the 1970 U.S. Census Data on Computer Occupations", AFIPS Press, N.J., 1974. Compares data from the Bureau of the Census with that from the Bureau of Labor Statistics for the four occupations Programmer, Systems Analyst, Computer Operator, and Keypunch Operator. Performs corrections on raw data to make the two sources comparable, and then attempts to explain the large resulting differences. Treats the years 1969-1973, inclusive.

**LabSPT.** US Dept. of Labor, *National Survey of Professional Administrative, Technical, and Clerical Pay,* published annually since 1960. Includes salaries and numbers of employees, with definitions of responsibilities, for accounting clerks, file clerks, keypunch operators, tab-machine operators, typists, and secretaries among others. Defines jobs.

**McLaR74,1.** McLaughlin, R.A., "EDP Salary Survey", *Datamation, 20,* 5 May 1974, 50-56. Gives job descriptions, then salaries for a number of EDP job categories as of late 1973. Shows averages, lows, highs, and quartiles, as well as ranges, as a function of hardware rental. Similar reports are published annually in *Datamation.*

### 2.0 INTRODUCTION

**AuerCTR.** Auerbach Information, Inc., *Auerbach Computer Technology Reports,* Philidelphia, Pennsylvania. A Comprehensive guide to systems (hardware and software) provided by the major computer manufacturers. Started in the early Sixties, the reports currently occupy about ten thick volumes, and are updated periodically as part of a service to subscribers. Information for systems from all manufacturers is presented in a standard or near-standard format to facilitate comparison of different systems. Price as well as performance data is supplied, along with configuration detail.

**ANSI.** ANSI, *American National Standard Vocabulary for Information Processing,* American National Standards Instutute, Inc., New York, N.Y. ANSI X3.12-1970. Defines the principal terms used in the industry.

**DProEDP.** Datapro Research Corp., *Datapro 70. The EDP Buyer's Bible,* Delran, N.J. A periodical, published in several looseleaf volumes since 1970, which provides technical and price data on the major computer equipment (including processors, memories, and peripherals) of the system manufacturers. Is similar to but more concise than AuerCTR.

**RoseS69.** Rosen, Saul, "Electronic Computers: A Historical Survey," *Computing Surveys, 1* no. 1, March 1969, pp.7-36. Reviews major hardware developments from ENIAC to

System 360. Concentrates on main frames, with little data on peripherals.

**SteeT67.** Steel, T.B., Jr., "Standards for Computers and Information Processing" in Alt, F.L., *Advances in Computers,* Vol. 8, 1967, pp.103-152. Reviews the history of standardization, describes American and International standards, organizations, and committes. Names the approved and proposed American standards.

## 2.11 PROCESSORS AND THEIR INTERNAL MEMORIES

**AdamA.** Adams Associates, *Computer Characteristics Quarterly.* Provides key comparative data on virtually all American computers and many foreign ones. Gives price range, date of first delivery, addition speed, memory cycle time, word size and internal memory storage capacity, and characteristics of many peripherals. Published continuously since 1960. Now called *Computer Characteristics Review,* published by the GML Corporation, 594 Merrett Road, Lexington, Massachusetts 02173.

**BellC71.** Bell, C. Gordon, and Newell, Allen, "Computer Structures: Readings and Examples", New York: McGraw-Hill Book Company, 1971. A marvelous account of the structure of most of the important, and many other interesting computer systems developed up to 1969. Proposes and uses two formal, shorthand systems for concisely describing system structure and instruction sets. Contains some data on peripherals, but mostly concentrates on processors and memory. Reproduces many early papers describing various sytems and design philosophies.

**BorgB78.** Borgerson, B.R., Hanson, M.L., and Hartley, P.A., "The Evolution of the Sperry Univac 1100 Series: A History, Analysis, and Projection," *Commun. of the ACM, 21,* 1, Jan 1978, pp. 25-43. Traces the history of the 1100 series from the 1107 in 1962 to the 1100/80 in 1977. Covers architecture, technology (briefly), operating systems, languages, database, and data communications software. Emphasizes multiprocessor system characteristics.

**CaleE79.** Cale, E.G., Gremillion, LL, and McKenney, J.L. "Price/ Performance Patterns of U.S. Computer Systems", *Commun. of the ACM, 22,* 4, April 1979, 225-233. Analyzes the characteristics of 82 GP and 85 SBC systems introduced between 1970 and 1977. Argues that Grosch's Law is in effect meaningless because there is no way to measure computer power. Derives relationships expressing system price as a function of internal and DASD memory capacity, and shows how price per byte has improved with time.

**CaseR78.** Case, R. D., and Padegs, A., "Architecture of the IBM System/370," *Commun. of the ACM, 21,* 1, Jan 1978, pp. 73-96. A succinct and well-organized review of the IBM 370 family from the 115 to the 3033. Discusses the architectural and other differences between 360 and 370 families, and the reasons behind those differences. Describes the motives behind the development effort and the constraints on it. Explains architectural control procedures. Provides tables comparing 360 and 370 processors, and giving announcement and shipping dates. Gives no performance data.

**CresM.** Cresap, McCormick, and Paget, "Computer Equipment Comparisons," *Control Engineering,* Oct., 1961 to March, 1964. A continuing, occasional series presenting tabular data on computer processors and peripherals offered by the major computer system manufacturers. Gives performance data, but no prices.

**DataproSBC.** Datapro, *All About Small Business Computers,* Datapro Research Corp., Delran, N.J., 1978 (updated). Provides details, in tabular form, on 289 SBC models. Datapro's summary states: half the systems are based on 16-bit CPU's, one-third on 8-bit processors; more than two thirds have MOS memory, most of the rest, magnetic core; over 70 percent offer floppy or cartridge disk drives or both, over 50% have disk pack drives; and over 95% at least one communication line attachment.

**GillF61.** Gille, F., *Data Processing Equipment Encyclopedia,* Gille Associates, Inc., Detroit, Mich. A survey of the characteristics of computers and other data processing equipment, including commercial machines and many early one-of-a-kind systems. Generally (but not uniformly) gives performance, price, and physical characteristics by model number.

**IBMCons.** *IBM Service for Consultants.* A loose-leaf notebook published by IBM containing hardware and software product information. Includes some very basic performance data, but not enough to be useful. Indicates configurations possible and required. Lists appropriate documentation, and gives prices. Hardware sections are sorted by model number, with a section on "systems" which provides an overview.

**KnigK66,68.** Knight, K.E., "Changes in Computer Performance," *Datamation, 12,* no. 9, Sept 1966, pp.40-58. Knight, K.E., "Evolving Computer Performance 1963-1967," *Datamation, 14,* no. 1, Jan 1968, pp.31-35. Defines a measure of system performance and applies it to all computers designed in U.S. to date. (See also KnigK76 in Section 2.23, below.)

**KoleK79.** Kolence, K. W., "The Software Physics Handbook," Inst. for Software Engineering, Palo Alto, CA., 1979. Gives detailed descriptions of methods used to measure CPU performance, together with results, for a number of IBM, Amdahl, Itel, and CDC processors.

**SoloM66.** Solomon, M.B., "Economies of Scale and the IBM System/360," *Comm. of the ACM, 9,* no. 6, June 1966, pp.435-440. Gives instruction timings and Gibson-mix speeds and execution costs for 3 types of problems on 5 machines: 360-30,-40,-50,-65, and -75.

**WeikM53,55,57,61,63.** Weik, Martin H., *A Survey of Domestic Electronic Digital Computing Systems.* Five invaluable reports on computers and peripherals covering the earliest years, and the first and second generation computers. Includes performance data, reliability, user costs, system physical properties such as size and weight, component counts, rental, purchase and maintenance costs and other information. Published with various titles (*A Survey of Automatic Digital Computers—1953, Third Survey of Domestic Electronic Digital Computers—1961*). 1953 survey published by the Office of Naval Research, others by US Dept of Commerce. The "third" survey in 1961 (actually the fourth) is the most voluminous. All but the first contain a statistical analysis of the principal characteristics of all systems covered by each report.

## 2.12 PERIPHERAL EQUIPMENT

**HarmG69.** Harmon, G.H., "Selecting the Right COM Unit", *Datamation, 15,* 12, December 1969, pp.102-106. Provides data, including prices, on 31 different COM units. One of five articles in this issue on COM systems and applications.

**HoagA72.** Hoagland, Albert S., "Mass Storage—Past, Present and Future," *AFIPS Conf. Proc., 41*, FJCC, 1972. Reviews the history of mass storage and speculates about the future. Discusses other technologies, but concentrates on magnetics—and IBM products.

**HousG73.** Houston, G.B., "Trillion-Bit Memories", *Datamation, 19*, 10, October 1973, pp.52-58. Reviews the history of all types of computer storage, and presents graphs showing access time vs. capacity, cost vs. capacity, and capacity vs. time. Then discusses several existing and proposed mass file systems.

**McLaR73.** McLaughlin, R.A., "Alphanumeric Display Terminal Survey", *Datamation, 19,* 11, November 1973, pp.71-92. Provides specifications and prices for over 100 CRT terminals. Includes prices for both stand-alone systems, and for systems installed in clusters, which share some common electronics.

**ReagF71-2.** Reagan, F.H., "Should OCR Be Your Data Input Medium?" *Computer Decisions, 3,* 6, June 1971, pp.19-23. Briefly discusses OCR concepts, and then provides specifications on 34 OCR devices from 23 different manufacturers.

## 2.13 DATA ENTRY EQUIPMENT

**AlriJ70.** Alrich, John C., "Keypunch Replacement Equipment", *Datamation, 16,* 6, June 1970, pp.79-89. Compares performance and cost of data entry equipment. Provides tabular information in a standard format on stand-alone processors from 22 manufacturers, and shared processor from 16 manufacturers.

**CareR70.** Caray, Robert F., "A History of Keyed Data Entry", *Datamation, 16,* 6, June 1970, pp.73-76. Briefly reviews the history of data entry equipment, starting with keypunches, mentioning the Sperry-Rand Unityper, and leading to the Mohawk Data Sciences Corp. keyboard-to-tape convertor first delivered in 1965. Continues with the subsequent history of the growth of keyboard-to-tape and keyboard-to-disk equipments.

**MillP73.** Mills, Peter D., "Before and After at Occidental's Medicare Administration", *Datamation, 19*, 3, March 1973, pp.54-56. One of several articles in this issue of *Datamation* describing the status of, prospects for, and specific applications of data entry equipment.

**StenR70.** Stender, Robert C., "The Future Role of Keyboards in Data Entry", *Datamation, 16,* 6, June, 1970, 60-72. An ambitious and excellent attempt to describe the data entry problem in the context of its position in the entire data processing industry. Gives data on the distribution of keypunch equipment and computers among organizations of various sizes.

## 2.14 DATA COMMUNICATIONS

**BalkM71.** Balkovie, M.D., et al, "High-speed Voiceband Data Transmission Performance on the Switched Telecommunications Network", *Bell System Technical Journal, 50*, 4, April 1971, pp.1349-1384. Reports results of a 1969-1970 connection survey which measured error rates on over 1500 calls with a total duration of about 700 hours. Data is presented on error rates and on error characteristics for circuits operating over short, medium, and long lines at bit rates of 1200, 2000, 3600, and 4800 bits per second.

**GerlM74.** Gerla, Mario, "New Line Tariffs and Their Impact on Network Design", *AFIPS Conf. Proc., 43,* 1974 N.C.C., pp.577-582. Gives old and proposed tariffs including the "high-low" tariff of AT & T, the new DDS tariff from AT & T, and the tariffs of various special communication carriers.

**KleinL74.** Kleinrock, L., and Naylor, W.E., "On Measured Behavior of the ARPA Network," *AFIPS Conf. Proc. 43,* 1974 N.C.C., pp.767-780. An excellent article presenting detailed data on a week's operation of the ARPA Network. Points out that design parameters (especially packet size) are wholly inappropriate to the actual size of messages in the network. Recommends that the system be revised to improve its efficiency in the light of the usage data presented.

**MartJ69.** Martin, J., "Telecommunications and the Computer", Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969. Provides an excellent introduction to data communications practice, procedure, equipment, and technology on an international basis.

**McGrP74.** McGregor, P., "Effective Use of Data Communication Hardware", *AFIPS Conf. Proc., 43,* 1974 N.C.C., pp.565-575. Discusses cost of various multiplexing and concentrating arrangements. Gives data on reliability of various elements. Discusses queuing delays.

**NordK71.** Nordling, Karl I., "Analysis of Common Carrier Tariff Rates," *Datamation, 17,* 9, May 1, 1971, 28-35. Compares various voice-grade communication services: private line, direct distance dialing, and wide area telephone service. Is unique in providing a complete schedule of WATS charges from and to all areas in the United States.

**ReagF71-1.** Reagan, F.H., "A Manager's Guide to Phone and Data Services," *Computer Decisions,* October, 1971, 21-23. Reviews the cost of voice-grade lines comparing direct distance dialing, wide-area telephone service, and leased lines. Provides a specific comparison of the cost per hour of each of these facilities over a range of distances and usage.

## 2.15 PROGRAM PRODUCTS

**BlayJ78.** Blaylock, J.W., "Comparing Programming Language Performance," *Datamation, 24,* 4, April, 1978, pp. 119-120. Describes an experiment carried out to measure the execution time (on a Univac 1108 system) of eight programs each written in two or more different languages and compiled by two or more different compilers.

**CalifEDP70.** State of California, Intergovernmental Board on EDP, *Survey of EDP Activities in State and Local Government—1970.* E1490-S9 1971. Gives status and plans of EDP activities in state and local government in California. Includes data on software usage at 128 sites.

**CowaR64.** Cowan, Roydan A., "Is COBOL Getting Cheaper?", *Datamation* June, 1964, pp.46-50. Compares COBOL compilers on 23 different computer systems, giving data on compiler speed and system cost.

**FlynJ77.** Flynn, J., and Kimber, D., "From COBOL to MARK IV," *Datamation, 23,* 1, Jan 1977, pp. 111-120. Describes the experience of McCulloch Properties, Inc., in transferring a set of applications from COBOL to Informatics MARK IV programming language. In addition to the results shown in Table 2.15.2a, the authors stated that: a) even greater improvements were achieved with small programs (the data given is for a 'large project'). b) An original programming staff of 16 spent 90% of their time on program maintenance; after MARK IV was in use, the staff was reduced to four, and only 10% of their time was spent on maintenance. c) New projects, which were infrequently requested when programs were written in COBOL, are now routinely requested and handled.

**KnutD71.** Knuth, D.E., "An Empirical Study of FORTRAN Programs," *Software Practice and Experience, 1,* 2, April, 1971, 105-121. Presents data on the static and dynamic characteristics of FORTRAN programs written at Stanford University and by employees of Lockheed Aviation.

**LienB76.** Lientz, B.P. "A Comparative Evaluation of Versions of BASIC," *Commun. of the ACM, 19,* 4, April 1976, pp. 175-181. Compares features and performance of ten current versions of BASIC with two older ones and with the proposed standard for minimum BASIC. The performance comparison shows the costs of running each of three matrix inversion problems on twelve different systems.

**MacdN75.** MacDonald, N., "Computer Programming Languages in Use in Business—A Survey", *Computers and People, 24,* 10, Oct. 1975, 22-25. Reports the results of a survey of program language "use" without defining that term. Shows replies of each of the 57 respondents. Also contains users' estimates of the time and cost of "training a new person to program competently in the language you use most."

**PhilA73.** Philippakis, A.S., "Programming Language Use", *Datamation, 19,* 10, October 1973, pp.109-114. Reports the results of a study conducted in the summer and the fall of 1972. A questionaire returned by 164 of 390 data processing equipment users asked what percent of programming man-hours went into each of several languages.

**PhilA77.** Philippakis, A.S., "A Popularity Contest for Languages," *Datamation, 23,* 12, Dec 1977, pp. 81-87. Describes a survey conducted at 132 computer sites asking what percent of programming time is spent among various languages. (See also PhilA73).

**RoseS64.** Rosen, Saul, "Programming Systems and Languages: A Historical Survey", *AFIPS Conference Proceedings, 25,* 1964 SJCC, pp. 1-15. Provides a fascinating look at early software developments. Includes discussion of COBOL, FORTRAN, and Algol. Includes brief discussion of early operating systems. Contains extensive bibliography.

**RoseS67.** Rosen, Saul (ed.), *Programming Systems and Languages,* NY: McGraw-Hill, 1967. A collection of papers on this subject, including a new one by the editor, entitled "Programming Systems and Languages: Some Recent Developments".

**RoseS72.** Rosen, Saul, "Programming Systems and Languages 1965-1975", *Communications of the ACM, 15,* 7, July 1972, pp. 591-600. Brings up to date two earlier surveys written in 1963 (RoseS64) and 1966 (RoseS67). Provides a particularly fascinating discussion of the many problems which arose in the development of Operating Systems.

**RosiR69.** Rosin, R.F., "Supervisory and Monitor Systems," *Computing Surveys, 1,* no. 1, Mar 1969, pp.37-54. Follows development of operating systems from before 1956 (when there were none) to the "refinements" of 1968. Short annotated bibliography.

**RubeR68.** Rubey, Raymond J., "A Comparative Evaluation of PL-I", *Datamation,* December 1968, pp.22-25. Summarizes the results of a study carried out for the Air Force and reported in ESD-TR-68-150. Seven professional programmers each wrote two programs for the same application. In each case, one program was written in PL-I, the other in another language—two in COBOL, three in FORTRAN, and two in Jovial. The number of statements in each program is reported, along with the coding and debugging time for each.

**SammJ69.** Sammet, Jean E., *Programming Languages: History and Fundamentals,* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969. Monumental and readable description of the important programming languages. Includes extensive bibliography. Discusses purposes and philosophy as well as development history. Gives sample programs for many languages.

**SammJ71.** Sammet, Jean E., "Problems in, and a Pragmatic Approach to, Programming Language Measurement", *AFIPS Conf. Procs., 39,* 1971 FJCC, 243-251. Suggests a system for evaluating the comparative usefulness of various programming languages for some specific application. Lists the important types of characteristics.

**SammJ72.** Sammet, Jean E., "Programming Languages: History and Future", *Communications of the ACM, 15,* 7, July 1972, pp.601-610. Briefly summarizes the history of language development through 1960. Lists key language concepts as: formal syntactic notation, formal semantic definitions, attempts at designing machines whose instruction codes are higher level languages, and user defined languages. Suggests important developments for the future.

## 2.16 MEDIA

**BroeC78-2.** Broemel, C.A., "The World Micrographics Industry/Markets", Market Research Dept., ICI Petrochemicals and Plastics Co., Wilmington, DE, June 1978. Gives data on shipments of microfilm and micrographic equipment, generally covering the years 1970-1978.

**GentR73.** Gentile, R.B., "On the Reading of Very Old Magnetic Tape", *Datamation, 19,* 10, October 1973, pp.59-62. Reports the results of a series of tests on tapes in Department of Defense archives. Among other things, states that: 22% of the tapes are full of data; the average tape contains three million characters, recorded on about 350 feet of tape; 76 of 596 tapes read had errors on the first reading; about 60% of tapes with errors could ultimately be read after one or more retries; tape cleaning was effective in curing permanent errors.

## 2.20 SYSTEM PERFORMANCE AND USAGE

**DennP71.** Denning, P.J., "Third Generation Computer Systems," *Computing Surveys, 3,* no. 4, Dec 1971, pp.175-216. An excellent and readable review of the user features provided by present-day systems and the measures taken to insure their operability and efficiency. Mostly concentrates on operating systems, their purpose and design. Extensive annotated bibliography.

**FitzA78.** Fitzsimmons, A., and Love, T., "A Review and Evaluation of Software Science," *ACM Computing Surveys, 10,* 1, March 1978, 3-18. An introduction to Software Science, which it also compares briefly to Software Physics. See HalsM77.

**GrocJ72.** Grochow, J.M., "Utility Functions for Time-Sharing System Performance Evaluation," *Computer, 5,* no. 5, Sept/Oct 1972, pp.16-19. Identifies the factors important in evaluating system performance, generally under the headings of Accessibility, Usability, Manageability.

**JohnR70.** Johnson, R.R., "Needed: A Measure for Measure," *Datamation,* Dec 15, 1970, pp.22-31. Excellent survey of the problems and progress in measuring digital system performance. Identifies capacity, throughput, raw speed, and ease of use as four practical parameters. Includes 27-item bibliography.

**WareW72.** Ware, Willis, "The Ultimate Computer," *Spectrum,* March, 1972, pp.84-91. Bibliography. Describes characteristics believed to be as far as we can expect to go in

system performance. Touches on theoretical limits of computing speed.

## 2.21 PROCESSING REQUIREMENTS (Workloads)

**ArmyMIS71** (See Note to Table II.2.21.1, p. 410)

**ElshJ76.** Elshoff, J.L., "An Analysis of Some Commercial PL-1 Programs," *IEEE Trans. on Software Engineering, SE-2,* 2, June 1978, pp. 113-120. Provides data on the characteristics of 120 production programs from several General Motors Corp. commercial computer installations.

**FerrD72.** Ferrari, D., "Workload Characterization and Selection in Computer Performance Measurement," *Computer, 5,* no. 4, July/Aug 1972, pp.18-27. Excellent review and summary of the variety of attempts which have been made to characterize computer users. Good bibliography.

**FostC71.** Foster, C.C., Gonter, R.H., and Riseman, E.M., "Measures of Op-Code Utilization," *IEEE Trans. on Computers, C-20,* 5, May 1971, pp.582-584. Gives graphs of percent of instructions outside a subset of total instructions, in dynamic and static cases, for CDC 3600. Shows that object codes use fewer instruction types than assemblers and compilers themselves. Concludes that for the 3600, if the instruction set were reduced from 142 to 64 instructions, only 2% of translator instructions would have to be recoded and none of object-code. If reduced to 32, corresponding figures are 10-16% and 0-3%.

**FreiI68.** Friebergs, I.F., "The Dynamic Behavior of Programs", *AFIPS Conf. Procs., 33,* 1968 FJCC, 1163-1167. Reports the results of applying a trace program to a number of IBM 7044 programs of various types. Gives data on the relative frequency of various types of instructions, on the number of instructions executed between supervisor calls, and on the number of pages required by the program under various conditions.

**GibsD67.** Gibson, D.H., "Considerations in Block-Oriented Systems Design", *AFIPS Conf. Procs., 30,* 1967 SJCC, 75-80. The original and definitive paper on that property of computer programs, known as "locality", which makes it possible for a processor to operate for a relatively long periods of time using only a small fraction of the total memory it ultimately requires to complete the job. Shows how the "cache" memory can be configured to take advantage of this property, and indicates that such a memory, with a 50 nanosecond cycle time and containing only 2,000 words can reduce the processor's average reference time from 800 nanoseconds (the cycle time for main memory without a local store) to 76 nanoseconds.

**HellL72.** Hellerman, L. "A Measure of Computational Work," *IEEE Trans. on Computers, C-21,* 5, 439-446. Proposes to measure the work of a process by counting the bits required in a memory used for its table-lookup implementation. Discusses the relationship between the work of a process and the work capacity of a facility.

**HuntE71.** Hunt, Earl, et al, "Who are the Users? An Analysis of Computer Use in a University Computer Center," *AFIPS Conf. Proc.,* 38, SJCC, 1971, pp.231-238. Gives statistical parameters for 527 research jobs and 1061 instructional jobs in a university computing center. Includes measures of cards read, lines printed, equipment times, FORTAN use.

**JohnR72.** Johnson, R. R., "Some Steps Toward an Information System Performance Theory", *Proc. Japan Computer Conference,* 1972. Suggests measures for Information-Work and Information-Capacity, and offers comments on how they may be used.

**LundA77.** Lunde, A., "Empirical Evaluation of Some Features of Instruction Set Processor Architectures," *Commun. of the ACM, 20,* 3, March 1977, pp. 143-153. Gives data on instruction set usage of 41 programs run on the DEC System 10. Emphasizes register usage, but includes some other data.

**MorrD67.** Morris, Derrick, and Sumner, F.H., "An Appraisal of The ATLAS Supervisor", *Proceedings ACM National Meeting,* 1967, 67-75. A quantitative analysis of the workload handled by the ATLAS computer during 1966, and of the system's response to that workload. Gives data on average compute and input-output time for several classes of problem. Also distinguishes compute time, idle time, and supervisor time for the average job.

**RaicE64.** Raichelson, E. and Collings, C., "A Method for Comparing the Internal Operating Speeds of Computers," *Comm. of the ACM, 7,* no. 5, May 1964, 309-310. Describes an instruction mix and uses it in a performance measure of fourteen second generation machines.

**RosiR65.** Rosin, R.F., "Determining a Computing Center Environment," *Comm. of the ACM, 8,* 7, July 1965, pp.463-468. Presents statistics on characteristics of over 10,000 jobs run at University of Michigan on IBM 7090 with IBM 1410 I/O processor. See also WaltE67.

**SissS68.** Sisson, S.S., and Flynn, M.J., Addressing Patterns and Memory Handling Algorithms", *AFIPS Conference Procs., 33,* 1968 FJCC, 957-967. Provides data on the simulated running of three test programs on the IBM 7094.

**SmitM68.** Smith, J. Meredith, "A Review and Comparison of Certain Methods of Computer Performance Evaluation", *The Computer Bulletin,* May, 1968, pp. 13-18. Compares benchmarks, mixes and "work units" as methods of measuring performance.

**SreeK74.** Sreenivasan, K., and Kleinman, A.J., "On The Construction of a Representative Synthetic Workload," *Comm. of ACM, 17,* 3, March 1974, 127-133. Provides data on compute-time and the number of blocks transferred to and from auxiliary storage for a sample of 6,126 jobs run at MITRE Corporation on their IBM 370/155. Fits the parameters of a synthetic program to this data in order to create a synthetic workload.

**ThayT76.** Thayer, T.A., Lipow, M., and Nelson, E.C., "Software Reliability Study," TRW Systems Engineering and Integration Division, One Space Park, Redondo Beach, CA 90278, March 1976. A voluminous and detailed study of errors in four programs, generally in the military command and control application area. Concentrates on classifying and analyzing error types, and attempting to determine how they might be prevented. Attempts to correlate number of bugs with various measures and concludes that number of executable statements, number of branches, and number of data handling statements are the best measures to use.

**WaltE67.** Walters, E.S. and Wallace, V.L., "Further Analysis of a Computing Center Environment," *Comm. ACM, 10,* no. 5, May 1967, pp.267-272. Continuation of RosiR65, analyzing same sample of 10,000 jobs in University of Michigan computer center.

## 2.22 HUMAN PERFORMANCE

**BryaG67.** Bryan, G.E., "JOSS: 20,000 Hours at a

Console—A Statistical Summary," *AFIPS Conf. Proc., 31,* FJCC, 1967, pp.679-777. Supplies user statistics including input/output character rates, program sizes, session and computer times, and turnaround times for the RAND Corp.'s JOSS system implemented on a PDP-6.

**DeroD67.** Deroe, D.B., "Alternatives to Handprinting in the Manual Entry of Data", *IEEE Trans. on Human Factors in Electronics, HFE-8,* 1, March 1967, pp.21-32. Reports the results of some experiments on human input of data into computers, including writing, printing, marking, and keying. Includes a review of background literature.

**GaliW69.** Galitz, W.O., and Laska, T.J., "Computer System Peripherals and the Operator", *Computer Design, 8,* 8, August, 1969, 52-56. Provides some data on computer operations, collected by observing operators and by analyzing responses to questionaires on the activities of computer operators running Univac 1108 and 494 large-scale computer systems.

**JackP69.** Jackson, P.E. and Stubbs, C.D., "A Study of Multiaccess Computer Communications", *AFIPS Conf. Procs., 34,* 1969 SJCC, 491-504. Describes data collected on a large number of calls to each of three multiaccess computer systems from two manufacturers.

**SackH68.** Sackman, H., "Time-Sharing vs. Batch Processing: The Experimental Evidence," *AFIPS Conf. Proc., 32,* SJCC 1968, pp.1-10. Attempts to compare time-sharing and batch processing operations from the users' point of view by analyzing the reported results of five (published) experiments.

**ScherA67.** Scherr, Allan, *An Analysis of Time-Shared Computer Systems,* Research Monograph No. 36. MIT Press, Cambridge, Mass. 1967. Detailed description and analysis of an IBM 7094 computer time-shared system. Derives mathematical models of the system and compares actual performance with that predicted by the model. Characterizes the time-sharing user.

**TurnR74.** Turn, Rein, "Speech as a Man-Computer Communication Channel", *AFIPS Conf. Proc., 43,* 1974 N.C.C., 139-143. Surveys man-computer communications briefly, then discusses advantages and problems with speech input/output. Gives data on various man-machine input rates—for reading, handwriting, typing, stenotype, touch-tone keyboards, etc. Contains a good bibliography.

## 2.23 COMPUTER SYSTEM PERFORMANCE

**ArbuR66.** Arbuckle, R.A., "Computer Analysis and Throughput Evaluation", *Computers and Automation,* Jan. 1966, pp.12-15. Emphasizes importance of throughput and points out how difficult it is to define and measure. Relates throughput to instruction mixes, kernels, benchmarks. Gives time distribution of specific 7094 installation.

**BalkE74.** Balkovich, E., et al., "Dynamic Memory Repackaging," *Comm. of the ACM, 17,* 3, March 1974, 133-138. Uses Gaver's model to derive conditions under which it is worthwhile to use processor capacity to repack internal memory in order to increase the average number of jobs simultaneously handled in a given memory size.

**BellT74.** Bell, Thomas E., "Computer Performance Variability", *AFIPS Conf. Proc., 43,* 1974 N.C.C., 761-766. Reports the results of some RAND tests on their IBM 360/65. The purpose was to determine repeatability of job performance measures as a function both of multiprogramming level (number of jobs in core) and of simply repeating a job under seemingly identical conditions several times.

**BrawB68.** Brawn, Barbara S., and Gustavson, Francis G., "Program Behavior in a Paging Environment", *AFIPS Conf. Procs., 33,* 1968 FJCC, 1019-1032. Reports the result of a study performed on an experimental IBM timesharing system designed and implemented by the research division of IBM. Provides data showing how program running time is affected by the amount of internal memory available to the central processor.

**BricR78.** Brice, R.S., and Browne, J.C., "Feedback Coupled Resource Allocation Policies in the Multiprogramming and Multiprocessor Computer System." *Commun. of the ACM, 21,* 8, Aug 1978, pp. 678-686. Describes a model for a CDC 6400/6600 system, and gives data for some experiments carried out to verify the model.

**BuchW69.** Buchholz, W., "A Selected Bibliography on Computer System Performance Evaluation", *Computer Group News,* Mar. 1969, pp.21-22. Lists fifty-two selected, not annotated, articles, all of which are "quantitative evaluations using objective and verifiable measures of the work of an entire computer system as seen by the user."

**BuzeJ73.** Buzen, J.P. "Computational Algorithms for Closed Queuing Networks with Exponential Servers", *Commun. of the ACM, 16,* 9, Sept 1973, pp. 527-531. Shows how to compute expected queue length for a generalized network under given assumptions. Easier to read if preceded by a reading of Buzen and Denning (DennP78).

**CartW64.** Carter, W.C., et al, "Design of Serviceability Features for the IBM System/360," *IBM Journal,* April, 1964, 115-126. Describes IBM's objectives in designing features which make the System/360 reliable and easy to maintain. Features include diagnostics to reduce duration of maintenance calls, and instruction retry to reduce system down time.

**DennP78.** Denning, P.J, and Buzen, J.P. "The Operational Analysis of Queuing Network Models," *ACM Computing Surveys, 10,* 3, Sept 1978, pp. 225-261. A marvellously clear review of the basic queuing models useful in evaluating computer systems. Shows how to compute device utilization, response time, average queue lengths, and system throughput as a function of average job time per device, and the probability distribution of jobs between devices. Contains an excellent bibliography.

**DickJ72.** Dickson, J.C., et al, "Quantitative Analysis of Software Reliability," *Proc. 1972 Annual Reliability and Maintainability Symposium,* IEEE Catalog no. 72CH0577-7R, 148-157. Proposes a mathematical model for software reliability, and applies it to a group of programs designed to operate on large, third-generation computers.

**DoheW70.** Doherty, W.J., "Scheduling TSS/360 For Responsiveness", *AFIPS Conf. Procs., 37,* 1970 FJCC, 97-111. Describes how the performance of a particular release of the software known as TSS/360 was "dramatically improved" during a three month period of study and analysis. The improvement was achieved simply by adjusting the parameters of the scheduler which drives the system.

**FreeD68.** Freeman, D.N., "A Storage-Heirarchy System for Batch Processing", *AFIPS Conf. Proc, 32,* 1968 Spring Joint Computer Conference, pp.229-243. Provides a concise and clear criticism and analysis of IBM's OS/360 as it existed in the years following its release. Supplies detail on three major performance problems: reliability, operator-intervention losses, and system I/O inefficiencies.

**GaveD67.** Gaver, D.P., "Probability Models for Multiprogramming Computer Systems," *JACM, 14,* 3, July 1967, pp. 423-438. Analysis of a model of a system in which J jobs exist, and each job is in one of four states: in a (single) queue waiting for service from the first of I I/O devices available; being served by an I/O device; in a queue waiting for CPU service; being served by the CPU. CPU and I/O services are assumed to alternate and the results are tabulated, in terms of relative system productivity, for a number of types of statistical distributions of computer time. (See also articles by Gaver and Shedler in *SIAM J. Comput., 2,* 3, Sept 1973, and by Balkovich et al in *JACM, 21* 2, April 1974.)

**KnigK76.** Knight, K.E., and Cerveny, R.P., "Performance of Computers," in *Encyclopedia of Computer Science,* edited by A. Ralston, Petrocelli/Charter, 1976, 1065-1070. A summary and revision of Knight's earlier work. (See KnigK66,68 in Section 2.11, above.) The equations describing the The equations describing the performance measure have been modified slightly, and the article presents the scientific index for several systems introduced between 1963 and 1971.

**KoleK76.** Kolence, K.W., *An Introduction to Software Physics,* Institute for Software Engineering, Palo Alto, CA 1976. (See also Kolence, K.W., 'Software Physics,' *Datamation, 21,* 6, June 1975, pp.48-51, and FitzA78). Describes a system model based on CPU and I/O performance, as measured basically in bytes per second. Shows how these measures can be used in practice to evaluate and improve system throughput.

**LockJ74.** Lockett, JoAnn, "Computer Performance Analysis in Mixed On-Line/Batch Workoads", *AFIPS Conf. Proc., 43,* 1974 N.C.C.. pp.671-676. Gives results of performance measures taken on an IBM 360/65 at the RAND Corp., with and without a large core memory.

**LoesR74.** Loeser, R., "Some Performance Tests of 'Quick Sort' and Descendants", *Communications ACM, 17,* 3, March 1974, pp.143-152. Provides detailed documentation of results of comparing several sorting algorithms, in terms of system resources used. Resources included are number of compares, fetches, stores, and partitions. Various initial arrays are included, including random, reverse order, already-sorted, almost-sorted, and sorted in blocks.

**LyncW75.** Lynch, W.C., Langner, W., and Schwartz, M.S., "Reliability Experience with Chi/OS", *IEEE Trans. on Software Engineering, SE-1,* 2, June 1975, pp.253-257. Provides data on software and hardware crashes observed in a newly-designed operating system. Private communication with the authors established the fact that the operating system contains about 40,000 machine instructions, and that the system operated about 20 hours per day, 22 days per month, during the 13-month period for which data is presented.

**ReynC75**. Reynolds, C.H., and Van Kinsbergen, J.E., "Tracking Reliability and Availability", *Datamation, 21,* 11, Nov. 1975, pp.106-116. Supplies data on various types of system failure occurring in a dual IBM 370/165 system at Hughes Aircraft Co. over a two-and-one-half year period.

**ShemJ72.** Shemer, J.E. and Robertson, J.B., "Instrumentation of Time-Shared Systems," *Computer, 5,* no. 4, July/Aug 1972, pp.39-48. Describes measurement techniques used to understand time-sharing system performance, and gives resulting data characterizing both user and system.

**TrivK78-1.** Trivedi, K.S., and Kinicki, R.E., "A Mathematical Model for Computer System Configuration Planning." *Proc. International Conf. on the Performance of Computer Installations,* Italy, June 1978. Shows how to maximize system throughput at a given computer system hardware cost. Throughput is modeled using the simple queuing theory model of DennP78.

**TrivK78-2.** Trivedi, K.S., "Analytic Modeling of Computer Systems," *Computer, 11,* 10, Oct. 1978, pp. 38-56. An excellent survey of a variety of models includes very brief descriptions, and a very complete bibliography.

**TsujM68.** Tsujigado, M., "Multiprogramming, Swapping, and Program Residence Priority in the FACOM 230-60," *AFIPS Cof. Procs., 32,* SJCC 1968, 223-228. Gives a simple model of a multiprogramming system, predicting the number of simultaneous users (programs) based on processor speed, program efficiency, number of I/O channels, external memory speed, etc.

**YourE72.** Yourdon, E., "Reliability Measurements for Third Generation Systems," *Proc. 1972 Annual Reliability and Maintainability Symposium,* IEEE Catalog no. 72CH0577-7R, 174-182. Records and analyzes failures over a fifteen-month period on a number of Burroughs 5500 systems. Lists the average number of failures per month in each of six categories.

## 3.0 APPLICATIONS-INTRODUCTION

**NolaR73.** Nolan, R.L., "Managing the Computer Resource: A Stage Hypothesis," *Commun, of the ACM, 16,* 7, July, 1973, pp. 399-405. Argues that data processing in an organization passes through various stages of maturity and growth, with growth ultimately levelling off.

## 3.11 COMPUTER USE IN ORGANIZATIONS

**AldeW52.** Alden, W.L, et al, *The Automatic Office: A Study of the Application of Electronic Digital Computer Principles to the Automization of Clerical and Accounting Routines,* Westboro, Mass.: Alden Systems Co., February 1952. Reviews developments in electronic computers and evaluates their potential usefulness to businessmen.

**AndeN68.** Anderson, N.D., "Data Processing on the Farm", *Datamation, 14,* 3, March 1968, pp.84-92. States that 15,000 farm enterprises in the United States rely on some form of automatic data processing now, but that a million could benefit—all those earnings more than $10,000 per year.

**BanK66,69.** "National Automation Survey of 1966", Sept. Oct. 1966; "The 1969 Automation Survey", Oct., Nov. 1969, *Banking.* These articles are reports of surveys on the use of data processing equipment and services by banks. (They also show some data from a 1963 survey.)

**BoozA68.** Booz, Allen and Hamilton, *Study of the Interdependence of Computers and Communications Services.* For the Business Equipment Manufacturer's Association, New York, 1968. This report was prepared for BEMA in connection with their submission to the Federal Communications Commission study on computers and communications. It contains a wealth of information on computer usage, and especially on communications-related usage.

**BurnE69.** Burnett, Ed, "Computers in Use, Analyzed by Standard Industrial Classification", *Computers and Automation* September 1969, 43-48. Analyzes a file of over 20,000 records of computer installations in a variety of industries. Compares the results with related data on the number of establishments (basically, plant locations) in each industry or subindustry, and computes the number of establishments per computer in each subindustry, analyzing the results in different ways.

**BurnE75.** Burnett, Ed "Computers in Use: Analyzed by Standard Industrial Classification: 1974 Compared with

1968", *Computers and People, 24*, 5-7, May, June, and July, 1975. Reappraises the number of computer locations per firm in the major SIC codes, and compares the result with the 1968 data (BurnE69). Data derived from 24,500 computer locations, compared with 17,600 in the 1968 survey—excludes computer service bureaus from both tabulations.

**CvSrv71.** Civil Service Dept, *Computers in Central Government 10 Years Ahead*, Management Study 2, Jan 1971, Her Majesty's Stationary Office, London. Forecasts the computer applications to be tackled, and the number of machines and personnel required, by the British Government during the 1970's.

**FiedE57.** Fiedler, E.R., and Kennedy, D.R., "A Survey of Users of the IBM 650 Computer" *Computers and Automation* October 1957, pp. 10, 28. Reports the results of a survey conducted in March of 1966. Questionaires were sent to 121 users of the IBM 650 computer, and responses were received from 81. The respondees answered questions about how many computers they had, what applications they had implemented, how many programmers they employed, and whether they favored centralized or decentralized computer operations.

**GSAInv.** General Services Administration, "Inventory of Automatic Data Processing Equipment in the U.S. Government", (also other similar titles), published annually. Lists the computers in use by the Federal Government at the close of each fiscal year. Usually provides additional data on the cost of data processing operations, and a number of summaries of various kinds.

**JackG69.** Jackson, Geoffrey G., "Information Handling Costs in Hospitals," *Datamation*, May 1969, pp.56-64. Differs from the usual qualitative story in that it provies quantitative data on the size, access requirements, and costs of hospital files.

**KompE72.** Kompass, E.J., "A Survey of On-Line Control Computer Systems", *Control Engineering*, January 1972, pp.52-56. Provides data on average cost, along with some configuration information, for over 100 control computer installations.

**LawlR62.** Lawlor, Reed C., "Information Technology and The Law", in Alt, F.L., *Advances in Computers*, Volume 3, 1962, pp.299-352. Considers applications such as the use of symbolic logic, file searching, and predicitng court decisions. Gives graphs and references on the growth of information in medicine, biology, and law.

**OsicM72.** Office of Statistical Standards, Bureau of the Budget, Executive Office of the President, *Standard Industrial Classification Manual—1972*, U.S. Government Printing Office. Describes the U.S. Government's system for classifying American industrial, business, and government activities. This book is periodically revised, and includes useful indices and appendices.

**OBriJ68.** O'Brien, J.A., *The Impact of Computers on Banking*, Boston Bankers Publishing Co., 1968. Chapter 4 considers in some detail the financial impact of computers on banks, and the effect they have had in reducing or stabilizing costs, and in providing new sources of revenue. The book gives examples of total computer operating costs for various applications, and in some instances compares electronic data processing costs with manual/bookkeeping machine costs.

**PykeT67.** Pyke, Thomas N., Jr., "Time Shared Computer Systems", in Alt, F.L., *Advances in Computers*, Volume 8, 1967, pp.1-46. An introduction to the subject, containing definitions, history, and some discussion. Treats terminals, communications, scheduling, accounting, and reliability.

**RideB69.** Rider, B.M., 'The 1969 Automation Survey", *Banking*, October-November, 1969, pp.61-65, pp.75-78. These two articles summarize the results of the third major survey of banking automation, carried out by The American Bankers Association. (The 1966 articles were published in September and October of that year. The principal conclusions and data for the two previous surveys are included in the third.) The survey was conducted by a questionaire sent to 4,885 banks, including all those with deposits over $25M.

**RIASurV69.** Research Institute of America, "Computers in Business—An RIA Survey of Users and Non-Users", April 1969, Research Institue of America, 589 5th Avenue, NY, 10017. An excellent report of a survey, conducted by questionaire, of 2,422 users and non-users of computer equipment and services. Analyzes the reasons for not using computers and for opting for computer services rather than equipment.

**Scie77.** *Science* Magazine. "Electronics" Issue, v. 195, No. 4283, 18 March, 1977. Surveys the electronics field, and contains a number of interesting papers. Major sections, with articles of interest in parenthesis: Introduction to the Continuing Revolution ("Evolution of Computers and Computing", by R.M. Davis; "Large-Scale Integration: What is Yet to Come?", by R.N. Noyce); The Pervasiveness of Electronics (Includes articles on the use of computers in Banking & Marketing, Medicine, & Research); Policy Problems ("Computing and Telecommunications" by D. Farber & P. Baran); Computers and People ("What Computers Mean for Man and Society" by H. A. Simon, "Software Engineering" by H. D. Wells); and Research Frontiers ("New Memory Technologies" by J. A. Rajchman, and "Physical Limits in Semiconductors", by R. W. Keyes).

**SelwL70.** Selwyn, L.L. *Economies of Scale in Computer Use. Initial Tests and Implications for the Computer Utility*, Cambridge, Mass.: Project MAC, MIT, June 1970. A PhD thesis which (a) analyzes U.S. Government computer usage data and concludes that average total costs per unit of computation decrease even faster than Grosch's Law would indicate, because operating costs are a diminishing proportion of total costs as system size increases. (b) Attempts to correlate industry size, firm size, etc. with average computer rent in that industry—for all the SIC code manufacturing industries. (c) Concludes that large computer installations are more efficient than small ones, and that "public policy" ought to encourage the wider use of large systems.

## 3.12 COMPUTER USE BY FUNCTION

**GreeH57.** Greenfield, H.I., "An Economist Looks at Data Processing", *Computers and Automation.* Oct 1957, pp.18-23. Gives an economic framework for assessing the role of data processing in the US. Points out that the amount of data processing required by industry has been increasing for a number of reasons, but that clerical productivity, unlike manufacturing and other productivities, has not been improving significantly. Suggests that computers should and will be used to solve this problem, and sets forth several reasons for the relatively slow adoption of computer techniques by American firms.

**IDCAppl69.** International Data Corporation, *Computer Applications and Their Implementation*, 1969. A report on a fascinating and ambitious survey of over 2000 computer user organizations in the United States. Provides data on the major computer applications, by industry. Shows which programming languages are used for implementation, by application. Supplies data on the programming manpower at the various sites, and on the programming effort necessary to develop and maintain software for various applications. Shows how users have spent money for proprietary software of various kinds.

**SmBus72.** U.S. Government Printing Office, *The Federal Paper Work Burden*, Hearings Before the Subcommittee on Government Regulation of the Select Committee on Small Business, U.S. Senate, 92nd Congress, 1972. Gives testimony and exhibits of people and organizations appearing before a senate committee to discuss and describe some of the many forms which much be filled out and submitted periodically to the U.S. Government.

## 3.2 DATA PROCESSING COSTS

**HayeR70.** Hayes, R.M., and Becker, J., *Handbook of Data Processing for Libraries*, NY: Becker and Hayes, Inc. (John Wiley and Sons), 1970. Extraordinarily comprehensive and well documented source of information on all library data processing applications including administrative, circulation, ordering, and cataloguing operations.

**LandH69.** Landau, H.B., "The Cost Analysis of Document Surrogation; A Literature Search", *American Documentations, 20*, 4, October 1969, pp.302-310. Reports on a search for data on the cost of classifying, cataloguing, indexing, and abstracting. Gives many references on the total subject of information storage and retrieval, indicating we don't have good cost figures.

**LockW70.** Locke, W.N., "Computer Costs for Large Libraries", *Datamation*, February 1970, pp.69-74. An informative and fact-filled article which documents the assertion that 'books are the most efficient way to store information ever invented. Libraries are going to be around a long time." Gives data on the approtionment of library budgets, on the principle functions libraries perform, and on data storage and transmission costs.

**ORMan69.** Office of Records Management, *Estimating Paper Work Costs*, National Archives and Records Service, GSA, U.S.G.P.O., (temporary edition) 1969. Excellent, quantitative discussion and analysis, with examples, of costs of directives, reports, forms, correspondence, mail operations, reproduction, automation input, file maintenance, and information retrieval. Gives tables of estimated times and costs of each.

## 3.21 DATA COLLECTION COSTS

**HammD68.** Hammer, D.P., "Problems in Conversion of Bibliographical Data—A Keypunching Experiment", *American Documentation*, January 1968, pp.12-17. Gives data on keypunching of over one million characters by twelve operators.

**LeeMa68.** Lee, Malcolm K., "The Demise of the Keypunch", *Datamation, 14*, 3, March 1968, pp.51-58. Describes the conversion from keypunch to cash register tape optical character recognition equipment and keyboard to tape units for the May Company department stores. Gives some data on costs and record sizes.

## 3.22 DATA STORAGE COSTS

**GSARec64.** General Services Administration, *Bibliography for Records Managers*, National Archives and Records Service, Office of Records Management, July 1964. A useful bibliography of publications having to do with the management of paperwork. Includes material on such things as correspondence, forms, reports, mail, files, source data automation, clerical work standards, and information retrieval.

## 3.25 SYSTEM OPERATING COSTS

**BrowR68.** Brown, Robert R. "Cost and Advantages of On-Line Data Processing", *Datamation, 14*, 3, March 1968, pp.40-44. Describes the incremental costs of changing a 360/50 from the batch to the on-line mode, updating files through terminals, and creating special long reports on a daily batch basis.

**CounS65-67.** Council of State Governments and Public Administrative Service, *Automation in State Government*, Chicago, 1965 and 1967. These two reports provide some small amount of information on salaries, personnel costs, and equipment rentals as seen by various states in the United States.

**FrieA65.** Frielink, A.B. (ed.), *Economics of Automatic Data Processing*, Amsterdam: North Holland Publishing Co., 1965. Papers presented at an international symposium organized by the International Computations Center—Rome, Oct 19-22, 1965. Contains some excellent articles on the economics of automation; the value of information; the elasticity of the market for data processing equipment; programming costs; costs of data storage; economics of leasing versus purchasing equipment; user's costs; and computer usage.

**HammJ69.** Hammerton, James C., "Business Time Sharing: User Economics", Datamation, June 1969, pp.70-82. This article represents an interesting and useful attempt to describe the prospects of providing more or less "standard" business data processing services via a time-sharing system to small businesses.

**KaimR69.** Kaimann, R.A. and Drzycimski, E.G., "3rd Party Leasing", *Data Management*, Jan 1969, pp. 32-36+. Excellent article with tables and calculations showing how lessor and lessee make out with a $9500 per month (plus $100 per month maintenance) system.

**McLaR74-2.** McLaughlin, R.A., "A Survey of 1974 DP Budgets", *Datamation, 20*, 2, February 1974, pp.52-57. Details the costs of data processing system operations as a function of hardware size in six categories from "under $25k per year" to "over $1M per year". Includes costs of processors/memory, data entry, peripherals, computer output microfilm, rote equipment, communication lines, services, supplies, salaries, training, conferences, etc. Data is from a survey of 181 U.S. and 13 Canadian installations, based on their 1974 *budgets*. Similar surveys by the same author have been published annually since 1973.

**SoloM70.** Solomon, M.B., "Economies of Scale and Computer Personnel", *Datamation*, March 1970, pp.107-110. Shows that, in a variety of installations, the percent of the data processing budget spent on personnel decreases as the size of the system increases.

**UrbaL67.** Urban Land Institute, *The Boom in Office Building—An Economic Study of the Past Two Decades,* Technical Bulletin 58, 1967. Gives data, largely in short form, on floor space per office worker, floor space per tenant, gross income, net income, and occupancy for office buildings in urban areas.

## 3.26 COMPARISONS

**GoldR75.** Goldstein, R.C., and Nolan, R.L. "Personal Privacy Versus the Corporate Computer", *Harvard Business Review,* March/April 1975, pp.62-70. Examines the economic impact on data bank system operators of the new privacy regulations. Reviews features of typical state Acts. Describes five existing computer systems, giving data on file size, transaction rates, development and operating costs, and the expected cost of adhering to privacy regulations.

**ParkE72.** Parker, E.B., and Dunn, DA., "Information Technology: Its Social Potential", *Science, 176,* June 30, 1972, pp.1392-1399. Proposes a program to make a national information utility available to every urban home and rural community in the United States by 1985.

**RuskV68.** Ruskin, V.W., 'A Potential Savings Yardstick", *Datamation 14,* 3, March 1968, pp.59-66. Compares the data processing costs of two similar fifty million dollar companies, finding one is 62% higher than the other though both are apparently carrying out the same applications.

## 4.0 COSTS

**PhisM79..** Phister, M., Jr. "Technology and Economics", *Computer Design,* 1979. A series of articles on various aspects of the economics of computer design, in the *Digital Technology Review* section of the magazine, starting in March, 1979. Subjects treated include: Optimum PM Strategy, 3/79; IC Power Distribution vs. Price (lists SSI/MSI part numbers), 4/79; Power System Packaging Considerations, 5/79; Diagnostic Programs and MTTR, 6/79; Market Elasticity, 7/79, 8/79; System Performance, 9/79; IC Manufacturing Costs, 10/79 and 11/79; Microprogrammed System Manufacturing Cost, 12/79. Some, but not all, of the material in these articles appears in this book.

### 4.11 LOGIC COSTS

**BellC72-1.** Bell, C.G., et al, "Effect of Technology on Near-Term Computer Structures", *Computer, 5,* no. 2, March/Apr. 1972, pp.29-38. Excellent article focusing on low-cost logic and its implications in computer design, especially in multi-processor systems.

**BTL72.** Bell Telephone Laboratories, *Physical Design of Electronic Systems,* in four volumes, NY: Prentice-Hall Inc., 1972. A comprehensive review of all aspects of electronic technology.

**DaviW72.** Davidow, William H., "General Purpose Microcontroller; Part I—Economic Considerations", *Computer Design, 11,* 7, July 1972, pp.75-80. An excellent article which attempts to quantify the cost difference between a machine with conventional control logic and one with microprogramed logic. Attempts to identify all the various support costs associated with a component.

**HartF64.** Hartmeyer, F.C., *Electronic Industry Cost Estimating Data,* NY: Ronald Press, 1964. Provides estimates of man-hours to conduct electronic assembly and fabrication functions, together with methods for estimating learning curves, overhead costs, material discounts, etc.

**HirsW78.** Hirschberg, W. "Switching Power Supplies, Pros and Cons, Today and Tomorrow," *Digital Design Magazine,* April 1978. Reviews reliability, performance, cost, and size of switching power supplies.

**HodgD77.** Hodges, D.A., "Progress in Electronic Technologies for Computers", Prepared for the U.S. Department of Commerce, National Bureau of Standards, Order No. T73219, March 21, 1977. Discusses device limits (of semiconductors, and magnetic, cryoelectronic, and optical devices), engineering limitations (in the areas of packaging and interconnect, reliability, data communications, and production costs), and their implications for large and small systems. A marvelous review of computer technology. Bibliography.

**HussS70.** Husson, S.S. *Microprogramming: Principles and Practices,* Prentice-Hall, Inc., N.J. 1970. The first and probably the best book on microprogramming. Has chapters on principles, on control storage technology, and on the actual design of IBM 360, RCA Spectra, and Honeywell computers.

**McAlH71.** McAleer, H.T., "A Look at Automatic Testing," *Spectrum, 8,* 5, May 1971, pp. 63-78. An excellent introduction to automatic testers for electronic components, assemblies, and systems. Discusses tester types, programming languages, equipment and operating costs, and economic justification.

**McWiT77.** McWilliams, T.M., et al, "Using LSI Processor Bit-Slices to Build a PDP-11—A case study in Microcomputer Design," *AFIPS Conf. Proc. 43* 1977 NCC, pp. 243-253. Describes design of DEC PDP-11 at Carnegie-Mellon using commercially available microprocessor chips. Compares size, complexity, cost, and performance of the result with various PDP-11's.

**RiceR67.** Rice, Rex, "Impact of Arrays on Digital Systems", *IEEE Journal of Solid State Circuits, Sc-2,* Dec. 1967, pp.148-155. Calculates that, if logic were free it could only reduce total users' processing costs by 1.5%. Concludes that we should use LSI to reduce problem and operating expense, and to increase the total market for digital products.

**SmitM72.** Smith, M.G., "LSI and Systems Architecture in the 1970's", *Japan Computer Conference,* Fall 1972. Discusses the expected effect LSI will have on systems of all sizes. Provides data on distribution of system costs, both hardware and operating.

**SuthI73.** Sutherland, I.E. and Oestreicher, D., 'How Big Should a Printed Circuit Board Be?" *IEE Trans. on Computers, C-22,* 5, May 1973, pp. 537-542. Derives a formula for PCB dimensions as a function of number of IC's, pins per IC and density of etched circuits. Shows that: optimum board is square; PCB area per IC must increase as board size increases; and pin arrangement in IC package has no effect on total board area required.

**WilkM51.** Wilkes, M.V., "The Best Way To Design an Automatic Calculating Machine," *Manchester University Computer Inaugural Conference Proceedings,* 1951, p. 16. The article in which microprogramming was named and first described as a means for designing the control unit of a computer. Wilkes describes the control as if mechanized by a matrix of diode circuits. However, he pointed out that a very fast ROM could be used, and that a WCS (writeable control store) would provide potentially unlimited flexibility.

### 4.12 INTEGRATED CIRCUIT COSTS

**AllaR77.** Allan, R., "Semiconductors toeing the (Microfine) Line," *Spectrum 14,* 12, Dec. 1977, pp. 34-40. Describes IC manufacturing operation, and discusses the various technologies being developed to reduce the size of circuit patterns formed on the silicon wafers.

**BellC72.** Bell, C.G., et al., "Large-Scale Integration—A Designer's Viewpoint", Pittsburgh, Pa.: Department of Computer Science, Carnegie-Mellon University, 1972(?). Describes circuit types, manufacturing, interconnection, and packaging techniques used with integrated circuits. Discusses logic functions implemented, including memory functions. Aims at providing a guide to research on computer structures.

**BrocL70.** Brock, Les, "Designing with MSI. Volume 1—Counters and Shift Registers", Signetics Corporation, 1970. Provides circuit and logic diagrams for a variety of Signetics IC's, and discusses how they may be applied.

**ChroC78.** Chrones, C., "Calculating the Cost of Testing LSI Chips," *Electronics,* Jan 5, 1978, pp. 171-173. Shows example of costs of operating a $300,000 tester and states that costs are typically $60 to $80 per hour.

**ClinR78.** Cline, R.L., "Design Limitations in Bipolar PROM's 16K and larger." *Wescon Proceedings,* 1978, Session 9/2. Discusses topological and performance considerations for bipolar PROM's.

**FaggF78.** Faggin, F., "How VLSI Impacts Computer Architecture," *Computer 15,* 5, May 1978, pp. 28-31. Shows changes in speed-power product, microprocessor logic density, and MOS LSI die sizes as a function of time.

**GuptA72.** Gupta, A., & Lathrop, J.W. "Yield Analysis of Large Integrated Circuit Chips." *IEEE J. of Solid State Circuits, SC-7,* 10, Oct. 1972. 389-395. Discusses IC manufacturing yield and gives a formula for estimating number of chips per wafer.

**HodgD75,** Hodges, D.A., "A Review and Projection of Semiconductor Components for Digital Storage," *Proc. of the IEEE 63,* 8, Aug 1975, pp. 1136-1147. Discusses cost, reliability and power consumption of MOS, CCD, and bipolar IC's as they are expected to evolve 1975-1980.

**ICE78-1, ICE78-2.** Integrated Circuit Engineering Corp., "A Report on the Integrated Circuit Industry–Status 1978," ICE Corp., 6710 East Camelback Road, Scottsdale Ariz. 85251. This comprehensive report (together with a second one "...status Mid-1978") contains chapters covering the IC market, applications and market needs, supplier positions, captive suppliers, the economics of IC manufacturing, and technology. There are also several appendices, providing names and addresses of a variety of firms supplying IC's and IC supplies and services. The "Market" chapter gives semiconductor sales broken down into discrete and integrated components, by year for 1974-1979. It and the "application" chapter also give breakdowns by country, by technology, and by application. The "economics" chapter derives a manufacturing cost for each of seven IC's: a 74xx SSI circuit; a 4-function calculator; a CMOS gate; a 4K RAM; a 16K RAM; and a 64K CCD circuit. The early report is based on the 3-inch wafer; the mid-1978 report shows the effect of the 4-inch wafer.

**LongT70.** Longo, T.A. (ed.), "Integrated Circuit Technology", Boston Technical Publishers, Cambridge, Mass., 1970. A compendium of articles on various aspects of IC technology. The papers on packaging are particularly helpful, and include articles on bonding the die to the header (Koshinz, p.127-130), connecting the chip to package leads (Ohanian, p.131-138), and manufacturing plastic IC packages (Budnick, p.139-144).

**LuecG73.** Leucke, G., Mize, J.P., and Carr, W.M., *Semiconductor Memory Design and Application,* McGraw-Hill Book Company, NY, 1973. An excellent introduction to IC memory technology as of 1972. Includes data on bipolar and MOS IC's and memory systems.

**LymaJ77.** Lyman, J., "Growing Pin Count is Forcing LSI Package Changes," *Electronics,* March 17, 1977, pp. 81-91. Describes some dozen IC package technologies, both existing and proposed. Gives dimensions and approximate prices, though price data seems unrealistic (one cent per lead for a plastic DIP?).

**MackI78.** Mackintosh, I., 'Large-Scale Integration: Intercontinental Aspects," *Spectrum 15,* 6, June 1978, pp. 51-56. Shows that semiconductor prices and computer cost per instruction have fallen at nearly the same rate over a 15-year period. Discusses expected IC usage by the U.S., Japan, and Europe, and describes the factors expected to influence IC development here and abroad in the future.

**MadlG69.** Madland, Glen, "MOS Integrated Circuits: The Designer's Dilemma", *Wescon Technical Papers,* 1969, pp.1-12. Compares cost and complexity of MOS and bipolar IC's.

**MotoMem72.** Motorola, Inc., "MOS and Bipolar Memories", Motorola Semiconductor Products Div., 1972. Supplies data including circuit and logic disgrams for various MOS products. Discusses the steps which must be taken in designing "custom" MOS IC's, and describes the IC manufacturing process.

**MotoTot72.** Motorola, Inc., *Total MOS,* Motorola Semiconductor Products Div., 1972. Supplies data including circuit and logic diagrams for various MOS products. Discusses the steps which must be taken in designing 'custom' MOS IC's, and describes the IC manufacturing process.

**MurpB64.** Murphy, B.T., "Cost-Size Optima of Monolithic Integrated Circuits", *Proc. IEEE, S-2,* Dec. 1964, pp.1537-1545. The classic paper modeling IC costs. Takes into account processing, assembly, and test costs as a function of chip area. Employs three different formulas for wafer yield, all of which were later discovered to give lower yields than those found in practice. Also employs an unrealistically low value for the number of IC pins as a function of the number of chip components. Shows there is a minimum cost per component or gate as a function of the number of components of gates on a chip, and plots generalized cost curves for many different sets of assumptions.

**NoycR68.** Noyce, R.N., "Making Integrated Electronics Technology Work", *Spectrum,* May 1968, pp.63-66. A succinct article presenting a simple model for IC manufacturing costs which shows how there is an optimum number of gates per chip for minimum cost, and indicates how that optimum changes from year to year. Paper is marred by some critical typographical errors.

**NoycR76.** Noyce, R.N., "From Relays to MPU's," *Computer, 13,* 12, Dec. 1976, pp. 26-29. Reviews and explains trends in IC size, complexity and performance.

**PetrR67.** Petritz, Richard L., "Current Status of Large Scale Integration Technology", *IEEE J. of Solid-State Circuits, SC-2,* 4, Dec. 1967, pp.130-147. Discusses four approaches to Large Scale Integration, including bipolar and MOS chips, full-wafer technology using discretionary wiring, and hybrid technology. Provides detailed data on 28 specific IC's in the 54/74 TTL family.

**PhilC67.** Phillips, C.D., et al., "Complex Monolithic Arrays: Some Aspects of Design and Fabrication", *IEEE J. of Solid-State Circuits, SC-2,* 4, Dec. 1967, pp.156-172. Describes the evolution of Medium Scale Integration, with emphasis on the geometric factor affecting IC design and cost. Provides detail on a variety of specific units manufactured starting in 1962.

**PricJ70.** Price, J.E., "A New Look at Yield of Integrated Circuits", *Proc. of the IEEE,* August 1970, pp.1290-1291. A brief note comparing derivations for IC yields based on wafer defects.

**RhoaW68.** Rhoades, W.T., "System Considerations in Large-Scale Integration Design", *1968 NEPCON Proceedings*, pp.707-719. Discusses chip cost and yield, and packaging costs for integrated circuits. Analyzes some of the implications of LSI on system design.

**ScruS71.** Scrupsi, S.E., "Plastic-Ceramic Duel Stirs Up New Design Concepts for LSI Packages", *Electronics*, April 12, 1971. Discusses about twenty new IC packages in various sizes and shapes being offered to IC manufacturers for packaging large chips. Gives dimensions but little or no cost information. A second article in the April 26 issue discusses the problems and prospects for batch connection techniques including beam-leads and solder bumps. **ScruS78.** Scrupki, S.E., "Why and How Users Test Microprocessors," *Electronics,* March 2, 1978, pp. 97-104. Discusses tests used both by microprocessor users and by suppliers. Describes commercially available testers.

**SpanL68.** Spandorfer, L.M., "Large Scale Integration–An Appraisal," in Alt, F.L. *Advances in Computers*, Vol. 9, 1968, pp.179-235. Excellent article on fabrication, packaging, interconnections. Describes Bipolar and MOS technologies. Treats memories. Extensive bibliography.

**SrinV77.** Srini, V.P., "API Tests for RAM chips," *Computer 10,* 7, July 1977, pp. 32-35. Shows how the test cycles required for an N-bit memory chip may be reduced fron $4N^2$ to 32N.

## 4.13 MAGNETIC CORE MEMORY COSTS

**GillT66.** Gilligan, T.J. and Persons, P.B., "Comparison of Core Memory Systems Organizations," *Computer Design,* May 1966, pp.28-30. Short but excellent analysis of difference in cost between 3D, 2D, and 2 1/2D core systems.

**KoppR76.** Koppel, R., and Maltz, I., "Predicting the Real Costs of Semiconductor Memory Systems," *Electronics,* Nov 25, 1976, pp. 117-122. An excellent article discussing reliability, testing and cost of IC memories. Shows the variation in cost per bit with bits per RAM, and estimates the difference in cost between dynamic and static RAM memories.

**MoorD66.** Moore, D.W., "Cost Performance Analysis of Integrated Circuit Core Memories", *AFIPS Conf. Procs., 29,* 1966 FJCC, pp.267-280. Establishes a cost model for 3D, 2D and 2 1/2D memories, and compares their costs over a range of memory sizes. Takes into consideration core stringing costs, drive, sense, and inhibit circuits. Omits discussion of cost of digital registers, cores, testing, and power since they are common to all memory types.

## 4.14 PERIPHERAL MANUFACTURING COSTS

**GreeB63.** Greenblott, B.J., "A Development Study of the Print Mechanism on the IBM 1403 Chain Printer," *Communications and Electronics,* Jan 1963, pp.500-509. Excellent article describes technical electromechanics of this important IBM printer.

## 4.20 INTRODUCTION

**HalsM77.** Halstead, M.H., *Elements of Software Science,* Elsevier North Holland, NY, 1977. A fascinating and original attempt to measure the complexity and other properties of a design, and to relate those measures to design time and to design error rates. The book applies these results primarily to the computer programming field; but Halstead also shows how the results may be applied to the analysis of English prose, and to the relationship between hardware logic complexity and pin count.

## 4.21 HARDWARE DEVELOPMENT COSTS

**BellC78.** Bell, C.G., Mudge, J.C., and MCNamara, J.E., *Computer Engineering,* Digital Press, Bedford, Mass., 1978. A remarkable ground-breaking book on the technical and economic factors which have influenced processor and memory design, and on the management of engineering functions to take advantage of these factors. Covers all DEC processor products from the PDP-1 to the VAX 11-780. Describes component, interconnect, packaging, and power technologies in some detail. Discusses the architectural decisions that were made for each family of products, and is frank in talking about mistakes that were made. Contains numerous tables with data on processor technologies, performance, and features. Points out various philosophies for product development over time, including performance-increasing-cost-constant (PDP-10) and performance-constant-cost-decreasing (PDP-8). Software and peripheral equipment development are barely treated–in the preface the authors mention they will be covered in later books.

**BrowR69.** Brown, R.R., "Design Automation," *Honeywell Computer Journal,* Winter 1969. Design Automation at Honeywell. History with some data on usage.

## 4.22 SOFTWARE DEVELOPMENT COSTS

**AkiyF71.** Akiyama, F., "An Example of Software System Debugging," *IFIPS Conference Proceedings,* 1971, Amsterdam,. North-Holland Publ. Co. pp. 353-359. Gives data on bugs found during a software development project. Derives a measure of program difficulty which correlates well with the bug count.

**BakeF72-1.** Baker, F.T., "Chief Programmer-Team Management of Production Programming", *IBM Systems J., 11,* 1, 1972, pp.56-73. Describes the use of a very senior and experienced "Chief Programmer" as a way to reduce programming costs and improve program quality. Gives data on productivity for one specific project.

**BakeF72-2.** Baker, F.T., "System Quality Through Structured Programming", *AFIPS Conf. Proc., 41,* 1972, pp.339-343. Gives data on the number and types of errors found during acceptance checking and operation of a system developed for the *New York, Times* by IBM.

**BakeF75.** Baker, F.T., "Structured Programming in a Production Programming Environment", *IEEE Trans. on Software Engineering, SE-1,* 2, June 1975, pp.241-252. Describes the use of development support libraries, structured coding, top-down development, and chief programmer teams by IBM's Federal Systems Division. Reports that structured coding gives a 50% improvement in productivity over non-structured methods.

**BelaL71.** Belady, L.A., and Lehman, M., "The Metadynamics of Systems in Maintenance and Growth", IBM Research Report RC 3546, (No. 16021), Sept. 17, 1971. Establishes a model describing the resources required to repair and enhance a software system after its release. Assumes errors discovered in any interval are proportional to the number present, and also that corrections and enhancements themselves contain new errors, and shows that under some conditions the errors in a system may actually increase with time.

**BlacR77.** Black, R.K.E. "Effects of Modern Programming Practices on Software Development Costs,' *Proc. Compcon*

*77,* 250-253. Presents the results of a study of 5 projects at Boeing Computer Services, Inc. Gives forecasted and actual man-months required, and distribution of those resources between definition, design, construction, and demonstrations.

**BoehB73.** Boehm, B.W., "Software and Its Impact—A Quantitative Assessment", *Datamation, 19,* 5, May 1973, pp.48-59. Calls attention to the disturbing fact that, after over twenty years of development and use, little is known and less understood about the quantitative aspects of software development and use. Pleads for the creation of a software data base. Provides numerous references.

**BoehB75-1.** Boehm, B.W., McClean, R.K., and Urfrig, D.B., "Some Experience with Automated Aids to the Design of Large-Scale Reliable Software", *IEEE Trans. on Software Engineering, SE-1,* 1, March 1975, pp.125-133. Describes results of using an automated system to test for certain inconsistencies between assertions made in software design. The design of the automated system is based on data on software error types, summarized here.

**BoehB75-2.** Boehm, B.W., "Structured Programming: A Quantitative Assessment", *Computer, 8,* 6, June 1975, pp.38-40. A brief overview of a conference panel which concluded that structured programming gives perhaps a 40% improvement in programmer productivity.

**BoehB76.** Boehm, B.W., "Software Engineering," *IEEE Trans. on Computers C-25,* 12, Dec. 1976, pp. 1226-1241. Defines software engineering, surveys present technology, and estimates trends. Emphasizes importance of maintenance. Excellent bibliography.

**BoieS74.** Boies, S.J., and Gould, J.D., "Syntactic Errors in Computer Programming," *Human Factors, 16,* 3, May-June, 1974, pp.253-257. Presents statistics on errors found in Fortran, PL-I, and assembly programs assembled or compiled on an IBM TSS/360 system at an IBM research laboratory. Concludes that syntactic errors are not a major bottleneck in the programming process.

**BrooF74.** Brooks, F.P., "The Mythical Man-Month", *Datamation,* Dec. 1974, pp.45-52. Summarizes data from several sources regarding programming productivity. Indicates that productivity seems constant in terms of source statements per unit time, but that large projects seem to engender lower productivity than small ones. Includes good bibliography.

**ClipR54.** Clippinger, R.F., Dimsdale, B., and Levin, J.H., "Automatic Digital Computers in Industrial Research", *J. Society Industrial and Applied Mathematics, 1 and 2,* 1953-1954. A series of articles in the very first editions of this journal, describing many practical aspects of computer use. The third article (in volume 2, number 1), treats system operating costs including programming costs.

**DalyE77.** Daly, E.B., "Management of Software Development," *IEEE Trans. on Software Engineering, SE-3,* 3, May 1977, pp. 230-242. Provides data on programming development experience for three large real-time projects and many other smaller ones, involving over 2 million development man-hours. Includes figures on programmer productivity, computer usage, project cost breakdowns, and error rates.

**DelaW66.** Delaney, W.A., "Predicting the Costs of Computer Programs", *Data Processing Magazine,* Oct. 1966, 32-35. Describes some guidelines to be used in planning programming projects.

**DoneW76.** Donelson, W.S., "Project Planning and Control," *Datamation, 22,* 6, June 1976, pp. 73-80. Gives a formula for cost estimation based on breaking a program down into modules and using estimates of the resources required in the past to program such modules. Describes 12 such standard modules and gives size, programming rate, and computer test hours for each.

**EndrA75.** Endres, A., "An Analysis of Errors and Their Causes in System Programs", *IEEE Trans. on Software Engineering, SE-1,* 2, June 1975, pp.140-149. Analyzes 432 program errors found in release 28 of IBM's DOS/VS. Errors occurred at the rate of 4.8 per thousand instructions of new code, and 7.8 per thousand instructions where there are mixtures of old and new code.

**ErshA72.** Ershor, A.P., "Aesthetics and the Human Factor in Programming," *Comm. ACM, 15,* no. 7, July 1972, pp.501-505. Remarkable qualitative paper on the difficulties of writing programs and of managing that activity. Apparently describes Russian practices, but uses words like "profit-thrust", "commercial pressure", and "corporate interests".

**FagaM70.** Fagan, M.E., "Design and Code Inspections to Reduce Errors in Program Development," *IBM System J., 15,* 3, 1976, pp. 182-208. Describes formalized procedures used in reviews of programs during development. Three reviews were carried out at three different stages of the development process: after design was complete but before coding began; after coding was complete but before unit test; and after unit test. The first two were found effective in improving overall productivity and apparently are now in common use within IBM. The latter was found ineffective and has been dropped.

**FarrL64.** Farr, L. and Nanus, B., "Factors That Affect the Cost of Computer Programming", *System Development Corporation TM-1447/000/02,* June 30, 1964. Discusses factors related to the programming job to be done, the resources (people and equipment) available, and the environment in which the programs are to be written.

**FrieL69.** Fried, Louie, "Estimating the Cost of System Implementation", *Data Processing Magazine,* April 1969, 24-28. Compares the results of several studies containing data on the proportion of time spent in design, coding, checkout, and documentation during a programming project.

**GilbT77.** Gilb, T., *Software Metrics,* Winthrop Publishers, Inc., Cambridge, Mass. 1977. A pioneering attempt to show how software performance and software development productivity can be measured, by an internationally-known consultant who has used many of the techniques he describes. Provides many examples of the measures and procedures discussed.

**GotlC54.** Gotlieb, C.C., "The Cost of Programming and Coding", *Computers and Automation,* Sept. 1954, p.14ff. Gives some data on programming effort required, both from a University and an industrial environment.

**HugoI77.** Hugo, I. "A Survey of Structured Programming Practice," *AFIPS Conf. Proc. 46,* 1977 NCC, pp. 741-747. Summary of a survey of 309 computer users, one third in the U.S., a quarter in the U.K., a further quarter from 15 other European countries, and the rest from the rest of the world.

**JohnJ77.** Johnson, J.R., 'A Working Measure of Productivity." *Datamation, 23,* 7, Feb 1977, pp. 106-112. Gives program size and programmer productivity data on 16 programs ranging in size from 3100 to 910,000 COBOL statements. Points out dangers of quoting productivity rates when terms are undefined.

**KnutD74.** Knuth, D., "Computer Programming as an Art", *Comm. of the ACM, 17,* 12, Dec. 1974, pp.667-673. A fascinating, entertaining, and informative argument favoring the thesis that good programming is elegant. Unfortunately, many of us who write programs haven't the wit and originality of artists, and need the kind of help that RPG provides, not the kind that permits a programmer to say, "Don't expect me to meet schedule and budget commitments. I am an artist."

**LaueS75.** Lauesen, S., "A Large Semaphone-Based Operating System", *Comm. of the ACM, 18*, 7, July 1975, pp.377-389. Describes a programming project for development of a new operating system. The original schedule was based on an estimate that the program would contain 7000 instructions, and that a programming rate of 200 instructions per man-month was feasible. The final program had 26,000 instructions and was completed with a productivity of 230 instructions per man-month.

**LienB78.** Lientz. B.P., et al, "Characteristics of Applications Software Maintenance," *Commun. of the ACM, 21*, 6, June 1978, pp. 466-471. Reports results of a 1976 survey of 69 organizations using computers. Gives data on industry classification, computer equipment suppliers, percent of effort in program creation vs. maintenance, programming languages used, programming aids used, and a listing of maintenance problem areas.

**LiskB75.** Liskov, B.H., and Zilles, S.N., "Specirication Techniques for Data Abstractions", *IEEE Trans. on Software Engineering, SE-1*, 1, March 1975, pp.7-19. Argues that a formal procedure for creating specifications from concepts would be valuable in software design. Gives tentative examples of various kinds of procedure.

**MusaJ75.** Musa, John D., "A Theory of Software Reliability and Its Application", *IEEE Trans. on Software Engineering, SE-1*, 3, Sept. 1975, pp.312-327. Develops a simplified model which predicts the number of errors found in a newly-developed program as a function of the time the program has run, and applies the model to four Bell Labs development projects.

**NaurP69.** Naur, P., and Randell, B. (eds.) *Software Engineering: Report on a Conference Sponsored by the NATO Science Committee*, Garmisch, Germany: Oct. 7-11, 1968. Summarizes the content of a series of meetings in which software development problems were discussed. Although much of the discussion is qualitative, there is also presented some very interesting data on software and on development problems.

**NelsE67.** Nelson, E.A., "Management Handbook for the Estimation of Computer Programming Costs", System Development Corporation TM-3225/000/01, March 20, 1967. Collects and reviews data from studies of 169 programs and from a review of technical literature, on the factors which govern program costs.

**PeepD78.** Peeples, D.E., "Measure for Productivity," *Datamation, 24*, 5, May 1978, pp. 222-230. Describes measures used by GT&E to monitor their software development and maintenance activities, and their data processing operations. Gives data on actual performance levels and percent improvements as determined by the measures.

**RubeR75.** Rubey, R.J., Dana, J.A., and Biche, P.W., "Quantitative Aspects of Software Validation", *IEEE Trans. on Software Engineering, SE-1*, 2, June 1975, pp.150-155. Analyzes over 1200 errors found during product verification of eleven projects. The authors estimate that product test uncovers one error per ten instructions, but that only two per 1000 instructions are found during product verification.

**SchwJ63.** Schwalb, Jerry, "Compiling in English", *Datamation*, July 1963, p.28-32. Describes results of using GECOM, a COBOL-like compiler by General Electric. Reports a saving of about 50% programming man-hours using GECOM compared to an assembly language on two 5000-instruction programs.

**ShawC66.** Shaw, C.J., "Assemble or Compile", *Datamation*, Sept. 1966, pp.59-62. Reports on System Development Corp. experience in using the Jovial Compiler, and concludes that procedure-oriented languages are substantially better than machine-oriented languages for many purposes.

**ShooM75.** Shooman, M.L., and Bolsky, M.I., "Types, Distribution, and Test and Correction Times for Programming Errors," *ACM SIGPLAN Notices, 10*, 6, June 1975, Proc. International Conference on Reliable Software, April 1975, Los Angeles. Presents an extensive analysis and discussion of failures detected during the development of a 4000-instruction control-type program written at Bell Labs. Data was collected by questionnaire.

**WalsC77.** Walston, C.E., and Felix, C.P., "A Method of Programming Measurement and Estimation," *IBM Systems J., 16*, 1, 1977, pp. 54-73. Corrections in *IBM Systems J., 16*, 4, 1977, pp. 421-423. Describes a system devised by IBM to collect and analyze data on programming development projects. Gives data on some 60 programs written since 1972 in 28 different languages on 66 different computers. Applications range from simple batch jobs to large process-control systems.

**WeinG70.** Weinworm, G.F., *On the Management of Computer Programming*, Auerbach Publ. 1970. Excellent quantitative book with extensive annotated bibliography.

**WeinG71.** Weinberg, G.M., *The Psychology of Computer Programming*, von Nostrand Reinhold, 1971. 288 pp. Extraordinarily readable and thought-provoking book about the troubled and troubling profession of programming, how it really works, and why. Provides no quantitative statements or descriptions, however, of the problems it treats.

**WolvR72.** Wolverton, R.W., "The Cost of Developing Large-Scale Software", *Doc. TRW-SS-72-01*, TRW Systems Engineering and Integration Division, Redondo Beach, Calif., March 1972. Describes problems involved in forecasting software development costs, and presents a cost estimating procedure used by TRW. Gives data on some specific projects.

## 4.4 MAINTENANCE COSTS

**CompG68.** Comptroller General of the U.S., *Maintenance of ADP Equipment in the Federal Government*. Report to Congress, April 3, 1968. Gives the ten-year maintenance charge and the system purchase price for computer equipment from eight different manufacturers. Shows that the ten-year maintenance cost varies from 18.5% to 45.8% of system purchase price.

**CurlT69.** Curl, T.S., "Reliability Assurance Maintenance Program", *Honeywell Computer Journal*, Summer 1969, p.27. Reviews the maintenance objectives of the Honeywell service organization. Gives some data on how the maintenance man spends his time; of the direct labor maintenance time, 50% is spent on unscheduled system malfunctions, 45% on preventive and scheduled maintenance, and 5% on installation, field changes, and parts chasing.

**GayF78.** Gay, F.A., "Evaluation of Maintenance Software in Real-Time Systems," *IEEE Trans. on Computers, C-27*, 6, June 1978, pp. 576-582. Presents data on accuracy and resolution of maintenance programs (or trouble locating programs) used on the Bell Systems electronic switching system, and shows how the data was used in planning improvements.

**IEEERel.** IEEE, *Reliability and Maintainability Symposium*, (Annual Report). These reports contain an interesting combination of data, statistical analyses, and mathematical models of systems and organizations. The 1972 issue contains a small but very interesting group of papers on digital computers.

**PlatE68.** Platz, E.F., "Solid Logic Technology (SLT) Computer Circuits—Billion Hour Reliability Data", *Proceedings 1968 Annual Symposium on Reliability*, pp.602-606. This report by IBM on IBM's third generation technology describes a program IBM ran to collect data and gives some statistical results. It states that the average SLT "module" has one transistor chip, two dual-diode chips, and three resistors. All failure rates measured were based on power-on time, confirmed failures (with the part returned from the field), no evidence of overstress on the part, and the actual part population including the effect of configuration changes. Over a three year period more than ten billion module hours of reliability data was collected. The module failure rate was less than .003% per thousand hours, and a variety of systems with power-on times from 2,000 to 12,000 hours were included. More than two-thirds of the component failures were caused by the mechanical opening of the solder joint which connects a chip to the substrate.

**WorsR67** Worsing, R.A., "Speech to IBM Field Engineering Branch Managers", given July 31, 1967. Copyright 1971 by the President and Fellows of Harvard College. A thoughtful and delightful criticism of industry practices in reliability and maintainability by the then Director of Systems Administration and Computing at the Boeing Company in Seattle.

## Indexes

Four indexes should help the reader locate specific items in the book.

**Index A—Subject Index.** This is the principal index for the book. It indexes the text, figures, and tables in Part I (including the Supplement) and the tables (but not, in general, the text) in Part II. The following notes may help the reader use the index.

1. Page numbers are usually accompanied by a letter a, b, c, or d, signifying which quarter of the page pertains to the referenced topic. The top of the left column of a page is referred to as a, the bottom left as b, the top and bottom right column as c and d, respectively.

2. Page numbers in italics identify a major subheading on that page.

3. Figure numbers are preceded by an F, and table numbers by a T. Page numbers are not given for figures and tables. The figure or table number itself specifies the section of the book where the figure or table appears, and that section can be located in the Table of Contents or (more conveniently) simply by observing the section numbers at the top of each page, as one thumbs through the book.

4. Tables and figures from Part II contain a Roman II in their number—thus, TII.1.31.1 is a table in Section 1.31 of Part II. Tables and figures in the Supplement always have a lower case letter following their number. Thus Figure 2.11.8a and Table II.1.31.2c will be found in the Supplement. When a topic is covered by a figure or table which has been updated in the Supplement, that figure or table number is marked with an asterisk: *. Thus T1.26.1* points to Table 1.26.1, which covers Data Processing Services in DPT&E, and to Table 1.26.1a, which covers the same subject in the Supplement.

5. Table references often contain a colon. Numbers after the colon designate pertinent line numbers in the table. A hyphen between two line numbers indicates all the lines between those two contain pertinent data. Three dots (...) between two line numbers indicate there is at least one line between those two which contains pertinent data.

6. Page numbers are *not* given for the text (i.e. the notes to the tables) in Part II. To find textual references in Part II, one simply finds the indicated tables in Part II, and then turns to the adjacent notes to those tables and looks for comments on the cited lines.

7. Citations on a topic are given in the order they appear in the book, and not in order of importance.

Here is a simple example of an index entry and its interpretation:

XYZ, 91b, 125a-c, *127*, F3.11.1,2,4-6,20, T4.11.2,7, TII.1.26*, TII.2.11.1:14-20, TII.2.23.5:4...18, F1.21.5a, TII.2.11.4a.

This entry would indicate that the subject XYZ is treated at the lower part of the left column of page 91; on all parts of page 125 except the lower right corner; on page 127, where there begins a substantial discussion of the subject; in Figures 3.11.1, 2, 4, 5, 6, and 20—that is, in figures 1, 2, 4, 5, 6, and 20 of Section 3.11; in Tables 4.11.2 and 4.11.7; in three tables of Part II—Table II.1.26, Table II.2.11.1 (lines 14 through 20 inclusive), and Table II.2.23.5 (line 4, line 18, and at least one line in between those two); and in Figure 1.21.5a and Tables II.2.11.4a and II.1.26a of the Supplement.

**Index B—System Manufacturer Index.** The primary source for references on companies is Index A, and that index should be consulted first when information about a particular company is desired. If that company is included in Index B, Index A will so state.

Index B shows the principal references to fifteen systems companies, in a standard format. Page references are given as the top line; all other references are to tables and figures, using the same format as described above in connection with Index A.

**Index C—Computer System Index.** The book provides data on specific computer systems and peripheral products of many manufacturers. The peripherals are not indexed by model number, although all peripheral product types covered in the book appear in Index A. (Thus line printers appear in Index A, but there is no index to the IBM 1403—a reader interested in that particular printer would have to read through all the line printer references to locate specifics about the 1403.)

Most of the major systems covered in the book are, however, indexed here in Index C. Each system covered appears as a column on the table, and the systems are in alphabetical order by company, and within a company appear in numerical order. Only the principal, systematic references, which appear in tables and figures, are given. Occasional and incidental references in the text are not indexed.

**Index D—Bibliographic Index.** Bibliographic citations in the book are identified generally by a seven-character code constructed from the first four letters of the author's last name, his first initial, and the last two digits of the year the citation appeared. The bibliography, in Part III, contains details on these references, organized by subject matter. Index D, in alphabetical order by bibliographic code (and therefore by author) provides a cross index to these citations.

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| Size Distribution | TII.1.31.2b | TII.1.31.2b | TII.1.31.2* | TII.1.31.2* | TII.1.31.2b |
| Value in Use | | | TII.1.31.1:91...106 | TII.1.31.1:85...101 | |
| Average Value | | | F1.31.15,16 | F1.31.15 | |
| | | | TII.1.31.1:118-120 | TII.1.31.1:112-114 | |
| Value Shipped | | | F1.31.18-21 | F1.31.18,19 | |
| | | | TII.1.31.1:131...145 | TII.1.31.1:126...141 | |
| U.S. Govt. Systems | | | F3.11.22a | F3.11.22* | |
| | | | TII.1.22.3 | TII.1.22.3 | |
| | | | TII.3.11.6*:13,23 | TII.3.11.6*:14,24 | |

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# INDEX C

**INDEX C—Index to the Principal Computer Systems: Page 1**
**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | BGH 205 | BGH 1710 | BGH 5500 | BGH 6700 | CDC G-15 | CDC LGP30 | CDC 160 | CDC 3600 | CDC 6600 | CDC Cyb76 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.346 | p.632 | p.346 | p.632 | p.348 | p.348 | p.348 | p.348 | p.348 | p.350 |
| **Operations Cost** | TII.3.26.2 | | | | | | | | | | |
| **Performance** | | | | | | | | | | | |
| Addition Time | F2.11.1* | x | | x | x | x | x | x | | x | x |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | x | x | x | x |
| Arithmetic Speed | F2.11.2* | x | | x | x | | x | x | | x | |
| | TII.2.11.1*:12 | x | x | x | x | x | x | x | x | x | x |
| Benchmarks | F2.23. | | | 3 | | | | | | 3 | |
| | TII.2.11.1:19-38 | x | | x | | x | x | x | x | x | x |
| | TII.2.23.1 | | | | | | | | | | |
| | TII.2.11.6a | | | | | | | | | | |
| | T2.11.1a | | | | | | | | | | |
| COBOL | TII.2.15.3 | | | | | | | | x | | |
| Memory—Cycle Time | F2.11.4* | x | | x | x | x | x | x | | x | x |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | | | x | x | | | x | | x | x |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | x | x | x | x | x | x | x | | x | x |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | x | x | x | x |
| | F2.10.8 | | | | | | | | x | x | x |
| Operations/$ | F2.11.7* | x | | x | x | x | x | x | | x | x |
| | TII.2.11.1*:16...41a | x | x | x | x | x | x | x | x | x | x |
| Reliability | TII.2.23. | 6,7 | | 5,7,8 | | 6,7 | | | | | |
| Throughput | F2.23. | | | 19 | | | | | | 19 | |
| | T2.23.2 | | | x | | | | | | x | |
| **Physical Char.** | | | | | | | | | | | |
| Floor Space | TII.3.25.6 | | | | | | | | | | |
| | TII.2.11.1*:100,108 | x | | x | | x | x | x | x | x | x |
| Heat Dissipation | TII.3.25.6 | | | | | | | | | | |
| | TII.2.11.1*:103,111 | x | | x | | x | x | x | x | x | x |
| Power Requirements | TII.3.25.6 | | | | | | | | | | |
| | TII.2.11.1*:102,110 | x | | x | | x | x | x | x | x | x |
| **Price** | | | | | | | | | | | |
| History | F2.11.13* | | | | | | | | | | |
| | TII.2.11.4 | | | | | | | | | | |
| Internal Memory | F2.11.* | | | 10,12 | 11,12 | | | | | 11,12 | |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | | x | | | | | | x | |
| Maintenance | F4.4.11* | | | | | | | | | | |
| | TII.2.11.1*:79...97 | x | x | x | | x | x | x | x | x | x |
| | TII.2.11.2* | | | x | | | | | | x | |
| & Performance | F2.11.8* | x | x | x | x | x | x | x | | x | x |
| **Systems** | | | | | | | | | | | |
| Configurations | TII.3.25.6 | | | | | | | | | | |
| Number in Use | F2.10. | 2 | | | | 3 | 3 | 3 | | | |
| | TII.1.31.1*: | :40 | | | | :46 | :48 | :50 | | :42 | |
| | TII.2.10*: | :36 | | :42a | | :47 | :48 | :49 | | :43 | |
| Performance in Use | F2.10. | | | 7 | | | | | 8 | 6,8 | |
| | TII.2.10*: | | | :110 | | | | | | :109 | |
| Value in Use | F2.10*. | | | | | | | | | | |
| | TII.2.10*: | | | | | | | | | | |
| Average Value | TII.2.10*: | | | | | | | | | | |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x | x | x |

1. Explanation of table entries (referring to the Burroughs 205—the first column of the table). The BGH 205 is described in Table II.2.11.1, page 346. Its addition time appears in lines 5 and 7 of that table; benchmark data appears on lines 19 to 38 inclusive; and operations per second data appears on line 11, line 41, and at least one other line between those two. The machine's arithmetic speed is plotted in Figure 2.11.2, and its memory cycle time appears in Figure 2.11.4. The number of systems in use is shown in Figure 2.10.2, and also appears in Table II.2.10.2, line 36. Data on reliability of the 205 is given in Tables II.2.23.6 and II.2.23.7.

2. Other machines whose characteristics are carried in Table II.2.11.1: **Burroughs** 200, (p. 346), 220 (p. 346), 500 (p. 348), 3500 (p. 348). **CDC** 1604 (p. 348). **GE** 115 (p. 350). **Honeywell** 120 (P. 350). **NCR** 50 (p. 352), 100 (p. 352), 500 (p. 352). **RCA** Bizmac (p. 352), 70/45 (p. 354). **Univac** II (p. 354.)

* Tables or Figures marked with an asterisk have been updated in the Supplement. The reader will typically find the older systems in the original figure or table, and the newer ones in the corresponding figure or table in the Supplement. He should examine both. For example, the Univac I appears in Figure 2.11.1 page 61, the IBM 4331 appears in Figure 2.11.1a, page 539, and the CDC 6600 appears in both figures.

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**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | DEC PDP8 | DEC PDP11 | DEC 780 | GE 225 | HIS 62 | HIS 200 | HIS 700 | HIS 800 | IBM S/1 | IBM S3/4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.350 | p.350, | p.634 | p.225 | p.634 | p.350 | p.634 | p.350 | p.630 | p.630 |
| **Operations Cost** | TII.3.26.2 | | | | | | | | | | |
| **Performance** | | | | | | | | | | | |
| Addition Time | F2.11.1* | x | | | | | | | | x | x |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | | x | x | x |
| Arithmetic Speed | F2.11.2* | | | | | | | | | | x |
| | TII.2.11.1*:12 | x | x | x | x | x | x | | x | x | x |
| Benchmarks | F2.23. | | | | | | 3 | | | | |
| | TII.2.11.1:19-38 | x | x | | x | | x | | x | | |
| | TII.2.23.1 | | | | | | | | | | |
| | TII.2.11.6a | | | | | | | | | | |
| | T2.11.1a | | | | | | | | | | |
| COBOL | TII.2.15.3 | | | | | | | | x | | |
| Memory—Cycle Time | F2.11.4* | x | | | | | | | | x | x |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | | | | | | | | | x | x |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | x | | x | | | | | | x | x |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | | x | x | x |
| | F2.10.8 | | | | | | | | | | |
| Operations/$ | F2.11.7* | | | | | | | | | | x |
| | TII.2.11.1*:16...41a | x | x | | x | x | x | | x | | x |
| Reliability | TII.2.23. | | | | 5,7,8 | | 5,7,8 | | 5,7,8 | | |
| Throughput | F2.23. | | | | | | | | | | |
| | T2.23.2 | | | | | | | | | | |
| **Physical Char.** | | | | | | | | | | | |
| Floor Space | TII.3.25.6 | | | | | | | | | | |
| | TII.2.11.1*:100,108 | x | x | | x | | x | | x | | |
| Heat Dissipation | TII.3.25.6 | | | | | | | | | | |
| | TII.2.11.1*:103,111 | x | x | | x | | x | | x | | |
| Power Requirements | TII.3.25.6 | | | | | | | | | | |
| | TII.2.11.1*:102,110 | x | x | | x | | x | | x | | |
| **Price** | | | | | | | | | | | |
| History | F2.11.13* | | | | | | | | | | |
| | TII.2.11.4 | | | | | | | | | | x |
| Internal Memory | F2.11.* | | | | | | | | | | 9 |
| | TII.2.11.1:77...81 | x | x | x | x | x | x | x | x | x | |
| | TII.2.11.2* | | | | | | | | | | x |
| Maintenance | F4.4.11* | | | | | | | | | | x |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | | | | | | | | | x |
| & Performance | F2.11.8* | x | | x | | | | | | x | x |
| **Systems** | | | | | | | | | | | |
| Configurations | TII.3.25.6 | | | | | | | | | | |
| Number in Use | F2.10. | 3 | | | | | | | | | |
| | TII.1.31.1*: | :52 | | | | | | | | | :26b |
| | TII.2.10*: | :50 | | | | | | | | | |
| Performance in Use | F2.10. | | | | | | | | | | |
| | TII.2.10*: | | | | | | | | | | |
| Value in Use | F2.10*. | | | | | | | | | | |
| | TII.2.10*: | | | | | | | | | | |
| Average Value | TII.2.10*: | | | | | | | | | | |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x | x | x |

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**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

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**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | IBM 704 | IBM 705 | IBM 709 | IBM 1401 | IBM 1410 | IBM 1440 | IBM 1460 | IBM 1620 | IBM 7010 | IBM 7030 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.338 | p.338 | p.338 | p.338 | p.340 | p.340 | p.342 | p.340 | p.342 | p.340 |
| **Operations Cost** | TII.3.26.2 | | | | x | | | | | | |
| **Performance** | | | | | | | | | | | |
| Addition Time | F2.11.1* | x | x | x | x | | | x | x | | |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | x | x | x | x |
| Arithmetic Speed | F2.11.2* | x | x | x | x | | | x | x | | |
| | TII.2.11.1*:12 | x | x | x | x | x | x | x | x | x | x |
| Benchmarks | F2.23. | | | | 1-3 | 2 | | | | | |
| | TII.2.11.1:19-38 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.23.1 | | | | x | x | | | | | |
| | TII.2.11.6a | | | | | | | | | | |
| | T2.11.1a | | | | | | | | | | |
| COBOL | TII.2.15.3 | | | | x | x | | | | x | |
| Memory–Cycle Time | F2.11.4* | x | x | x | x | x | | | x | | |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | x | x | x | x | | | x | x | | |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | x | x | x | x | | | x | | | |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | x | x | x | x |
| | F2.10.8 | x | x | | | | | | | | x |
| Operations/$ | F2.11.7* | x | x | x | x | | | | x | | |
| | TII.2.11.1*:16...41a | x | x | x | x | x | x | x | x | x | x |
| Reliability | TII.2.23. | 6,7 | 6,7 | | 5-8 | 5,7,8 | | 5,7,8 | | | |
| Throughput | F2.23. | | 18 | | 17 | | | | | | |
| | T2.23.2 | | x | | x | | | | | | |
| **Physical Char.** | | | | | | | | | | | |
| Floor Space | TII.3.25.6 | x | | | x | | | | | | |
| | TII.2.11.1*:100,108 | x | x | x | x | x | x | x | x | x | x |
| Heat Dissipation | TII.3.25.6 | x | | | x | | | | | | |
| | TII.2.11.1*:103,111 | x | x | x | x | x | x | x | x | x | x |
| Power Requirements | TII.3.25.6 | x | | | x | | | | | | |
| | TII.2.11.1*:102,110 | x | x | x | x | x | x | x | x | x | x |
| **Price** | | | | | | | | | | | |
| History | F2.11.13* | | x | | x | | | | | | |
| | TII.2.11.4 | | | | x | | | | | | |
| Internal Memory | F2.11.* | | 10 | | 9,12 | | | | | | |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | x | | x | | | | | | |
| Maintenance | F4.4.11* | | | | | | | | | | |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | x | | x | | | | | | |
| & Performance | F2.11.8* | x | x | x | x | | | x | | | |
| **Systems** | | | | | | | | | | | |
| Configurations | TII.3.25.6 | x | | | x | | | | | | |
| Number in Use | F2.10. | | | | 1 | | | | 2 | | |
| | TII.1.31.1*: | :4 | :5 | | :9 | | | :11 | :12 | | |
| | TII.2.10*: | :9 | :12 | | :18 | | | :24 | :38 | | |
| Performance in Use | F2.10. | 6 | 6 | 7 | 7 | | | | | | |
| | TII.2.10*: | | | :105 | :107 | | | | | | |
| Value in Use | F2.10*. | 5 | 5 | | 4 | | | 5 | | | |
| | TII.2.10*: | :67 | :68 | | :70 | | | :72 | | | |
| Average Value | TII.2.10*: | :10 | :13 | | :19 | | | :25 | | | |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x | x | x |

# INDEX C

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| | Table or Figure | IBM 7044 | IBM 7074 | IBM 7090 | IBM 7094 | IBM 360 /20 | IBM 360 /30 | IBM 360 /40 | IBM 360 /44 | IBM 360 /50 | IBM 360 /65 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.342 | p.340 | p.338 | p.340,342 | p.344 | p.342 | p.342 | p.344 | p.342 | p.342 |
| **Operations Cost** | TII.3.26.2 | | | | | x | | | x | x | |
| **Performance** | | | | | | | | | | | |
| Addition Time | F2.11.1* | | | x | x | x | x | | | | x |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | x | x | x | x |
| Arithmetic Speed | F2.11.2* | | | x | x | x | x | x | | x | x |
| | TII.2.11.1*:12 | x | x | x | x | x | x | x | x | x | x |
| Benchmarks | F2.23. | | | | 2 | 1,2 | 1,2 | 2 | | 2 | 2,3 |
| | TII.2.11.1:19-38 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.23.1 | | | | | x | x | x | | x | x |
| | TII.2.11.6a | | | | | x | x | x | | x | x |
| | T2.11.1a | | | | | | | | | | x |
| COBOL | TII.2.15.3 | x | x | x | x | | | | | | |
| Memory—Cycle Time | F2.11.4* | | | | | x | x | x | | | x |
| | TII.2.11.1:4 | x | x | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | | | x | x | x | x | x | | x | x |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | | | x | x | x | x | x | | x | x |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | x | x | x | x |
| | F2.10.8 | | | x | | | | | x | | |
| Operations/$ | F2.11.7* | | | x | x | x | x | x | x | x | x |
| | TII.2.11.1*:16...41a | x | x | x | x | x | x | x | x | x | x |
| Reliability | TII.2.23. | 5,7,8 | | | 5,7,8 | | 5,7,8 | | | | |
| Throughput | F2.23. | | | | | | 17 | | | | 18 |
| | T2:23.2 | | | x | | | x | | | x | |
| **Physical Char.** | | | | | | | | | | | |
| Floor Space | TII.3.25.6 | | | x | | | x | | | | x |
| | TII.2.11.1*:100,108 | x | x | x | x | x | x | x | x | x | x |
| Heat Dissipation | TII.3.25.6 | | | x | | | x | | | | x |
| | TII.2.11.1*:103,111 | x | x | x | x | x | x | x | x | x | x |
| Power Requirements | TII.3.25.6 | | | x | | | x | | | | x |
| | TII.2.11.1*:102,110 | x | x | x | x | x | x | x | x | x | x |
| **Price** | | | | | | | | | | | |
| History | F2.11.13* | | | | | | x | | | | |
| | TII.2.11.4 | | | | | | x | | | | |
| Internal Memory | F2.11.* | | | | | 9,12 | 9,12 | 10,12 | | 10,12 | 11,12 |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | | | | x | x | x | x | x | x |
| Maintenance | F4.4.11* | | | | | | x | x | | x | x |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | | | | x | x | x | x | x | x |
| & Performance | F2.11.8* | | | x | x | x | x | x | | x | x |
| **Systems** | | | | | | | | | | | |
| Configurations | TII.3.25.6 | | | x | | | x | | | | x |
| Number in Use | F2.10. | | | | | 1 | 1 | | | | |
| | TII.1.31.1*: | | | :8 | :10 | :21 | :16 | :22 | :17 | :18 | :23 |
| | TII.2.10*: | | | :15 | :21 | :40 | :27 | :30 | | | :44 |
| Performance in Use | F2.10. | | | 6 | 6 | | | | | | 6 |
| | TII.2.10*: | | | :106 | :108 | | | | | | :111 |
| Value in Use | F2.10*. | | | 4 | 5 | | | 5 | | | |
| | TII.2.10*: | | | :69 | :71 | | :73 | :74 | | | |
| Average Value | TII.2.10*: | | | :16 | :22 | | :28 | :31 | | | |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x | x | x |

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**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | IBM 370 /115 | IBM 370 /125 | IBM 370 /135 | IBM 370 /138 | IBM 370 /145 | IBM 370 /148 | IBM 370 /155 | IBM 370 /158 |
|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.346 | p.346 | p.346 | p.631 | p.344 | p.631 | p.344 | p.630 |
| **Operations Cost** | TII.3.26.2 | | | | | | | | |
| **Performance** | | | | | | | | | |
| Addition Time | F2.11.1* | x | x | x | x | x | x | x | x |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | x | x |
| Arithmetic Speed | F2.11.2* | | | | x | x | x | x | x |
| | TII.2.11.1*:12 | x | x | x | x | x | x | x | x |
| Benchmarks | F2.23. | | | 2 | | 2 | | | |
| | TII.2.11.1:19-38 | x | x | x | | x | | x | |
| | TII.2.23.1 | | | x | | x | | | |
| | TII.2.11.6a | x | x | x | x | x | x | x | x |
| | T2.11.1a | | | | | | x | | x |
| COBOL | TII.2.15.3 | | | | | | | | |
| Memory—Cycle Time | F2.11.4* | | | | x | | x | | x |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | | x | x | x | | x | | x |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | x | x | x | x | x | x | x | x |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | x | x |
| | F2.10.8 | | | | | | | | |
| Operations/$ | F2.11.7* | x | x | x | x | x | x | x | x |
| | TII.2.11.1*:16...41a | x | x | x | x | x | x | x | x |
| Reliability | TII.2.23. | | | | | | | | |
| Throughput | F2.23. | | | 16,17 | | | | | |
| | T2.23.2 | | | x | | | | | |
| **Physical Char.** | | | | | | | | | |
| Floor Space | TII.3.25.6 | | | x | | | | | |
| | TII.2.11.1*:100,108 | x | x | x | x | x | x | x | x |
| Heat Dissipation | TII.3.25.6 | | | x | | | | | |
| | TII.2.11.1*:103,111 | x | x | x | x | x | x | x | x |
| Power Requirements | TII.3.25.6 | | | x | | | | | |
| | TII.2.11.1*:102,110 | x | x | x | x | x | x | x | x |
| **Price** | | | | | | | | | |
| History | F2.11.13* | | | | | | | | |
| | TII.2.11.4 | | | x | x | | | | |
| Internal Memory | F2.11.* | | 10,12 | 10,12 | 11,12 | 11,12 | 10-12 | 11,12 | 11,12 |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | x | x | x | x | x | x | x |
| Maintenance | F4.4.1 | | x | x | x | x | x | x | x |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | x | x | x | x | x | x | x |
| & Performance | F2.11.8* | x | | x | x | x | x | x | x |
| **Systems** | | | | | | | | | |
| Configurations | TII.3.25.6 | | | x | | | | | |
| Number in Use | F2.10. | | | | | | | | |
| | TII.1.31.1*: | :25a | :25b | :25c | :25ca | :25d | :25da | :25e | :25f |
| | TII.2.10*: | | | :35a | | :32a | | :33 | :35d |
| Performance in Use | F2.10. | | | | | 7 | | 6 | 6a |
| | TII.2.10*: | | | | | :114 | | :113 | :62c |
| Value in Use | F2.10*. | | | 5 | | | | 4 | 4a |
| | TII.2.10*: | | | :75a | | :74a | | :75 | :75b |
| Average Value | TII.2.10*: | | | :35b | | :32b | | :34 | :35e |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x |

**INDEX C—Index to the Principal Computer Systems: Page 8**
**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | IBM 370 /165 | IBM 370 /168 | IBM 3031 | IBM 3032 | IBM 3033 | IBM 4331 | IBM 4341 | NCR 100 | NCR C101 |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.344 | p.630 | p.631 | p.631 | p.631 | p.631 | p.631 | p.352 | p.634 |
| **Operations Cost** | TII.3.26.2 | | | | | | | | x | |
| **Performance** | | | | | | | | | | |
| Addition Time | F2.11.1* | x | x | x | x | x | x | x | | |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | x | x | x |
| Arithmetic Speed | F2.11.2* | x | x | x | x | x | x | x | | |
| | TII.2.11.1*:12 | x | x | x | x | x | x | x | x | x |
| Benchmarks | F2.23. | 2,3 | | | | | | | | |
| | TII.2.11.1:19-38 | x | | | | | | | x | |
| | TII.2.23.1 | x | | | | | | | | |
| | TII.2.11.6a | x | x | x | x | x | x | x | | |
| | T2.11.1a | | x | x | x | x | | | | |
| COBOL | TII.2.15.3 | | | | | | | | | |
| Memory–Cycle Time | F2.11.4* | x | x | x | x | x | x | x | | |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | x | x | x | x | x | x | x | | |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | x | x | x | x | x | x | x | | x |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | x | x | x |
| | F2.10.8 | | | | | | | | | |
| Operations/$ | F2.11.7* | x | x | x | x | x | x | x | | |
| | TII.2.11.1*:16...41a | x | x | x | x | x | x | x | x | x |
| Reliability | TII.2.23. | 11 | | | | | | | | |
| Throughput | F2.23. | 18 | | | | | | | | |
| | T2.23.2 | x | | | | | | | | |
| **Physical Char.** | | | | | | | | | | |
| Floor Space | TII.3.25.6 | x | | | | | | | | |
| | TII.2.11.1*:100,108 | x | x | x | x | x | | | x | |
| Heat Dissipation | TII.3.25.6 | x | | | | | | | | |
| | TII.2.11.1*:103,111 | x | x | x | x | x | | | x | |
| Power Requirements | TII.3.25.6 | x | | | | | | | | |
| | TII.2.11.1*:102,110 | x | x | x | x | x | | | x | |
| **Price** | | | | | | | | | | |
| History | F2.11.13* | | | | | | | | | |
| | TII.2.11.4 | | | | | | | | | |
| Internal Memory | F2.11.* | 11,12 | 11,12 | 11,12 | 11,12 | 11,12 | 10,12 | 11,12 | | |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | x | x | x | x | x | | | | |
| Maintenance | F4.4.11* | x | x | x | x | x | | | | |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | x | x | x | x | x | | | | |
| & Performance | F2.11.8* | x | x | x | x | x | x | x | | x |
| **Systems** | | | | | | | | | | |
| Configurations | TII.3.25.6 | x | | | | | | | | |
| Number in Use | F2.10. | | | | | | | | | |
| | TII.1.31.1*: | :25g | :25h | :25j | :25j | :25j | | | | |
| | TII.2.10*: | | :35g | | | :45a | | | | |
| Performance in Use | F2.10. | | 7a | | | 6a | | | | |
| | TII.2.10*: | | :62d | | | :62e | | | | |
| Value in Use | F2.10*. | | 5a | | | | | | | |
| | TII.2.10*: | | :75c | | | | | | | |
| Average Value | TII.2.10*: | | :35h | | | | | | | |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x | x |

**INDEX C—Index to the Principal Computer Systems: Page 6**
**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | NCR 315 | NCR 390 | RCA 301 | RCA 501 | Uni I | Uni III | UNI 90-30 | Uni 1004 | UNI 1106 |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | p.352 | p.352 | p.35 | 2p.352 | p.354 | p.35 | p.634 | 4p.35 | p.634 |
| **Operations Cost** | TII.3.26.2 | | | | | | | | | |
| **Performance** | | | | | | | | | | |
| Addition Time | F2.11.1* | | | | | x | | | x | |
| | TII.2.11.1*:5,7 | x | x | x | x | x | x | x | x | x |
| Arithmetic Speed | F2.11.2* | | | | | x | x | | x | |
| | TII.2.11.1*:12 | x | x | x | x | x | x | x | x | x |
| Benchmarks | F2.23. | | | | | | | | 3 | |
| | TII.2.11.1:19-38 | x | x | x | x | x | x | | x | |
| | TII.2.23.1 | | | | | | | | | |
| | TII.2.11.6a | | | | | | | | | |
| | T2.11.1a | | | | | | | | | |
| COBOL | TII.2.15.3 | x | | x | | | x | | | |
| Memory–Cycle Time | F2.11.4* | | | | | x | | | x | |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | x | x |
| Transfer Rate | F2.11.5* | | | | | x | x | | x | |
| | TII.2.11.1*:18 | x | x | x | x | x | x | x | x | x |
| Operations/Sec. | F2.11.6*,8* | | | | | x | x | x | x | x |
| | TII.2.11.1*:11...41 | x | x | x | x | x | x | x | x | x |
| | F2.10.8 | | | | | | | | | |
| Operations/$ | F2.11.7* | | | | | x | x | | x | |
| | TII.2.11.1*:16...41a | x | x | x | x | x | x | x | x | x |
| Reliability | TII.2.23. | | | 5,7,8 | 5,7,8 | 6,7 | | | | |
| Throughput | F2.23. | | | | | | | | | |
| | T2.23.2 | | | | | | | | | |
| **Physical Char.** | | | | | | | | | | |
| Floor Space | TII.3.25.6 | | | | | | | | | |
| | TII.2.11.1*:100,108 | x | x | x | x | x | x | x | x | |
| Heat Dissipation | TII.3.25.6 | | | | | | | | | |
| | TII.2.11.1*:103,111 | x | x | x | x | x | x | x | x | |
| Power Requirements | TII.3.25.6 | | | | | | | | | |
| | TII.2.11.1*:102,110 | x | x | x | x | x | x | x | x | |
| **Price** | | | | | | | | | | |
| History | F2.11.13* | | | | | | | | | |
| | TII.2.11.4 | | | | | | | | | |
| Internal Memory | F2.11.* | | | | | | | | | |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | | | | | | | | |
| Maintenance | F4.4.11* | | | | | | | | | |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | | | | | | | | | |
| & Performance | F2.11.8* | | | | | x | | x | x | x |
| **Systems** | | | | | | | | | | |
| Configurations | TII.3.25.6 | | | | | | | | | |
| Number in Use | F2.10. | | | | | | | | 2 | |
| | TII.1.31.1*: | | | | | :31 | | | :32 | |
| | TII.2.10*: | | | | | :6 | | | :39 | |
| Performance in Use | F2.10. | | | | | | | | | |
| | TII.2.10*: | | | | | | | | | |
| Value in Use | F2.10*. | | | | | 5 | | | | |
| | TII.2.10*: | | | | | :66 | | | | |
| Average Value | TII.2.10*: | | | | | :7 | | | | |
| | TII.2.11.1*:93,94 | x | x | x | x | x | x | x | x | x |

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**(See the footnote at the end of Page 1 of this index, for explanations and other data.)**

| | Table or Figure | Uni 1108 | UNI 1110 | UNI 1160 | UNI 1180 | Uni 9200 | Uni 9300 | Uni 9400 | WANG 2200T |
|---|---|---|---|---|---|---|---|---|---|
| **(Major Table)** | TII.2.11.1* | 4p.354 | p.634 | p.634 | p.634 | p.356 | p.35 | 6p.35 | p.634 |
| **Operations Cost** | TII.3.26.2 | | | | | x | x | | |
| **Performance** | | | | | | | | | |
| Addition Time | F2.11.1* | x | | | | | | | |
| | TII.2.11.1*:5,7 | x | x | | | x | x | x | |
| Arithmetic Speed | F2.11.2* | x | | | | x | x | x | |
| | TII.2.11.1*:12 | x | x | | | x | x | x | |
| Benchmarks | F2.23. | 3 | | | | | | | |
| | TII.2.11.1:19-38 | x | | | | x | x | x | |
| | TII.2.23.1 | | | | | | | | |
| | TII.2.11.6a | | | | | | | | |
| | T2.11.1a | | | | | | | | |
| COBOL | TII.2.15.3 | | | | | | | | |
| Memory—Cycle Time | F2.11.4* | x | | | | x | x | | |
| | TII.2.11.1*:4 | x | x | x | x | x | x | x | |
| Transfer Rate | F2.11.5* | x | | | | | x | | |
| | TII.2.11.1*:18 | x | x | | | x | x | x | |
| Operations/Sec. | F2.11.6*,8* | x | x | | | | x | | |
| | TII.2.11.1*:11...41 | x | x | | | x | x | x | x |
| | F2.10.8 | | | | | | | | |
| Operations/$ | F2.11.7* | x | | | | x | x | | |
| | TII.2.11.1*:16...41a | x | x | | | x | x | x | |
| Reliability | TII.2.23. | 10 | | | | | | | |
| Throughput | F2.23. | 19 | | | | | | | |
| | T2.23.2 | x | | | | | | | |
| **Physical Char.** | | | | | | | | | |
| Floor Space | TII.3.25.6 | | | | | | | | |
| | TII.2.11.1*:100,108 | x | | | | x | x | x | x |
| Heat Dissipation | TII.3.25.6 | | | | | | | | |
| | TII.2.11.1*:103,111 | x | | | | x | x | x | |
| Power Requirements | TII.3.25.6 | | | | | | | | |
| | TII.2.11.1*:102,110 | x | | | | x | x | x | x |
| **Price** | | | | | | | | | |
| History | F2.11.13* | | | | | | | | |
| | TII.2.11.4 | | | | | | | | |
| Internal Memory | F2.11.* | 11,12 | | | | | | | |
| | TII.2.11.1*:77...81 | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | x | | | | | | | |
| Maintenance | F4.4.11* | | | | | | | | |
| | TII.2.11.1*:79...97 | x | x | x | x | x | x | x | x |
| | TII.2.11.2* | x | | | | | | | |
| & Performance | F2.11.8* | x | x | | | | | | |
| **Systems** | | | | | | | | | |
| Configurations | TII.3.25.6 | | | | | | | | |
| Number in Use | F2.10. | | | | | | | | 3b |
| | TII.1.31.1*: | :33 | | | | | | | |
| | TII.2.10*: | :45 | | | | | | | :52g |
| Performance in Use | F2.10. | 7 | | | | | | | |
| | TII.2.10*: | :112 | | | | | | | |
| Value in Use | F2.10*. | | | | | | | | |
| | TII.2.10*: | | | | | | | | |
| Average Value | TII.2.10*: | | | | | | | | |
| | TII.2.11.1*:93,94 | x | x | | | x | x | x | x |

# INDEX D

## INDEX D—Index to the Bibliography

**FROM THE INTRODUCTION:**

"A study of the science of technology defines what is possible; a study of the economics of technology establishes which of the possibilities is practical and useful."

Montgomery Phister, Jr.

**REVIEWERS' COMMENTS:**

"This remarkable book contains by far the most comprehensive collection of facts about the data processing industry ever published in one place. . . . No one can fully understand the modern data processing industry or the market without some knowledge of how they came to be this way, and this book is by far the best source of quantitative historical data available."

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