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A HISTORY OF THE USE OF QUANTITATIVE TOOLS AND TECHNIQUES IN BUSINESS

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by

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Commander, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

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IN

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ABSTRACT

This paper presents a historical review of selected material covering the development of quantitative methods and tools involved in management decision-making. Although the science of the computer has evolved rather recently the principles behind them can be traced over many years in the past. Men such as Taylor and Fayol not only developed quantitative techniques but also wrote most of the material which describes the results of their experiments. They believed that sciences such as engineering should have some basis in management and did much to encourage the teaching of management in the engineering schools. In some areas managers did not develop the tools but they were instrumental in the application of the techniques.

This paper traces these tools from the development of the abacus around the year 1100 B. C., followed by an enumeration and explanation of various operations research tools, methods and models. I believe that this paper will show that managers have played an important part in the development and use of quantitative tools and techniques in business.

The writer wishes to express his appreciation to Commander S. W. Blandin, USN, of the United States Naval Postgraduate School for his suggestions and assistance given in the preparation of this paper.

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I. THE HISTORICAL DEVELOPMENT OF CALCULATING DEVICES

The Chinese Abacus. The oldest computer, and one that is still in wide use, is the Chinese Abacus. As a physical device for computing, the abacus can be traced back to 1100 B. C. ; in its latest general pattern it has existed for at least seventeen centuries. The calculation methods, which are essential for the efficient use of the abacus, had their genesis more than 3,000 years ago. About 1,000 years ago applied mathematicians had advanced abacus mathematics to operating criteria verses. All computing operations are stated in standard terminology and are expressed in concise criteria verses which are executed by actuating the relevant beads. The correct answer appears on the abacus as soon as the operation of the beads is finalized. The abacus is in use for accounting and control operations in banks, business establishments and government agencies in China, Korea, Japan and Southeast Asian countries, and to a lesser extent in India and Russia. At the present the abacus is being used as the principle computing device by over half the world's population.

Mechanical Calculators. The first calculating machine was invented by Blaise Pascal in 1642. In 1671, Gottfried Leibniz conceived a machine which could perform multiplication by repeated addition. The initial model of this calculator, which was completed in 1694, utilized several advanced mechanical principles which are still in common use today. The first successful calculating machine was invented by Charles Thomas of Alsace, France, in 1820. Frank Stephen and W. T. Odhner made an important mechanical contribution in 1875, which led to a more compact design for the calculating gears. By 1905, mechanical calculators had incorporated features such as motor-drive, keyboard set-up, multiplication keys, and the self-stepping carriage. Since then the design has been greatly refined but few new features have been added.

The first key-driven adding machine, which could add only a single column of digits, was patented in the United States by D. D. Parmalee in 1850. Multiple-order machines were introduced in 1887, and refined to their current state by 1903. E. D. Barbour incorporated a printing device with an adding machine in 1872, but the first practical adding and listing machines were produced by Felt in 1889, and by W. S. Burroughs in 1892.

Punched-card Machines. The invention of the punched card is generally credited to Jacquard who utilized cards to control the weaving pattern of the Jacquard-loom which he first built about 1804. However, according to Usher, in the History of Mechanical Inventions, Jacquard borrowed this control mechanism from Bouchon, who first used rolls of perforated paper tape to control a loom in 1725, and Falcon, who substituted punched cards for the perforated paper roll in 1739. The development of punched-card machines for numerical calculation began in the 1880's when Dr. Herman Hollerith, a noted statistician, suggested that a machine should be devised to facilitate the tabulation of the 1890 census. The 1880 census had taken seven and a half years to tabulate and it appeared that the 1890 census might not be completed until its information was completely useless. The first machine completed was a sorter (1886) but by 1914, Hollerith and an assistant, James Powers, had also developed the key punch, reproducer and accumulating tabulator. The tabulator, or accounting machine, not only played an important role in the development of punched card data processing systems but also provided the prototype model for the high speed printer which is an essential component of all electronic data processing systems.

The ideas of Hollerith were developed by the International Business Machines Corporation and the British Tabulating Corporation; the ideas of Powers were developed by the Powers-Samas and Remington Rand Companies. This split, which was primarily concerned with the configuration of the punched card, still exists in the computer manufacturing industry today and is a major hindrance to the interchangeability of equipment.

Early uses of punched cards were for insurance tables, payrolls, cost accounting, utility accounting and inventory control. Accountants accepted punched-card systems reluctantly because the record produced was not in the format desired for statements or reports, but by 1940 punched-card accounting systems were in widespread use all over the world. In 1946, the electro-mechanical multiplier was added to the family of punched-card machines.

Although this machine and its successors never achieved widespread useage, they were the forerunners for an important branch of electronic computers; the I. B. M. 650 (1954), the first computer with more than 1,000 installations, and the I. B. M. 1401 (1960), the most widely used computer at the present time (more than 7,000 machines are installed or on order).

The history of automatic computation dates from 1812, when Charles Babbage, an Englishman, conceived the idea of developing a machine to compute tabular functions. The major idea underlying Babbage's Difference Engine, of which he built a small model in 1822, was that appropriate level differences between the values computed from a formula are constant, so that the values themselves are obtainable by addition. The small model of 1822 led to a much larger version of the Difference Engine that was finally completed in 1859, and used in 1863, for calculating life tables for rating insurance.

In 1833, while still working on his Difference Engine, Babbage conceived the idea of an Analytical Engine to perform any type of digital calculation. Babbage's computer was designed for punched-card input, an arithmetic unit, storage for 1,000 numbers of 50 decimal digits each, an auxiliary memory of punched cards, a built in power of judgment to follow a program and an output in the form of either punched cards or type, set and ready to print tables. Babbage also visualized a mechanical computer capable of carrying out a sequence of instructions and of modifying them to cope with situations encountered during operations. Because existing manufacturing techniques could not produce the precision-made components required for Babbage's Analytical Engine, a model was never completed. Thus, all of the essential components of present-day computers were invented well over 100 years ago, but none were built until the 1940's.

The modern history of computers dates from 1937 when Howard H. Aiken of Harvard University conceived the Automatic Sequence Controlled Calculator (Mark I), an electromechanical machine which could add two 23 digit numbers in .3 of a second. Input required standard punched cards, hand-set dial switches, and long loops of punched paper tape. Output was similar except that an electric typewriter was used instead of switches. Instructions were entered by the use of switches, buttons, wire plug boards and punched tape. The Mark I was the first machine that was able to perform long sequences of arithmetical and logical operations.

The ENIAC (Electronic Numerical Integrator and Calculator) was the first machine to use electronic tubes in the place of electromechanical relays. It was built between 1942 and 1945 by Eckert and Mauchy of the Moore School of Electrical Engineering at the University of Pennsylvania under a contract with the U. S. Army Ordnance Corps. The ENIAC could execute 5,000 additions a second on 10 digit numbers that were stored in 20 registers. Initially it was programmed by means of plug-wired instructions but later modifications permitted the internal storage of programs which were made up from a repertoire of 60 standard instructions. The ENIAC was a decimal computer utilizing 19,000 vacuum tubes which were stored in 30 separate units with a total weight of more than 30 tons. The machine was used for ten years for computing ballistic tables and for various scientific calculations.

In 1945, before the ENIAC was completed, a report on the logical design of computers prepared by the eminent mathematician, John Von Neumann, and his co-workers contained a detailed proposal for the design of a new type of computer which would be much less complex and much faster than the ENIAC. This report resulted in the construction of the EDVAC (Electronic Discrete Variable Automatic Computer) in the United States and the EDSAC computer built at Cambridge University in England. These computers, which were binary, stored-program computers, incorporated most of the basic concepts which are found in the present highspeed scientific computers. The EDVAC stimulated the design of many similar computers including the Remington Rand UNIVAC I, introduced in 1951, as the first commercially available computer. The first UNIVAC I, like the first punched-card machines, was built for the U. S. Bureau of the Census (where it is still in productive use) to assist in processing the data from the 1950 population census. This was the first computer to utilize magnetic tapes to provide an auxiliary storage unit with a capacity of hundreds of millions of digits. Thus, the UNIVAC I was the first computer which could be used for the commercially important work of data processing.

In the early 1950's, the market forecasts for large computers ranged from the pessimistic estimate that six large computers could satisfy the total computing needs in the United States to the optimistic estimate that the total demand for large computers might be as great as 50 in the next decade. Despite these rather discouraging market forecasts, the International Business Machine Corporation introduced the IBM 701 in 1953, in competition with the UNIVAC I and thus precipitated a competitive struggle which still rages between computer manufacturers. Although Remington Rand had a two-year lead on all other manufacturers, IBM soon took over a commanding share of the market which they have maintained to date despite the entry of 21 other manufacturers.[1] Because of this strong competition new computers have been introduced into the commercial market at a very rapid rate. This has created a strong buyers market but has also resulted in much confusion in the evaluation of the machines and services offered by each producer.

The current status of the computer market is clearly shown by (1) "The Computer Tree" (Figure 1) prepared by the Ballistics

[1] Since IBM policy is to withhold information on the number and type of computers which it installs it is impossible to determine accurate share of market data. An estimate made in late 1961 gave IBM 81%, RemRand 7%, RCA 3%, NCR 2%, Burroughs 1.5%, Philco 1.5%, Control Data 1.5%, Bendix .7%, Honeywell .6%, General Electric .5%, and all others .7%. In November 1961, Remington Rand claimed 14% of the market but this was doubted by most authorities.

THE COMPUTER TREE

THIS TREE SHOWS THE ACCELERATED EVOLUTION OF ELECTRONIC DIGITAL COMPUTERS. THE AUTOMATIC COMPUTING AND DATA PROCESSING INDUSTRY IS A DIRECT OUTGROWTH OF THE RESEARCH, SPONSORED BY THE ARMY ORDNANCE CORPS, THAT PRODUCED THE ENIAC, THE WORLD'S FIRST ELECTRONIC DIGITAL COMPUTER. THIS INDUSTRY HAS GROWN TO A MULTI-BILLION DOLLAR ACTIVITY THAT HAS PENETRATED EVERY PROFESSION AND TRADE IN GOVERNMENT, BUSINESS, INDUSTRY, AND EDUCATION. THE TRUNK RESTS ON THE ENIAC. THE SERIAL COMPUTERS, REPRESENTED BY THE EDVAC, AND THE PARALLEL COMPUTERS, REPRESENTED BY THE ORDVAC, ARE SHOWN AS SEPARATE LIMBS. THIS SEPARATION TENDS TO DISTINGUISH THE BUSINESS COMPUTERS ON THE LEFT LIMB FROM THE SCIENTIFIC COMPUTERS ON THE RIGHT LIMB. THE COMPUTERS THAT WERE DEVELOPED SPECIFICALLY TO MEET MILITARY NEEDS ARE SHOWN ON THE CENTER LIMB. MANUFACTURERS HAVE ENTERED THE ELECTRONIC COMPUTER FIELD AT DIFFERENT TIMES, SHOWN AS VARIOUS BRANCHES. ONLY UNIVERSITY AND GOVERNMENT SPONSORED COMPUTERS ARE SHOWN ALONG THE LIMBS. THE RADIAL DISTANCE FROM THE ENIAC IS AN APPROXIMATE INDICATION OF THE YEAR EACH COMPUTER WAS EITHER DEVELOPED, CONSTRUCTED, OR PLACED IN OPERATION.

THE ENIAC, EDVAC, ORDVAC, AND BRLESC WERE SPONSORED OR DEVELOPED BY THE BALLISTIC RESEARCH LABORATORIES, ABERDEEN PROVING GROUND, MARYLAND, AN AGENCY OF THE U. S. ARMY ORDNANCE CORPS.

FIGURE 1

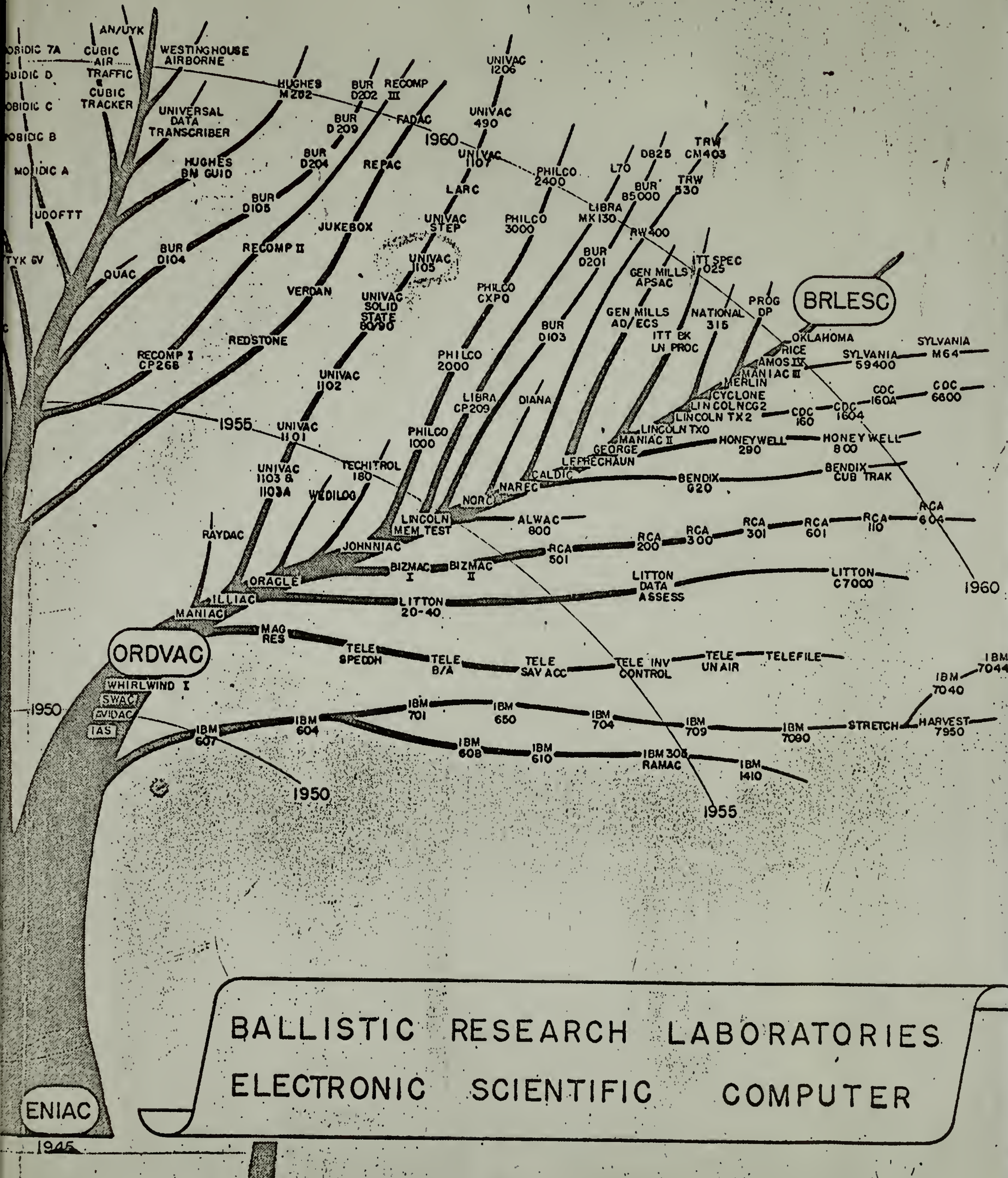
BALLISTIC RESEARCH LABORATORIES
ELECTRONIC SCIENTIFIC COMPUTER
ENIAC
1945
ORDVAC
BRLESC
1950
1955
1960
WHIRLWIND I
SWAC
EDVAC
IAS
MANIAC
ILLIAC
ORACLE
RAYDAC
JOHNNIAC
LINCOLN MEM TEST
NORC
NAREC
CALDIC
LEPRECHAUN
GEORGE
MANIAC II
LINCOLN TXO
LINCOLN TX2
LINCOLN CG2
CYCLONE
MERLIN
MANIAC III
AMOS IV
RICE
OKLAHOMA
PROG DP
IBM 607
IBM 604
IBM 701
IBM 650
IBM 704
IBM 709
IBM 7090
STRETCH
HARVEST 7950
IBM 7040
IBM 7044
IBM 608
IBM 610
IBM 305 RAMAC
IBM 1410
MAG RES
TELE SPEECH
TELE B/A
TELE SAV ACC
TELE INV CONTROL
TELE UN AIR
TELEFILE
LITTON 20-40
LITTON DATA ASSESS
LITTON C7000
BIZMAC I
BIZMAC II
RCA 501
RCA 200
RCA 300
RCA 301
RCA 601
RCA 110
RCA 604
ALWAC 800
BENDIX G20
BENDIX CUB TRAK
HONEYWELL 290
HONEYWELL 800
CDC 160
CDC 1604
CDC 160A
CDC 6600
SYLVANIA 59400
SYLVANIA M64
NATIONAL 315
ITT EK LN PROC
ITT SPEC 025
GEN MILLS AD/ECS
GEN MILLS APSAC
RW400
BUR D103
BUR D201
LIBRA MX130
BUR B5000
TRW 530
TRW CM403
D825
L70
PHILCO 2400
PHILCO 3000
PHILCO CXPQ
PHILCO 2000
PHILCO 1000
LIBRA CP209
DIANA
UNIVAC 1101
UNIVAC 1102
UNIVAC 1103 & 1103A
TECHITROL 180
WEDILOG
UNIVAC SOLID STATE 80/90
UNIVAC 1105
UNIVAC STEP
LARC
UNIVAC 1107
UNIVAC 490
UNIVAC 1206
REDSTONE
VERDAN
JUKEBOX
REPAC
FADAC
RECOMP I CP266
RECOMP II
RECOMP III
BUR D104
BUR D105
BUR D204
BUR D209
BUR D202
HUGHES BN GUID
HUGHES M202
UNIVERSAL DATA TRANSCRIBER
WESTINGHOUSE AIRBORNE
QUAC
UDOFTT
MOBIDIC A
MOBIDIC B
MOBIDIC C
MOBIDIC D
MOBIDIC 7A
CUBIC AIR TRAFFIC
CUBIC TRACKER
AN/UYK

FIGURE 1

Research Laboratories of the U. S. Army Ordnance Corps and by (2) the "Computer Characteristics Chart" (Appendix I) which is prepared by Adams Associates, Inc., a management consulting firm. The "Computer Tree" traces the major branches of computer development in the United States and the "Computer Characteristics Chart" summarizes the important characteristics of all of the 78 commercial computers which are currently being manufactured in the United States. It is interesting to note that a few of the newer computers can execute 1,000,000 additions per second; a 200-fold increase over the speed of the ENIAC, accomplished in less than 20 years.

A rough estimate of the current computing power in the United States is given in the "Datamation Quarterly Index of Computing" (Figure 2). This index contains (1) an estimate of the total speed of all computers currently installed in the United States (in millions of operations per second), (2) an estimate of the total monthly rental for these computers, and (3) the ratio of the speed index to the rental index. In the twenty-seven month period ending in December 1962, the speed index increased by a factor of 6.6 and the rental index increased by a factor of 2.8. This has resulted in a steady increase in the ratio of speed to rental, as shown in Figure 2, which primarily reflects the improved computing efficiency due to the introduction of the newer transistorized computers.

Although developed independently of operations research, computers have played an important role in the application of the operations research to practical problems. In fact, as the techniques

DATAMATION'S QUARTERLY INDEX OF COMPUTING

With the inclusion of initial installations of the large scale 1107 plus the typical growth rate experienced over the past year, the computing index for the fourth quarter of 1962 resumed its upward trend.

The number of ops/sec rose to 135 million, a gain of slightly more than 10% over the third quarter's figure of 122 million. Continuing installations of large scale systems in the 7000 class plus small scale computers such as the 1401 contributed to this gain. (It might be noted that 1401 installations have tapered off slightly during the past three months, for the first time during the year.)

Monthly rentals show a total of 84 megabucks, or approximately the same as in the previous quarter. Again, the slight drop-off of 1401s affected this figure.

The ratio of computing power per dollar represents the quotient of the Speed Index and Operations per Dollar Index. Since the Ratio Index represents a measure of a condition, the units (operations per second) ÷ (dollars per month) need not be meaningfully related to provide an intelligible result.

This ratio reversed itself during the fourth quarter as compared to the previous period, moving upward to 1.608, a gain of 10%. It is felt that the number of small scale installations, with high throughput cost as compared to large scale systems, tends to offset the lower operation/cost balance achieved by the larger machines. ◘

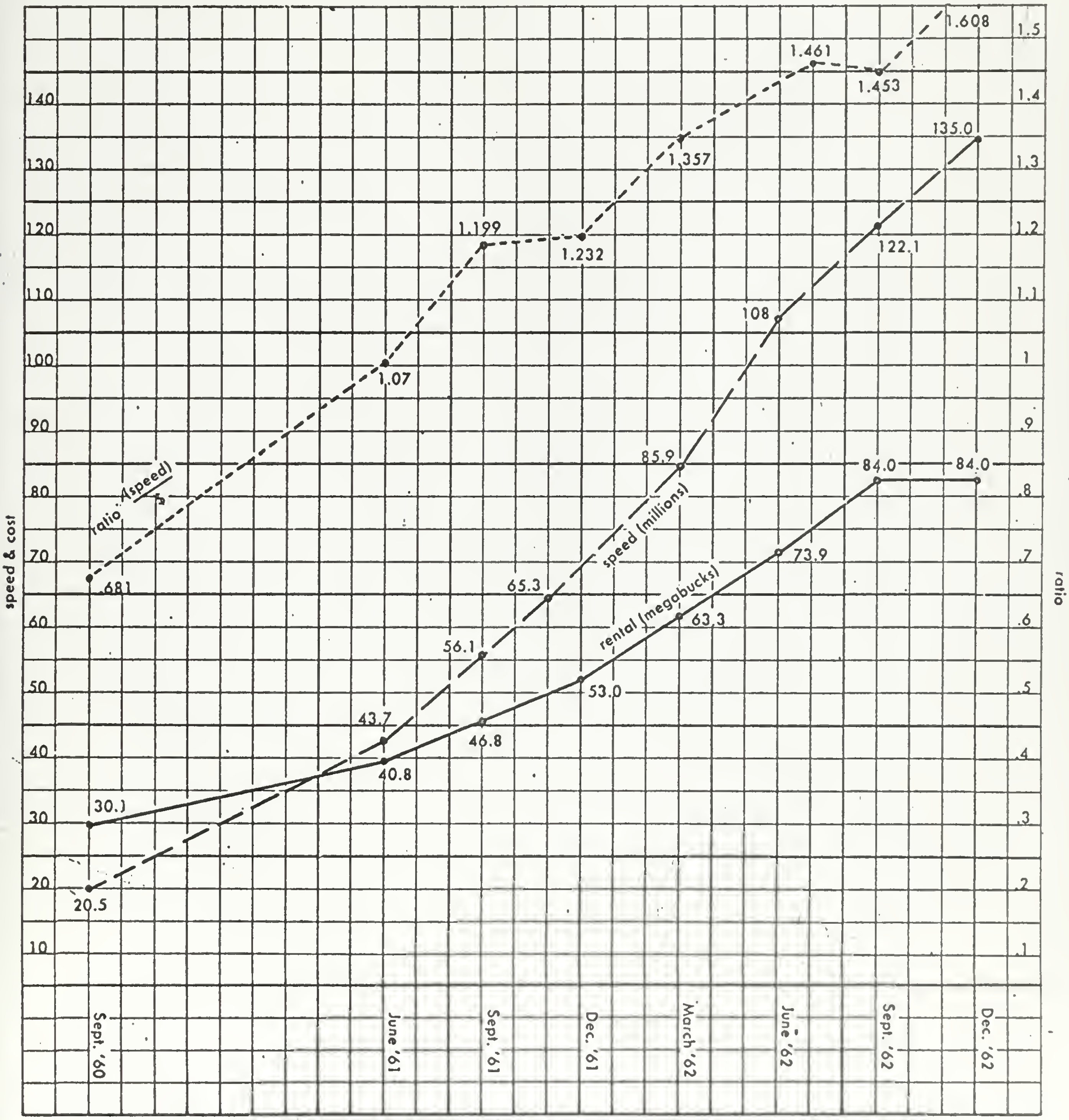

FIGURE 2

of operations research are refined and extended, it is becoming clear that the use of a computer is essential for the application of these techniques to almost all real business problems.

II. THE HISTORICAL DEVELOPMENT OF THE USE OF QUANTITATIVE TECHNIQUES IN BUSINESS

A. The Development of Accounting Techniques. Bookkeeping in one form or another is linked with the earliest organization of men for government purposes, thus, its origin may be dated to 6000-5000 B. C. The oldest written "documents" which survive in the world were produced about 5,000 years ago in Mesopotamia; they were primitive books of account written on clay tablets. Thousands of years later, when the first printing press was set up in Europe by Gutenberg, many of the earliest books which were printed were text-books of commercial arithmetic. Single entry bookkeeping, which was never a science, was the only form of accounting until the 14th century and was in common use until the middle of the 19th century. Double entry bookkeeping was originated in Italy at least as early as 1340 A. D.; the first treatise on double entry bookkeeping was written by Lucus Pacioli in Italy in 1494. In America, instruction in bookkeeping began in the lower public schools as early as 1670, and by the end of the 19th century instruction had advanced to the public high schools and a few universities. The earliest proposal for the establishment of a collegiate school of business in the United States was contained in a report written in 1869 by Robert E. Lee to the trustees of the institution that later became known as Washington and Lee University, but this proposal was not carried out. The Wharton School of Commerce and Finance at the University of Pennsylvania, the first business school to actually be established, was opened in 1881.

The development of the theory of accounting was very slow. From 1550 to 1795 there was a gradual shift from the standard entry form concerned only with changes in the owner's capital to a more complete system which also accounted for what the capital produced and consumed. This change was brought about by the development of larger firms and the trend toward the separation of ownership and management. In the 19th century accounting forged ahead to assume the form which is in use today. In the first half of the century there was strong resistance to the introduction of new methods and to the development of a theory of accounting. In the latter half of the century the opposition was overcome and the theoretical basis of accounting was laid. From 1000 to the present there has been a slow shift of emphasis from financial accounting to managerial accounting; cost accounting, accounting systems, accounting for decision-making, etc. In its most refined forms management accounting is basically an operations research technique. Although accountants have adopted these new techniques slowly, the management accounting approach has had a significant impact on the teaching and practice of accounting. Accountants, who were slow to accept punched-card accounting systems, have also been slow in accepting computerized accounting systems. However, in view of the continued acceptance of computers by management, most accounting firms have now accepted the computer as an accounting tool and a few firms have become the leaders in the development of the techniques of electronic data processing.

B. <u>The Use of Statistics in Business.</u> It is very difficult to accurately date the beginning of the use of statistical techniques in business and government. Although the earliest records date back several thousand years, reliable population data are available for only a few hundred years. The first good records of the population in England were not made until the 16th century, and an official census was not made until 1801. Very few countries took an official census of the population until the end of the 18th century.

The first use of statistics was probably for insurance. Mortality tables were prepared by the Romans as early as 346 A. D. but insurance did not get on a business-like basis until the 15th century. Fire insurance was first used in Europe in the 15th century but it was not successfully introduced in England until after the disastrous fire in London in 1666. The first life insurance company in England was chartered in 1706 and the first life insurance company in the United States was established in 1759. The first books dealing with the application of probability theory to life insurance were published during the 1800's. The early issues of <u>Publications of the American Statistical Association</u>, which began publication in 1888, are almost entirely devoted to the presentation of descriptive statistical data related to the government and business. Thus, until the early 20th century statistics were used primarily for the description of various populations.

Between 1910 and 1920 a major change occurred in the use of statistics in business when emphasis was shifted from description to analysis. This change, which seems to have emanated from the Harvard School of Business, emphasized the use and analysis of time series and the testing of hypotheses by the techniques of "classical statistics". In 1917, Business Statistics, the first text book specifically concerned with the application of statistics to business was published by M. T. Copeland, a Harvard professor. The Review of Economic Statistics was first published in 1919 as the culmination of several years of research by some of the faculty at the Harvard School of Business. After 1920, the existing techniques of classical statistics were highly developed and applied to many new areas (such as the problem of production and quality control), but very few new techniques were introduced.

In 1959, a second major innovation in business statistics occurred with the publication of Probability and Statistics for Business Decisions by Robert Schlaifer of Harvard. This introductory text presented for the first time the practical implementation of the key ideas of Bayesian statistics: that probability is orderly opinion, and that inference from data is nothing more than the revision of such opinion in the light of relevant new information. Baye's theorem, which specifies how modifications of opinion should be made, is a simple and fundamental fact about probability that seems to have been clear to Thomas Bayes when he wrote his famous article in 1763, though he did not state it there explicitly. Thus, from a very broad point of view, Bayesian statistics date back to at least 1763. Two more recent lines of development which are important for the philosophical and mathematical basis of Bayesian statistics are the ideas of statistical decision theory, based on the game-theoretic work of Borel, von Neumann and Morgenstern, and the personalistic definition of probability which was crystallized by Ramsey and de Finetti in the 1930's. Except for the personalistic view of probability, all the elements of Bayesian statistics were invented and developed within, or before, the classical approach to statistics; only their combination into specific techniques for statistical inference is at all new. The Bayesian approach is still a subject of much controversy among theoretical statisticians. Nevertheless, the practicality of Bayesian statistics as a decision tool is currently being investigated in several university and industrial research centers. So far, there have been few, if any, publications of the successful application of these techniques to practical business problems.

C. The Use of Mathematics and the Scientific Method in Business.

Although the use of mathematics in business was rare before the 19th century (with the exception of the arithmetic of accounting), its possible value in training businessmen was recognized at an early date. In 1716, in An Essay on the Proper Method of Forming the Man of Business, Thomas Watts stressed the importance of teaching arithmetic, accounting, amd mathematics, including algebra, geometry and mensuration (statistics). In 1776, Adam Smith applied the principles of the scientific method when he stated in Wealth of Nations that the division of labor would increase the quantity of work completed because there would be (1) an increase in dexterity for each workman, (2) a saving of time lost in passing from one type of work to another and (3) the invention of labor saving machines. In the book, On the Economy of Machinery and Manufactures, published in 1832, Charles Babbage described and classified the tools and machinery used in various manufacturing operations which he observed in England and on the continent, and discussed the "economical principles of manufacturing". In the mood of an operational research man of today, Babbage took apart the manufacture of pins; the operations involved, the kinds of skills required, the expense of each process, etc. He suggested a number of methods for analyzing factories and processes, and for finding the proper size and location of factories. One very practical result of his research was the adoption of the penny post in England. Sir Rowland Hill was encouraged to standardize the cost of sending a letter anywhere in England because Babbage's analysis of postal operations showed that the cost of handling mail in the post office was much greater than the cost of transportation. Edwin T. Freedley also showed the necessity of considering the entire situation by the following simple example, taken from A Practical Treatise on Business, published in 1854. "A man who spends a dollar and a half in hiring a horse, and also the greater part of a day to purchase 6 or 8 bushels of wheat at a sixpence a bushel less than he must have given nearer home, is not so economical as he may have imagined."

Out of these early beginnings the first definitive movement toward understanding the managerial implications of rapid technological progress began to emerge at the end of the 19th century. The information required to establish a true "science of managine" was not yet at hand because the techniques required for controlled experiments, accurate observations and statistical correlation were still weak. Nevertheless, in the last years of the century the foundations of management science were laid and the important work of Taylor and Gilbreth was begun. The first decade of the 20th century was the beginning of the investigation of the principles of management along lines which provide statistical validity. In 1910, the movement was given the name "scientific management" and was officially introduced by Harrington Emerson in testimony regarding the inefficiency of the U. S. railroads. A conference was held at the Amos Tuck School of Administration and Finance at Dartmouth College in 1911 to discuss possible courses of action uncovered by new avenues of management thinking. During the second decade of the century major emphasis was placed on the practical aspects of scientific management, especially after the demands of the war effort required the application of every organizational and functional skill available. In 1915, an "economic order quantity" equation was published by Ford W. Harris and used by Westinghouse Electric and Manufacturing Co., but it had little impact on most firms. Thomas A. Edison made the first OR study for the Navy in 1917, but its results were never implemented. This study involved a thorough statistical analysis of submarine activities and their results in an attempt to develop strategic plans to reduce the number of ships lost. From his analysis, Edison developed a set of rules which ships should follow to reduce the danger of a surprise attack. To present his plan in concrete form, Edison developed a simple simulation of the problem which consisted of a ruled peg board with one set of pegs representing cargo ships and another set representing submarines. Although played as a game, this simulation clearly showed that when the prescribed rules were followed a surprisingly small number of ships would even be seen by a submarine. This study made no impression on the Navy, possibly because of an organization problem. In World War I, the Navy Consulting Board, which Edison headed, reported to the civilian Secretary of Navy who made very few operational decisions. However, in World War II, operations research analysts reported directly to an operational command which was in a position to put their recommendations into effect.

In the 1920's and 30's a deeper philosophy of scientific management was distilled and assembled out of the diverse objectives which had been the goals of earlier investigators. Over-all planning and measurement were replacing the patchwork approach. In 1924, H. C. Levinson turned from astronomy to management and applied the principles of science and mathematics to the problems of L. Bamberger and Co., a large mail order house. Although little has been written about his specific accomplishments in this position, Levinson was undoubtedly one of the early leaders in applying OR techniques to business. In 1935, Dr. Harry Hopf suggested that the time was right to transform management science to the "science of the optimum", a goal which is still the basis of most of our present OR techniques.

The official birthdate of operations research is generally given as the beginning of World War II when teams of civilian scientists were asked to analyze some of the major problems faced by the military. The first OR studies were made in England in 1939, in connection with the integration of newly developed radar into the existing early warning system. In the United States the first operations research section was established by the Navy in May 1942, to study anti-submarine operations and by the Air Force in October 1942, to study the effectiveness of bombing missions. By V-J Day, almost 500 persons were engaged in operations research for the various military commands. At the close of the war the techniques of OR began to be applied to various business problems and by 1950, the movement was growing rapidly. The first OR text, Methods of Operations Research by Morse and Kimball, was published in 1951. The first OR society, The Operations Research Society of America, was established in 1953 and the first journal followed shortly thereafter. By 1962, two societies with a combined membership of approximately 5,000 members existed in the United States and at least 10 other groups existed in other countries. A study of 36 universities made in 1953 showed that only six offered courses in OR and only one had a curriculum leading to the M. S. degree. By 1962, at least 10 universities offered a Ph. D. with a major in operations research and approximately 10 other universities allowed the selection of OR problems for dissertations in at least one field. In the last decade the refinement of existing techniques and the development of new techniques, combined with the tremendous power of high speed computers have resulted in the rapid growth and acceptance of the OR approach in almost all phases of business.

III. A SUMMARY OF OR TECHNIQUES AND MODELS

The relationship between OR tools and techniques and OR mathematical models is presented in Figure 3. The left side of the diagram contains a list of the most important tools and techniques that are currently being used in OR studies. The mathematical models which are most frequently used in OR are listed across the top of the table. The X's indicate which techniques are used in the various models. First we will discuss the tools and techniques, in the order in which they are listed in Figure 3 and then we will turn our attention to the OR models.

A. The Tools and Techniques of Operations Research. The description of each of the eleven techniques listed in Figure 3 is intended (1) to briefly describe the technique, (2) to indicate the extent of its applicability to the various OR models, (3) to indicate whether the results obtained are analytic optimum solutions or approximations to optimal solutions and (4) to discuss the limitations of the technique.

1. Calculus. A knowledge of calculus is fundamental for the derivation and the complete understanding of many OR techniques, however, the techniques of calculus are directly applicable to a limited number of OR models. Calculus provides powerful techniques for determining the values for the variables which will maximize a functional relationship. Thus, the techniques are used to obtain the much sought after "optimum solution". Although analytic solutions are

OPERATIONS RESEARCH MODELS

TOOLS AND TECHNIQUES	STATIC INVENTORY	DYNAMIC INVENTORY	ALLOCATION	WAITING LINE	SEQUENCING	COMPETITIVE	REPLACEMENT
CALCULUS	X	X					
STATISTICS AND PROBABILITY	X	X	X	X	X	X	X
MATHEMATICAL PROGRAMMING		X	X		X	X	X
DYNAMIC PROGRAMMING		X	X		X		X
HEURISTIC PROGRAMMING			X		X	X	
QUEUING THEORY				X			
GAME THEORY						X	
LINEAR GRAPH THEORY					X		
SIMULATION		X		X	X	X	X
ENUMERATION	X		X		X	X	
ECONOMIC THEORY	X	X	X	X	X	X	X

Figure 3. A Summary of the Tools, Techniques and Models of Operations Research

obtained it is often necessary to greatly simplify the "real" problem so that these techniques can be used. The classical techniques of calculus are limited to static problems, however, the development of dynamic programming has extended the use of the techniques to dynamic problems.

2. Probability Theory and Statistics. The techniques of classical or Bayesian statistics are an essential element in almost all practical OR problems. It is usually necessary to determine the probability distribution for one or more of the parameters of any realistic business problem. It is often also necessary to use statistical techniques to evaluate the effect of variations in the input parameters for many types of OR problems. Statistical decision theory is useful for all problems which attempt to maximize expected profits or minimize expected losses. The solutions obtained from statistical techniques are not analytic but are approximations to optimum solutions in the long run. The techniques are limited to parameters which have known distributions however parameters with unknown distributions can usually be handled by using Monte Carlo techniques and simulation.

3. Mathematical Programming. The term"mathematical programming" is not rigidly defined but is generally used to describe a large group of algorithms which provide analytic solutions to specific types of problems. Although often based on advanced mathematics, these techniques can usually be used by anyone with a knowledge of algebra and the ability to follow directions. The best known

algorithm is the simplex method for solving linear programs which was developed by Dantzig in 1947. Linear programming theory has been used in many industrial applications such as the following: resource allocation, transportation scheduling, warehouse planning, production scheduling, inventory control, portfolio selection, gasoline blending, personnel assignment, assembly line balancing, decentralization and plant layout. Recently these techniques have been expanded to include non-linear programming, integer programming and quadratic programming. Although the algorithms for these techniques are much more complex than the simplex algorithm, they are applicable to a much wider group of problems. The techniques of mathematical programming give analytic solutions but they are limited to a certain set of problems which satisfy the restrictions of the algorithm.

4. Dynamic Programming. The theory of dynamic programming was developed by Richard Bellman in the early 1950's to treat OR problems involving (1) multi-stage processes, (2) large numbers of variables, (3) chance events and (4) the determination of policies rather than functions. This technique provides a theoretical framework for handling some of the more complex OR problems which cannot be solved with the older techniques of calculus. Dynamic programming is a general technique which can be applied to many of the basic OR models. With the recent publication of several books explaining the original theory, the use of dynamic programming will probably grow rapidly and may become one of the most important techniques in operations research.

5. <u>Heuristic Programming</u>. The major aim of heuristic programming is to prepare computer programs which can solve problems that have hitherto required intelligence. Although most applications to date have been to non-business problems such as playing chess and checkers, proving elementary theorems and composing music some attempts have been made to solve a few of the non-structured problems in business. Heuristic programs have been written for balancing assembly lines, selecting portfolios, and production planning. Heuristic techniques have been applied to these problems because the mathematical solution is either too complex or requires too many computations. In general, the techniques of heuristic programming are not economically competitive with the techniques of mathematical programming or with human decision making. However, in the development of any decision system which attempts to make all decisions without human intervention, heuristic programming will be required if the system involves any non-structured decisions. Since all business decision systems involve a large number of non-structured decisions, heuristics techniques will probably play a more important role in operations research in the future.

6. <u>Queuing Theory</u>. Queuing or waiting-line theory dates back to the work of Erlang in 1909. Until 1945, applications were restricted in general to the operation of telephone systems, but since 1945, the theory has been extended and applied to a wide variety

of phenomena. Queuing theory is a special technique which applies to only one of the OR models listed in Figure 3. In its present form, the theory is limited to fairly simple systems, however, the solution to more complex waiting-line problems can be approximated by the technique of simulation.

7. Game Theory. The analysis of the mathematical form and underlying principles of games was made by von Neumann as early as 1928. However, it was not until 1944, when von Neumann and Morgenstern published the Theory of Games and Economic Behavior, that interest in the mathematical treatment of games began to grow rapidly. Although the theory of games itself can be applied to only a limited number of OR problems, it had a major impact on the development of linear programming and statistical decision theory. Game theory provides analytic solutions for only a few specialized situations, such as two-person, zero sum games, but the technique provides a new way of thinking about competitive decisions which is very useful in analyzing more complex decision problems.

8. Linear Graph Theory. The theory of graphs has been developed primarily in France by Berge. In recent years the theory has been applied to the solution of sequencing problems, usually under the name of PERT (Program Evaluation and Reporting Technique). The use of linear graph theory for this type of problem is both natural and desirable: it is natural because directed graphs provide a convenient description of the sequencing problem; it is desirable because it provides

a connection between an applied problem and a developed branch of mathematics. The use of linear graph theory for the solution of sequencing problems has barely tapped the large potential which this technique seems to possess, thus, it will probably continue to grow in importance in the next few years.

9. Simulation. Most OR specialists resort to the technique of simulation only when they can not obtain an analytic solution to a problem. However, proponents of simulation believe that the technique provides a natural mode of expression for many OR problems. Simulation will not provide a precise solution to a problem but it will usually provide a good numerical approximation to the solution in a reasonable time (frequently sooner than an analytic solution if the problem does not fit one of the standard OR models). It is also possible to combine mathematical analysis and simulation to reduce the time required to obtain a satisfactory solution. Many real problems can be solved with a pencil and a table of random numbers, but most realistic business problems require the use of a computer. A well designed simulation program for a computer will not only provide the solution to the problem, but will also provide an output which is meaningful to management, thus, the results are often easier to "sell" than results obtained by an analytic method. Simulation is a general technique which can be applied to all of the OR models.

10. Enumeration. The method of enumeration is nothing more than the "trial and error" technique, i. e., try all

possible combinations of parameters and select that set of parameters that gives the "best" results. Although this technique can be used to obtain solutions for simple problems, it is almost impossible to use the method for most realistic business problems. For example, in a production scheduling problem the assignment of 15 jobs to 15 machines involves 1.3 trillion possibilities. It should be noted that in many problems the number of possibilities can be greatly reduced by the application of heuristics (rules-of-thumb). Thus, the combination of heuristic programming and enumeration is a powerful technique for obtaining approximate solutions to complex problems. This combined technique is, of course, the procedure used by most managers in making many types of business decisions.

11. Economic Theory. Although economic theory is seldom listed as a technique of operations research, it is obvious that at least a minimum amount of economic theory must be involved in any business problem, especially if the aim is to obtain a solution which maximizes some economic parameter. The fact that almost all operations research teams include an economist is another indication that economic theory plays an essential part in most OR studies. Thus, I believe that economic theory should be included as a general technique that is applicable to any of the OR models.

B. Operations Research Models. Although each operations research problem requires the construction of a model which is specifically tailored for the particular problem, these specific models are usually constructed by appropriately modifying one of the standard OR models which has been developed for each major problem area. Seven of these models are described below.

1. Static Inventory Models. More work has been done in the area of inventory control than in any other problem area in business. As far back as 1915, F. W. Harris developed an equation for determining economic-order-quantity (EOQ), which minimized the sum of the inventory carrying costs and the setup costs if demand was known and constant. The probability aspects of inventory control were considered as early as 1928, but none of these techniques were in general use until the 1950's. Present models include the consideration of (1) buffer stocks to protect against shortages, (2) delivery time lags as a probability distribution, (3) simultaneous demands for several items and (4) the interdependence of demand in the various time periods. The effect of quantity discounts on purchases and the imposition of restrictions resulting from limited facilities, time, or money have also been considered. Although many general models exist, it is usually necessary to develop a specific model for each situation if useful results are to be obtained.

2. Dynamic Inventory Models. The dynamic inventory problem is concerned with the effect of a decision in the current period on the inventory situation in subsequent periods. The available techniques are designed to set a total production level which minimizes the sum of inventory carrying cost, setup cost, shortage cost, and the cost of changing the level of production. Linear programming has been applied

to the problem where there are significant seasonal fluctuations in demand and where demand is assumed to be known. Dynamic programming makes it feasible to approach the dynamic inventory problem with the calculus of variations. Quadratic programming has been applied to the problem when cost functions have a quadratic rather than a linear form. The problem has also been solved by using the servomechanism concept which requires some form of feedback to adjust production or purchases to changing demand.

3. Allocation Models. Allocation models are used to solve the problem of combining activities and resources in such a way as to maximize over-all effectiveness. These problems are of two types: (1) A specified amount of work is to be done with the available resources. The problem is to use the limited resources and/or materials to accomplish the required work in the most economical manner. (2) The facilities and/or materials to be used are fixed. The problem is to determine what work, if performed, will yield the maximum return on the use of the facilities and/or materials.

The tool which is most closely associated with allocation problems is linear programming and the related procedure of activity analysis. Two important cases of linear programming problems are (1) the transportation problem which was first solved in 1941 and (2) the assignment problem which was first investigated in 1916, but did not come into general interest until the 1940's.

4. <u>Queuing Models</u>. Waiting-line problems involve arrivals which are randomly spaced and/or service time which is of random duration. This class of problems includes situations which require the determination of either the optimal number of service facilities or the optimal arrival rate, or both. Waiting-line theory, which dates back to 1909, was rather restricted until 1945 when the theory was extended and applied to a wide variety of phenomena. The construction of models of waiting-line processes involves relatively complex mathematics for all but the simplest cases. Therefore, realistic problems can usually be solved more simply by the use of simulation techniques.

5. <u>Sequencing Models</u>. The sequencing problem deals with a fixed number of servicing facilities for which arrivals and/or the sequence of servicing the waiting customers are subject to control. The problem is to schedule arrivals or to sequence the jobs to be done so that the sum of the pertinent costs is minimized. Sequencing problems are most frequently encountered in the context of a production department. Many production control departments attempt to achieve maximum utilization of facilities by the means of visual aids such as Gantt charts, but such devices often fail to yield optimum sequences. Although mathematical programs can be used to solve simple problems, the most success has been obtained with linear graph theory and with dynamic programming. Simulation and heuristic programming have also been used to obtain approximate solutions to large sequencing problems.

6. <u>Competitive Models.</u> Competitive models attempt to take into account conflict that is external to the organization. Competition manifests itself in these problems because the effectiveness of decisions by one party is dependent on the decisions made by another party. If the models include the possibility of bidding, the theory of probability becomes essential to game theory. Although there are several procedures for solving simple games, linear programming is required to solve complex games. Because the mathematical theory is limited to only simple situations, game theory has not found much direct application in operations research. Nevertheless, the underlying logic is important because it indicates the different kinds of reasoning that apply in different kinds of conflict.

7. <u>Replacement Models</u>. Replacement processes are of two kinds: (1) those in which the equipment deteriorates or becomes obsolete and (2) those in which the equipment does not deteriorate but is subject to failure. For items which deteriorate, the problem consists of balancing the cost of new equipment against the cost of maintaining efficiency on the old equipment and/or the cost due to the unavoidable loss of efficiency. Although no general solution to this problem has been obtained, models have been developed and solutions found for various sets of assumptions. In the case of items which must be replaced when they fail, the problem is one of determining which items to replace and how frequently to replace them so as to minimize the sum of (1) the cost of

the equipment, (2) the cost of replacing the unit, and (3) the cost associated with the failure of the unit. Life spans of items that fail are usually probabilistic, thus, the expected number of failures per unit time must be developed by statistical analysis or by the use of Monte Carlo techniques.

IV. SUMMARY

There is little doubt that managers have made a significant contribution in the area of quantitative methods, particularly in the specific function of adapting the various techniques to the problems of business.

In the earliest years of the scientific management, managers such as Taylor, Gantt, Gilbreth and Fayol not only developed the quantitative techniques but also wrote most of the material which describes the results of their experiments. It is clear that managers made most of the important contributions to the new techniques which resulted in the birth of management science.

In some areas managers did not develop the techniques but they were instrumental in the application of the techniques. For example, in the area of statistics, the development of time series analysis and the techniques for testing hypotheses took place in the universities. However, the application of these techniques to quality control, production planning, etc., was pioneered in industrial laboratories. Today, industrial research laboratories are common but such facilities were found in only a few firms in the 1920's. Certainly the support of such nonprofit making activities necessitated enlightened managers whose thinking was not limited to the single goal of maximizing short-run profits.

Although a few OR techniques were developed by managers as a part of management accounting systems, the majority of the techniques used in operations research were not developed by managers. In many instances, however, the application of these techniques to practical problems was the direct result of management action. The essential role played by military managers in pioneering the use of OR techniques for the solution of problems in military logistics is well known. Immediately after World War II, managers of several large firms recognized the possibility of applying these techniques to business problems and initiated the development of industrial operations research Although the movement was slow at first, the application of OR techniques to business problems has grown very rapidly during the last decade.

Managers have also been instrumental in the application of punched-card and electronic data processing equipment to business problems. The census bureau lead in both the development of punched-card equipment in the 1890's and the development of electronic data processing in the 1950's. Almost all of the techniques of business data processing have been developed by business firms, often by managers themselves. A recent study of business computer installations indicated that in successful installations the computer had become an important tool in <u>all</u> phases of management. Successful computer installations were found only in those firms in which the managers had an active interest in developing better management tools and applying these tools to a continuously increasing number of management problems.

I believe that the record clearly shows that managers have played an important role in the development and use of quantitative techniques in business. The field of inquiry is several hundred years old, but it is only within our generation that specialized attention has been focused on it.

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APPENDIX I

COMPUTER CHARACTERISTICS CHART

COMPUTER CHARACTERISTICS REVISITED

by CHARLES W. ADAMS, President
Adams Associates, Inc., Bedford, Mass.

"Tell me, daddy, which computer is best?" Number-One son asked the other day after thumbing hurriedly through the 76 entries in the September 1962, issue of Adams Associates Computer Characteristics Quarterly. "How should I know?" was the reply. *Never get into a debate with a six-year old* is my motto. Besides, I'm sure his second-grade class can ill afford a Minivac, let alone a Monrobot XI or any of the others even on the extreme low end, in terms of price, of our listings.

But this is also a question asked every day by serious-minded and perceptive businessmen. Our booklet, the contents of which are reprinted in the next few pages, does not seek to answer this question directly. Nor do any of the more elaborate multi-volume reporting services available from several sources. For one thing, the question as stated is unanswerable, except by a counter-interrogation: "Best for what?"

The most a pocket-sized compilation can do, we feel, is provide a reliable, up-to-the-minute list of the salient features of *all* computers which ought to be considered. From these, experienced computer people can readily decide which warrant detailed study to determine how well and inexpensively they can do the job required. The most a book-shelf compilation can do is provide, in readily-acessible form, all the information on prices, instruction codes, physical size, power consumption, and other information needed for detailed studies.

A good thing that is, too. If unequivocal or categorical answers were readily available, Adams Associates and its numerous competitors would lose a fascinating and potentially lucrative part of their business. People would no longer ask for our help in deciding on equipment; they would need us only on initial problem definition and actual program preparation. There would be no computer salesmen either — and precious few computer manufacturers!

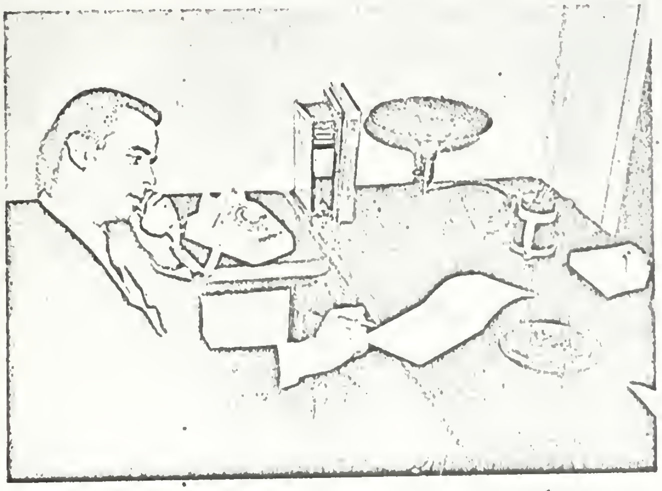
So "what is best" can only be decided in reference to a given mix of applications, and even then only after considerably study. Such studies give rise to anomalies, however. Consider, for example, a fifty-fifty division of use between business and scientific applications. In such a case, a system twice as good on business as on scientific work will spend two-thirds of its time on scientific applications while one strong on scientific work will spend most of its time on business work.

Judging from both the enthusiastic response to the reprinted versions which have appeared annually in DATAMATION and the number of people and firms willing to shell out the modest yearly subscription fee to be kept up to date each quarter, a handy compilation of basic facts about available computers serves a useful purpose. Bowing to numerous requests, Adams Associates will shortly add to the Quarterly computers aimed primarily at process control, those built for military use, and foreign-made systems.

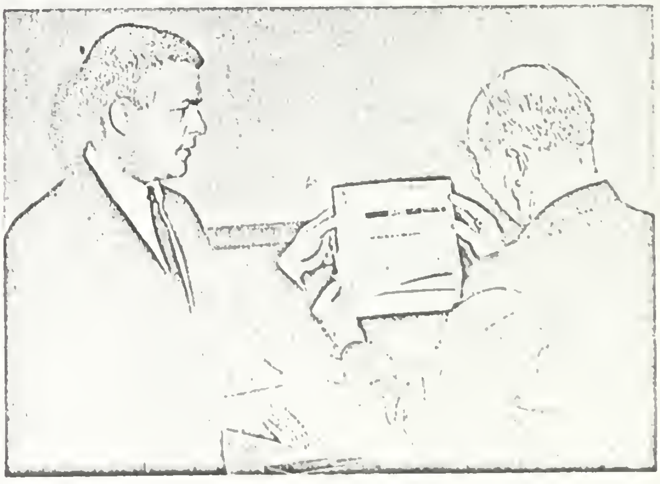
Many of these will appear in the December 1962 issue, and more will be added as rapidly as the data can be collected and verified. Even with this greatly expanded coverage, the material can be presented in the traditional plastic-bound folder as well as in the new 8½ x 11" booklet useful for inclusion in reports, wall mounting, and the like.

Incidentally, we will have to up the price of the quarterly to $10 for an annual subscription and to $3.50 for a single issue. This is being done with regret — if not in response to many requests!

Allen Rousseau, editor of the Quarterly, checks out data with manufacturer. ("Never ask them; tell them and get them to confirm it — and don't depend entirely on the mails.")



Alder Jenkins, in charge of production, shows copy of new issue to Richard Hamlin, director of systems services. ("A new typographer again this time, but I think now it's really under control.")



For the third consecutive year, Charles W. Adams Associates, Inc., has offered DATAMATION readers the full use of the data which appears in the most recent issue of its quarterly compilation of the salient features of all commercially-available, stored-program electronic digital computers. As in the past, military, process-control and foreign computers are specifically excluded, though this omission will be corrected starting with the December issue of the Quarterly.

INDEX OF COMPUTER MANUFACTURERS

CHRONOLOGICAL LISTING

VACUUM-TUBE SYSTEMS
(still widely used)

3/51 — UNIVAC I
/53 — IBM 701*
7/54 — Burroughs 205
11/54 — IBM 650
/55 — Alwac IIIE
/55 — IBM 702*
8/55 — Bendix G-15
/56 — Burroughs E-101
3/56 — IBM 705
3/56 — UNIVAC 1103A
4/56 — IBM 704
9/56 — RPC LGP-30
11/57 — UNIVAC II
12/57 — IBM 305 Ramac
1/58 — UNIVAC File Computer I
8/58 — IBM 709
9/58 — UNIVAC 1105
12/58 — Burroughs 220

SOLID-STATE SYSTEMS

11/58 — Philco 2000-210
11/58 — Recomp II
10/59 — IBM 1620
11/59 — IBM 7090
11/59 — NCR 304
11/59 — RCA 501
1/60 — Control Data 1604
1/60 — UNIVAC SS 80/90
1/60 — LIBRASCOPE 3000
3/60 — Philco 2000-211
5/60 — Monrobot XI
5/60 — UNIVAC LARC
6/60 — IBM 7070
7/60 — Control Data 160
9/60 — IBM 1401
9/60 — RPC 9000
11/60 — DEC PDP-1
11/60 — General Electric 210
11/60 — RPC 4000
12/60 — Honeywell 800
12/60 — Packard Bell 250
2/61 — Bendix G-20
2/61 — RCA 301
3/61 — General Electric 225
3/61 — Ramo-Wooldridge 400
4/61 — NCR 310
4/61 — IBM 7030 Stretch
5/61 — 3C DDP-19
5/61 — NCR 390
6/61 — Honeywell 290
6/61 — Recomp III
7/61 — CDC 160A
7/61 — Gen'l Mills AD/ECS-37
8/61 — CDC 924
8/61 — IBM 7080
8/61 — Ramo Wooldridge 130
9/61 — Burroughs B250
11/61 — IBM 7074
11/61 — IBM 1410
12/61 — Honeywell 400
12/61 — UNIVAC 490
1/62 — NCR 315
4/62 — ASI 210
7/62 — Burroughs B270-280
9/62 — DEC PDP-4

(Future Delivery

ASI 420
Burroughs B5000
CDC 6600
CDC 3600
Honeywell 1800
IBM 7040
IBM 7044
IBM 7072
IBM 7094
Philco 2000-212
Philco 1000
RCA 601
UNIVAC 1107
UNIVAC III
UNIVAC 1004
SDS 910
SDS 920

*Many computers delivered in 1953 through 1958 but no longer being produced have not been included in this list; the 701 and 702 are not in the chart but appear here for old time's sak

		CENTRAL PROCESSOR				FILE STORAGE: Magnetic Tape	FILE STORAGE: Random Access	INPUT-OUTPUT EQUIPMENT			OTHER FEATURES							
Typical Monthly Rental Monthly Rental Range	Date First Delivery	Add Time in Micro-seconds	Cycle Time in Micro-seconds	Storage Capacity and Type	Word Size Instruction Addresses	Thousands of Characters per Second Buffering Maximum Tape Units	Average Access Time	Cards per Minute (In / Out)	Paper Tape Characters per Second (In / Out)	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler

EXPLANATION OF COLUMN HEADINGS

Typical Monthly Rental: What a customer might pay for a system with basic peripheral equipment and, if available, magnetic tapes.

Monthly Rental Range: The first figure in parentheses is the cost, in thousands of dollars, of the minimum useful configuration. The second figure, where given, is the approximate cost of the maximum configuration likely to be ordered.

Add Time: Time required to acquire and execute one add instruction in millionths of a second. In drum machines, where add is lower than cycle time, maximum optimization has been assumed.

Cycle Time: Storage cycle time (including, for core storage, the total time to read and restore or, for drum storage, a full revolution in millionths of a second).

Storage Capacity and Type: Number of words or characters of addressable internal storage available, K representing thousands. (Example: "32K core" for the IBM 7090 indicates that 32,000 words of magnetic core are available.) "Fast" indicates a serial type area of fast access secondary storage.

Word Size: Number and type of digits comprising one storage word (a = alphanumeric, 6, 7 or 8 binary digits, depending on parity and addressing logic; d = decimal, 4 binary digits; b = binary, 1 binary digit).

Instruction Address: Number of separate storage addresses in a conventional instruction.

Thousands of Characters per Second: Transfer rate between computer and magnetic tape, measured in six-bit characters (one alphabetic, one decimal, or six binary digits) unless otherwise noted.

Buffering: Combinations of reading magnetic tape (R), writing it (W), and computing (C) can be performed simultaneously. (M) indicates that multiple simultaneous operations are possible.

Maximum Tape Units: Maximum number connectable to and addressable by the computer.

Random Access Capacity: Maximum number of BCD characters available (M representing million) in an external mass storage unit such as tape loop, drum or disc. Remarks indicate incremental units and characteristics of storage unit.

Average Access Time: Time required to locate a single record, including read-write head positioning and normal rotational access time (i.e., half the revolution time for drum and disc storage).

Peripheral Equipment: Speed of punched card, punched tape and line printer equipment available. For card and tape, the prime input equipment is listed above and prime output equipment below. Additional equipment is mentioned in the remarks if available. The column headed "Off-line Equipment" refers to a smaller satellite computer which can process data off-line ("same" means the on-line equipment can also be used off-line).

Other Features: Check indicates the special feature is obtainable. For index registers the maximum number available is shown. For console typewriters, O refers to a device capable of printing alphanumeric characters at the console; I/O refers to a console keyboard capable of supplying data to the computer and actuating the printing device. Floating-point arithmetic can be programmed in any system even though not a built-in feature; but only the latter is indicated.

Algebraic Compiler and Business Compiler: Dates indicate the availability of a compiler and remarks indicate its name (e.g., COBOL '61 means English language compiler representing 1961 specifications of COmmon Business Oriented Language).

SOLID-STATE SYSTEMS

	CENTRAL PROCESSOR						FILE STORAGE: Magnetic Tape		Random Access	INPUT-OUTPUT EQUIPMENT				OTHER FEATURES						
System	Typical Monthly Rental Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size Instruction Addresses	Thousands of Characters per Second Buffering	Maximum Tape Units	Capacity Average Access Time	Cards per Minute In Out	Paper Tape Characters per Second In Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
S1 IBM 7030 STRETCH	$300,000[A] (200-)	5/61	1.5[C]	2.2	16-262K core	64b 1	62 MRWC[J]	256	710M 132m[M]	1000 250	— —	600	1401	√	16	√	√	I/O	—	—
S2 UNIVAC LARC	$135,000 (135-)	5/60	4[C]	4	10-97K core	12d 1	25 MRWC[J]	40	36M[L] 68m	[N]	[P]	[Q]	[R]	—	99	√	√	I/O	—	—
S3 CDC 6600	$120,000[A]	—	1.3	1.3	16-262K core	60b 1	30-83 MRWC	—	— —	1000 250	350 110	1000	—	√	√	√	√	—	—	—
S4 IBM 7094	$71,000 (56-75)	12/62	4[C]	2	32K core	36b 1	15-170[H] MRWC[J]	80	280M[L] 160m	250 100	— —	150	1401 same	√	7	√	√[V]	—	12/62[X]	12/62[Y]
S5 PHILCO 2000 Model 212	$68,000 (47-89)	/63	.75[C]	1 1.5	16-65K core	48b 1[G]	90-240 MRWC[J]	64[K]	167M[L] 135m	2000 100	1000 100	900	1000 same	√	8	√	√[V]	I/O	/59[X]	/62[Y]
S6 IBM 7090	$64,000 (50-69)	11/59	4.4	2.2	32K core	36b 1	15-170[H] MRWC[J]	80	280M[L] 160m	250 100	— —	150	1401 same	√	3	√	√	I/O	/59[X]	12/62[Y]
S7 CONTROL DATA 3600	$55,000 (40-75)	4/63	1.3[C]	1.3	32-262K core	48b 1[G]	30-83[H] MRWC[J]	4096[K]	720M 100m	1000 250	350 110	1000	160A	√	6	√	√[V]	I	4/63[X]	4/63[Y]
S8 IBM 7080	$55,000 (40-73)	8/61	11[C]	2 1	80-160K core 1K core	1a[F] 1	15-170[H] MRWC	40	280M[L] 160m	60 —	500 —	—	1401	√	0	√	—	I/O	8/61[X]	12/61[Y]
S9 LIBRASCOPE 3000	$50,000 (25-)	1/60	16[C]	5	4-64K core	8a 1[G]	50 MRWC	1023	200M 90m	200 100	350 60	1000	√ same	√	11	√	√	I/O	—	—
S10 UNIVAC 1107	$45,000 (32-60)	/62	4[C]	4 .6	16-65K core 128 film	36b[F] 1[G]	25-120 MRWC	180[K]	566M[L] 1/m	600 300[N]	400 300[P]	600 700	SS80 90	√	15	√	√	I/O	10/62[X]	12/62[Y]
S11 PHILCO 2000 Model 210, 211	$40,000 (24-66)	11/58	15[C] .75	10 1.5	8-32K core	48b 1[G]	90 MRWC	16[K]	262K[L] 17m	2000 100	1000 100	900	1000 same	√	32	—	√	I/O	/59[X]	/62[Y]

S1 IBM 7030 STRETCH: A. Computer no longer marketed. C. Instruction look-ahead and overlapped core banks allow increased internal speed. J. Input-output under separate control. M. Access time varies from 51–231 ms depending on file organization.

S2 UNIVAC LARC: C. Instruction look-ahead and overlapped core banks allow increased internal speed. J. Input-output under control of a separate computer and it is possible to add a second computing unit. L. Up to 24 drums of 250,000 words each. N, P, Q, R. All UNIVAC peripheral equipment (including high speed film printer) can be used.

S3 CDC 6600: A. Preliminary information not confirmed by manufacturer. System has not been formally announced by CDC.

S4 IBM 7094: C. Instruction look-ahead where some instruction references make two instructions available reducing number of instruction cycles allows increased internal speed. H. See information on tape speeds (IBM 7090, entry S6 and IBM 7080, entry S8). J. Data channels (up to 8) are separate input-output controls for up to ten tape units or peripheral equipments. L. IBM 1301 disc file has 56 million BCD characters per unit (up to five storage units). V. Double precision floating point available. X. FORTRAN. Y. COBOL.

S5 PHILCO 2000 Model 212: C. Instruction look-ahead (4 level) and asynchronous, overlapped core banks allow increased internal speed. G. Instructions stored two per word. J. Two separate input-output processors, each of which controls up to 32 tape units. K. Magnetic tapes read in forward and reverse directions. L. Up to four disc file units of 5,242,880 words each (41,943,000 characters per disc) are available. V. Double precision floating point available. X. ALTAC (Fortran type). Y. COBOL '61.

S6 IBM 7090: H. For all 7000 series, 729 II tape units operate at 15K and 41.6K while 729 IV tape units operate at 22.5K and 62.5K. 729 V and 729 VI tape units (with 800 characters per inch density) operate at 60K and 90K respectively. (See IBM 7080, entry S8.) J. Data channels (up to eight) are separate input-output controls for up to ten tape units. L. IBM 1301 disc file has 56 million BCD characters per unit (up to five storage units). X. FORTRAN. Y. COBOL '61, COMmercial TRANslator (9/61).

S7 CONTROL DATA 3600: C. Overlapped core banks allow increased internal speed. G. Instructions stored two per word. H. CDC Model 606 or IBM 729 tape units. J. Data channels (up to eight) are separate input-output controls for tape units and other peripheral equipment. K. Magnetic tapes are IBM compatible. V. Double precision floating point available. X. FORTRAN. Y. COBOL.

S8 IBM 7080: C. Add time assumes a five-character field. F. A variable-word length computer (see IBM 705, entry V5). H. The IBM 7340 (1963 delivery) Hypertape Drive, with cartridge load, will read in both directions or write 170,000 alphabetic (or 340,000 numeric) characters per second. (For 729 tape speeds see IBM 7090, entry S6.) L. IBM 1301 disc file. X. FORTRAN. Y. COBOL '61, COMmercial TRANslator (8/61).

S9 LIBRASCOPE 3000: C. Full cycle time; instruction look-ahead and overlapped core banks allow increased internal speed. G. Variable field addressing allows designation of operands from one to eight characters. Preliminary information not confirmed by publishers.

S10 UNIVAC 1107: C. Overlapped core banks and thin film memory usage allow increased internal speed. F. A half, third or sixth word may be addressed directly. G. Designators in each instruction permit use of virtual two or three-address instruction logic. K. Magnetic tapes read in forward and reverse directions. An IBM compatible tape unit is available. L. Each flying head drum unit (8 per subsystem with maximum of 15 subsystems) has a capacity of 786,432 words or 4,518,592 BCD characters (See Univac 490, entry S17 for disc file information). N. 150 cpm punch available. P. 110 ch/sec punch available. X. ALGOL, FORTRAN. Y. COBOL '61.

S11 PHILCO 2000 Model 210, 211: C. Asynchronous, overlapped core banks allow increased internal speed. G. Instructions stored two per word. K. Magnetic tapes read in forward and reverse directions. L. Additional drums of 32,768 words (262,144 characters) each are available. X. ALTAC (Fortran-type). Y. COBOL '61.

SOLID-STATE SYSTEMS

System	CENTRAL PROCESSOR: Typical Monthly Rental / Monthly Rental Range	Date First Delivery	Add Time in Micro-seconds	Cycle Time in Micro-seconds	Storage Capacity and Type	Word Size / Instruction Addresses	BULK STORAGE — Magnetic Tape: Thousands of Characters per Second / Buffering	Maximum Tape Units	Random Access: Capacity / Average Access Time	INPUT-OUTPUT EQUIPMENT: Cards per Minute (In / Out)	Paper Tape Characters per Second (In / Out)	Printer Lines per Minute	OTHER FEATURES: Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
S12 HONEYWELL 1800	$35,000 (30-60)	/63	8	2	8-32K core	12d[F] 3	89-124[H] MRWC	64[K]	720M[L] 100m	800[N] 250[N]	1000[P] 110	150 900	same	√	64[T]	√	√	I/O	/61[X]	/61[Y]
S13 CONTROL DATA 1604	$34,000 (19-35)	1/60	4.8[C]	6.4	8-32K core	48b 1[G]	30-83[H] MRWC	96[K]	— —	1300[N] 100	350 110	150 1000	160A	√	6	√	√	I/O	/60[X]	2/62[Y]
S14 RCA 601	$32,000 (24-68)	/62	5.7 6.7[C]	1.5[D] 2.5	8-32K core	56b[F] 1-3[G]	33-120[H] MRWC	48	— —	600 200	1000 300[P]	1000	301	√	8[T]	√	√	I/O	/62[X]	9/62[Y]
S15 IBM 7074	$29,300 (17-36)	11/61	10[C]	4	5-30K core	10d[F] 1	15-170[H] RWC[J]	40	280M[L] 160m	500 250	— —	150	1401	√	99	√[U]	√	I/O	/61[X]	2/62[Y]
S16 IBM 7044	$26,000 (20-55)	6/63	5	2.5	8-32K core	36b 1	7.2-90[H] MRWC	50	280M 160m	250[N] 125	500 —	600	1401	√	3	√	√	I/O	6/63[X]	9/63[Y]
S17 UNIVAC 490	$25,500 (18-)	12/61	4.8[C] 12	6	16-32K core	30b 1[G]	25-125[H] MRWC	192[K]	377M[L] 17m	600 150	350 110	600 700	—	√	7	—	—	I/O	/61[X]	10/62[Y]
S18 IBM 7070	$24,000 (12-31)	6/60	60[C]	6	5-10K core[E]	10d[F] 1	15-90 RWC[J]	40	280M[L] 160m	500 250	— —	150	1401	√	99	√[U]	√	I/O	/60[X]	2/62[Y]
S19 UNIVAC III	$22,500 (16.6-30)	6/62	8	4	8-32K core	6d[F] 1[G]	25-133[H] MRWC	38[K]	√[L] —	700 300	500 110	700[Q]	same	√	15	√	—	I/O	12/62[X]	10/62[Y]
S20 HONEYWELL 800	$22,000 (12-30)	12/60	24	6	4-32K core	12d[F] 3	64-124[H] MRWC	64[K]	720M[L] 100m	800[N] 250[N]	1000[P] 110	150 900	same	√	64[T]	√	√	I/O	/61[X]	/61[Y]
S21 BENDIX G-20	$20,000 (7.3-35)	4/61	15[C]	6	4-32K core	32b 1[G]	120[H] MRWC	500	62M[L] 90m	800 250	500 100	1000 300	same	√	63	√	√	I/O	2/62[X]	12/62[Y]

S12 HONEYWELL 1800 — F. Word size is 12d plus sign or 48b with binary and decimal arithmetic instructions included. H. Numeric information can be transferred at 133,000 or 186,000 ch/sec. K. Magnetic tapes read in forward and reverse directions with programmed error correction (Orthotronic count). L. Units of 12 (Bryant) discs contain 45 million BCD characters with increments of 24 discs up to a maximum of 96 discs. N. 240 and 650 cpm readers and 100 cpm punch available. P. 200 ch/sec reader available. T. Up to eight programs can be processed concurrently. X, AUTOMATH 800, AUTOMATH 1800 (/63), Fortran type. Y. FACT, COBOL '61 (/63).

S13 CONTROL DATA 1604 — C. Overlapped core banks allow increased speed. G. Instructions stored two per word. H. CDC Model 606 tape unit operates at 30K (with 200 characters per inch density) or 83K (with 556 characters per inch density), while IBM tape units operate up to 62.5K. K. Compatible with IBM tape units. N. 100 and 250 cpm readers available. X. FORTRAN. Y. COBOL '61

S14 RCA 601 — C. Asynchronous, overlapped core banks allow increased internal speed. D. 604 central processor has faster staticizing and address modification than 603. F. Binary and decimal arithmetic instructions included. G. Variable length instructions (1, 2, 3, or 4 half-words) operate on character, half-word or word. H. Numeric information can be transferred at a rate of 180,000 ch/sec. P. 100 ch/sec punch available. T. 8 index registers available for each program. X. ALGOL. Y. COBOL '61.

S15 IBM 7074 — C. Parallel adder circuit increases speed over serial circuit in IBM 7070 (see entry S18). F. Word size is 10d plus sign. H. See IBM 7090 (entry S6) and IBM 7080 (entry S8) for 729 and 7340 tape data. J. MRWC possible when four channels used. L. IBM 1301 disc file (see entry S18). U. Indirect addressing limited to scatter-read and gather-write operations. X. FORTRAN. Y. COBOL '61, COMmercial TRANslator (8/61).

S16 IBM 7044 — H. For tape information see IBM 7090 (entry S6). N. IBM 1401 can be connected on-line through input-output synchronizers or 800 cpm reader and 250 cpm punch and/or printer can be connected to I/O channel through 1414 synchronizer. X. FORTRAN. Y. COBOL.

S17 UNIVAC 490 — C. 4.8μ is add time for repeat mode only. G. Half-word logical operations can be performed. H. Numeric information can be transferred at a rate of 175,000 ch/sec. K. Magnetic tapes read in forward and reverse directions. L. Each flying head drum unit (8 per subsystem with maximum of 12 subsystems) has a capacity of 786,432 words or 3,932,160 BCD characters. Disc units contain approximately 117 million characters each. X. NELIAC. Y. COBOL '61.

S18 IBM 7070 — C. Add time varies by number of digits in field to be added and does not include indexing time. E. Up to 30K core memory available. F. Word size is 10d plus sign. J. MRWC possible when four channels used. L. IBM 1301 disc file has 28 million 6-bit characters per 25 disc (50 surfaces of which 40 are used for storage) module or 43 million 4-bit characters stored in packed (8-bit) format. Model II 1301's have two modules or 50 discs. U. Indirect addressing limited to scatter-read and gather-write operations. X. FORTRAN. Y. COBOL '61, COMmercial TRANslator (8/61).

S19 UNIVAC III — F. Word size is 6d plus sign. G. Instruction may process up to four data words. H. Numeric information can be transferred at a rate of 200,000 ch/sec. Model IIA tape units operate at 25K while Model IIIA units function at speeds of 120K to 133K dependent on internal logic variations of UNIVAC 1107, 490 and UIII. K. Magnetic tapes read in forward and reverse directions. L. Specifications not available. Q. 922 lpm for completely numeric data. X. FORTRAN. Y. COBOL '61.

S20 HONEYWELL 800 — F. Word size is 12d plus sign or 48b with binary and decimal arithmetic instructions included. H. Numeric information can be transferred at 96,000, 133,000 or 186,000 ch/sec. K. Magnetic tapes read in forward and reverse directions with programmed error correction (Orthotronic count). L. Units of 12 (Bryant) discs contain 45 million BCD characters with increments of 24 discs up to a maximum of 96 discs. N. 240 and 650 cpm readers and 100 cpm punch available. P. 200 ch/sec reader available. T. Up to eight programs can be processed concurrently. X. AUTOMATH 800, Fortran type. Y. FACT, COBOL '61 (/63).

S21 BENDIX G-20 — C. All arithmetic operations done in floating-point mode. G. Variable instruction length permits multiple operations. H. Numeric information can be transferred at 240,000 ch/sec. Independent search while computing. L. Bryant disc has capacity of 15.6, 31.2, 48.6 or 62.4 million 8-bit characters. X. ALCOM 2/62, FORTRAN 5/62. Y. COBOL '61.

SOLID-STATE SYSTEMS

CENTRAL PROCESSOR — INPUT-OUTPUT EQUIPMENT

System	Typical Monthly Rental / Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size / Instruction Addresses	Thousands of Characters per Second / Buffering	Maximum Tape Units	Capacity / Average Access Time	Cards per Minute In / Out	Paper Tape Characters per Second In / Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
S22 BURROUGHS B 5000	$16,200 (13.5-50)	/62	3[G]	6 17000	4-32K core 32K drum[E]	48b 0[G]	24-66 MRWC	16[K]	— —	800[N] 300	1000 100	700	B280	√	—[T]	√[U]	√[V]	I/O	/62[X]	/62[Y]
S23 RCA 501	$16,000 (11-26)	11/59	360[C]	15	16-262K core	1a[F] 2	33-66 RC, WC, or RW	63[K]	— —	600 200	1000 100[P]	600 900	same[R]	—	8	√[U]	—	O	—	/60[Y]
S24 IBM 7072	$15,800 (14-32)	/62	12	6	5-30K core	10d[F] 1	7.2-20[H] RWC	20[K]	— —	60	—	—	1401	√	99	√[U]	√	I/O	/60[X]	12/62[Y]
S25 NCR 304	$15,000 (12.5-19)	11/59	600 120[C]	60	2-4K core	10a 3[G]	30 RW[J]	64[K]	— —	2000 250[N]	1800 60	680 900	same	—	10	—	√	I/O	—	8/61[Y]
S26 GENERAL ELECTRIC 210	$14,000 (10.5-36)	11/60	64	32	4-8K core	6d[F] 1[G]	30 RWC	13	— —	1500[N] 250[N]	200 —	1000[Q]	—	—	1	—	—	I/O	—	/61[Y]
S27 IBM 7040	$14,000 (9-33)	6/63	16	8	4-32K core	36b 1	7.2-90 MRWC[J]	50	280M 160m	250 125	500 —	600	1401	√	3	√	√	I/O	6/63[X]	9/63[Y]
S28 UNIVAC 1206	$13,000[A]	/58	9.6[C] 11.2	8	16-32K core	30b 1	25 MRWC	168[K]	377M[L] 17m	600 150	1500[P] 110	600 700	—	√	7	—	—	I/O	—	—
S29 ADVANCED SCIENTIFIC ASI-420	$12,500 (8.5-33.5)	/62	10[C]	2	4-32K core	42b 1	22.5-62 MRWC	64[K]	— —	800[N] 250	500 110	300	—	√[S]	√[T]	√	√	I/O	8/62[X]	—
S30 CONTROL DATA 924	$10,000 (8.7-20)	8/61	9.3[C]	6.4	8-32K core	24b 1	15-33[H] MRWC	96[K]	— —	1300[N] 100	350 110	150 1000	160A	√	6	√	—	I/O	—	—
S31 IBM 1410	$10,000 (6-32)	11/61	88[C]	4	10-80K core	1a[F] 2	7.2-90 RWC	20	280M[L] 160m	800[N] 250	500 —	600[Q]	1401	√	15	—	—	I/O	12/61[X]	12/61[Y]
S32 NCR 315	$8,500 (3.8-30)	1/62	48[C]	6	2-40K core	2a[F] 1	24-60 none	8	88M[L] 200m	2000[N] 250	1000 110	680[Q] 900	—	√	32	—	—	I/O	—	1/62[Y] 5/62[Y]
S33 HONEYWELL 400	$8,000 (4-15)	12/61	120	10	1-4K core	12d 3	32-89[H] RW	8	96M[L] 100m	800[N] 250[N]	1000 110	900	same	√	3	—	—	I/O	/63[X]	/63[Y]

S22 BURROUGHS B 5000 — C. Instruction look-ahead allows increased internal speed. E. 2 drums available. G. Polish notation allows operations to be performed without designation of addresses. K. Magnetic tapes read in forward and reverse directions. N. 200 cpm reader and 100 cpm punch available. T, U. All addressing relative to Program Reference Table. V. Double precision floating point. X. ALGOL. Y. COBOL '61.

S23 RCA 501 — C. Add time assumes five character field. F. Variable-word length computer using four character (tetrad) parallel transfer. K. Magnetic tapes read in forward and reverse directions. P. 300 ch/sec punch available. R. Card equipment and printer may be used off-line. U. Indirect addressing limited to scatter-read and gather-write operations. Y. COBOL '60.

S24 IBM 7072 — F. Word size is 10d plus sign. H. Low-speed magnetic tape only; input-output version of the IBM 7070 (see entry S18). K. IBM 7330 tape units. U. Indirect addressing limited to scatter-read and gather-write operations. X. FORTRAN. Y. COBOL '61, COMmercial TRANslator (8/61).

S25 NCR 304 — C. Micro-flow, single address instructions. G. Two words per instruction. J. In processing inactive records, RWC is achieved. K. Magnetic tapes have no space between records. N. 100 cpm punch available. Y. COBOL '61.

S26 GENERAL ELECTRIC 210 — F. Word size is 6d plus sign. G. Double precision arithmetic instructions included. N. 400 cpm reader and 100 cpm punch available. Two 1200 MICR-document per minute sorter-readers can be multiplexed. Q. Printer can print magnetically encoded characters and also be used off-line. Y. CAP.

S27 IBM 7040 — J. (See IBM 7044, entry S16.) 7094 data channels available for separate input-output control of up to ten peripheral units. X. FORTRAN. Y. COBOL.

S28 UNIVAC 1206 — A. Price and information not confirmed by manufacturer. Price derived from estimated purchase price. C. 9.6μ is add time for repeat mode only. K. Magnetic tapes read in forward and reverse directions. L. Each flying head drum unit has a capacity of 3,932,160 BCD characters. P. 350 ch/sec reader available.

S29 ADVANCED SCIENTIFIC ASI-420 — C. Includes indexing and I/O channel reference. K. Magnetic tapes are IBM compatible. N. Analog equipment buffer available. S. Data channel "traps" may be set by program to ignore or recognize an interrupt. T. Any memory location may be used as an index register. X. FORTRAN, Intercom Translator.

S30 CONTROL DATA 924 — C. Overlapped core memory banks allow increased internal speed. H. CDC Model 606 tape unit or IBM 729 tape units. See tape information CDC 1604 (entry S 13). K. Magnetic tapes compatible with IBM tape units. N. 100 and 250 cpm readers available.

S31 IBM 1410 — C. Add time assumes a five-character field. F. Variable-length instructions operate on variable length data fields. L. Up to five IBM 1301 disc units available in 28 million or 56 million alphanumeric characters each. N. Optical and MICR readers available. Q. See reference Q, IBM 1401 (entry S38). X. FORTRAN. Y. COBOL '61.

S32 NCR 315 — C. Add time assumes a five or six-character field. F. Decimal format allows 3d word size. L. Magnetically encoded cards on a drum (CRAM) permit random and sequential file processing. Sixteen units with 5.5 million alphanumeric or 8.3 million BCD characters each. N. MICR documents can be read at 750 or 1620 per minute. Up to four similar peripheral devices may be attached to each peripheral I/O channel. Q. Numeric information only printed at 1750 lpm. Y. COBOL '61, 1/62-tape. 5/62-CRAM.

S33 HONEYWELL 400 — H. Numeric information can be transferred at rate of 48,000, 96,000 or 133,000 ch/sec. L. Bryant discs in increments of 24 million BCD characters. N. 650 cpm reader and 100 cpm punch available. X. AUTOMATH 400, Fortran type. Y. COBOL '61.

SOLID-STATE SYSTEMS

CENTRAL PROCESSOR | FILE STORAGE (Magnetic Tape, Random Access) | INPUT-OUTPUT EQUIPMENT | OTHER FEATURES

System	Typical Monthly Rental / Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size / Instruction Addresses	Thousands of Characters per Second / Buffering	Maximum Tape Units	Capacity / Average Access Time	Cards per Minute (In / Out)	Paper Tape Characters per Second (In / Out)	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
S34																				
UNIVAC SS 80/90 Model I	$8,000	1/60		3400	2.4-7.6K drum[E]	10d[F]	25	10	240M[L]	600	500	600	—	—	3	—	—	—	—	/61[Y]
	(3.6-13)		85	850	.2-1.6K fast	1[G]	RC, WC[J]		385m	150	100									
Model II	$8,500		51	17	1.2K core		12.5-25	20							9					

E. STEP card and tape systems allow increments of 400 words drum and 200 words fast memory. F. Word size is 10d plus sign. G. Last part of instruction words indicates address of next instruction. J. In Model II, which will have core memory and magnetic tape, it is possible to achieve RWC with use of a second synchronizer. L. Up to ten Randex drum units (2 drums) have a capacity of 24 million digits each. Y. COBOL '60 compiled on UNIVAC II.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S35																				
PHILCO 1000	$7,010	/63	39[C]	3	8-32K core[E]	1a[F]	90	48[K]	—	2000	1000	900	—	—[S]	4	—	—	I/O	—	—
	(6-15)					1	RC, WC or RW		—	100	100									

C. Add time assumes a five-character field. E. Asynchronous core banks allow increased internal speed. F. Four character instructions operate on variable length data fields. K. Magnetic tapes read in forward and reverse directions. S. Dual program control facility present.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S36																				
GENERAL ELECTRIC 225	$7,000	3/61	36	18	4-16K core	20b	15-66	64	600M[L]	1500[N]	1000[P]	900	same	√	96[T]	—	√	O	1/62[X]	1/62[Y]
	(2.5-26)					1[G]	MRWC		158m	250[N]	110									

G. Binary, decimal and double precision arithmetic instructions included. L. Up to 32 Telex units of 16 discs each available. Each module capacity is 18.8 million characters. N. Two 1200 MICR document-per-minute sorter-readers can be multiplexed. 400 cpm reader and 100 cpm punch available. P. 250 ch/sec reader available. T. Three index registers standard; additional 93 optional. X. ALGOL functions as a part of GECOM. WIZ. Y. COBOL '61 as part of GECOM.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S37																				
BURROUGHS B280 & B270	$6,500[A]	7/62	777[C]	10	9.6K core	1a[F]	50	6	—	800[N]	1000	700	—	—	0	—	—	—	—	—
						3	none		—	300	100									

A. Model 270, when used in proof and transit operations, has up to two six-tally registers. For card system see entry 42a. C. Add time assumes five-character field. F. Instruction word is 12 characters. N. Two simultaneous readers available; 200 and 800 cpm in any combination. MICR documents can be read at 1560 per minute.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S38																				
IBM 1401 (tape)	$6,500[A]	9/60	230[C]	11.5	1.4-16K core	1a[F]	7.2-62	6	20M[L]	800[N]	500	600[Q]	—	—	3	—	—	I/O	12/61[X]	6/62[Y]
	(2.5-12)					2	none[J]		600m	250	150									

A. Typical rental for magnetic tape system. For card system see entry 48a. C. Add time assumes a five-character field. F. Variable length instructions operate on variable length data fields. J. Normally only magnetic tape start-stop time may be overlapped with computing but Processing Overlap Feature permits input-output operations to overlap computing. L. IBM 1405 disc with 10 million or 20 million alphanumeric characters each. N. Optical and MICR readers available. Q. Numeric information only printed at 1285 lpm. 1404 printer used for printing on cards. X. FORTRAN. Y. COBOL '61.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S39																				
RCA 301	$5,200	2/61	126[C]	7	10-40K core[E]	1a[F]	10-66	14[K]	176M[L]	800[N]	1000	1070	—	—	3	√	√[V]	I/O	—[X]	3/62[Y]
	(3.3-25)					2	RC, WC, or RW		100m	250	100									

C. Add time assumes an eight-character field. E. A 320 character position table is used for arithmetic operations in place of adder circuits in Models 350 through 353. F. Variable length data fields. K. Magnetic tapes read in forward and reverse directions. L. Up to two disc file (Bryant) units, each of four modules of 22, 44, 66 or 88 million alphanumeric characters, are available; or up to six record files of 4.6 million characters each also are available. N. 600 cpm reader and 100 cpm punch available. Optional MICR sorter/reader operates at 1560 documents per minute. V. Floating point operations available with Models 354 and 355. X. UMAC (University of Miami Algebraic Compiler). Y. COBOL '61.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S40																				
RW 130	$4,500	8/61	12	6	8-32K core	15b	15-41	16	—	14	300	150	—	√	—[T]	√[U]	—	I/O	—	—
	(2.5-6)					0-1[F]	none		—	—	60									

F. Instructions stored two per word when using the no-address mode. T, U. Index registers and indirect addressing available through micro-commands or "logands" portion of stored logic.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S41																				
GENERAL MILLS AD/ECS-37	$4,400[A]	7/61	80	20	4-8K core	37b[F]	15	64[K]	—	250	250	600	—	√	1	—	√	I/O	—	—
						1[G]	RWC		—	125	60									

A. No rental price announced. Price is derived from purchase price and does not include cost of magnetic tape units. F. Word size is 36b plus sign. G. Instructions stored two per word. K. Magnetic tape units are IBM compatible.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S42																				
CONTROL DATA 160A	$4,000	7/61	12.8	6.4	8-32K core	12b	15-83[H]	40[K]	—	1300[N]	350	150	—	√	0	√	—	I/O	/62[X]	—
	(2.2-9.5)					1[G]	RC, WC or RW[J]		—	100	110	1000								

G. Instructions use no address, direct address, indirect address, constant address and relative address modes. H. CDC Model 606 or IBM 729 tape units. J. Buffered version of CDC 160 (see entry S53). K. Magnetic tapes are IBM compatible. N. 100 and 250 cpm readers available. X. FORTRAN.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S42a																				
BURROUGHS B260	$3,800	11/62	777	10	9.6K core	1a	—	—	—	800	1000	700	—	—	0	—	—	—	—	—
						3	—		—	300	100									

A. Punched card input-output version of entry S37.

System	Rental / Range	Date First Delivery	Add Time	Cycle Time	Storage	Word Size / Instr. Addr.	Thousands Char/sec / Buffering	Max Tape Units	Capacity / Access Time	Cards	Paper Tape	Printer	Off-line	Prog. Interrupt	Index Reg.	Indirect Addr.	Floating Point	Console Typewriter	Algebraic Compiler	Business Compiler
S43																				
DEC PDP-1	$3,600[A]	11/60	10	5	1-16K core	18b	15	64	—	100[N]	400	600[Q]	—	√	0	√	—	I/O	12/61[X]	—
	(2.9-15)					1	MRWC[J]		—	100	60									

A. No rental prices announced. Prices derived from purchase price and do not include cost of magnetic tape units. J. Up to 16 high speed input-output channels may be connected. N. 2000 cpm reader available. Q. Cathode ray tube display with light pen available. X. DECAL (Algol-type).

SOLID-STATE SYSTEMS

	CENTRAL PROCESSOR						FILE STORAGE: Magnetic Tape		FILE STORAGE: Random Access	INPUT-OUTPUT EQUIPMENT				OTHER FEATURES						
System	Typical Monthly Rental Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size Instruction Addresses	Thousands of Characters per Second Buffering	Maximum Tape Units	Capacity Average Access Time	Cards per Minute In Out	Paper Tape Characters per Second In Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
S44 COMPUTER CONTROL DDP-19	$3,500[A] (2.3-)	5/61	10	5	4-16K core	19b[O] 1	15-62 MRWC[J]	64[K]	— —	400 —	1000 100	600	—	√	1	—	—	I/O	11/62	—
Notes	A. No rental prices announced. Prices derived from purchase price and do not include cost of magnetic tape units. Word size expandable to 22 and 24b. J. Up to 16 program-addressable input-output channels operable in interrupt mode. Magnetic tapes compatible with IBM tape units.																			
S45 HONEYWELL 290	$3,100 (2.5-4.5)	6/61	140	20	1-8K core 8-96K drum	18b 1	15 RWC	2	2M 158m	15 15	110 110	300[Q]	—	√	√[T]	—	√	I/O	12/61[X]	—
Notes	Q. 11 characters per line. T. Special single instructions permit the use of as many and any core memory locations as index registers. X. FAST, Fortran type.																			
S46 ADVANCED SCIENTIFIC ASI-210	$2,600[A] (2.3-7.5)	4/62	10[C]	2	4-8K core	21b 1	22.5-62 MRWC	32[K]	—	800[N] 250	500 110	300	—	√[S]	3	√	—	I/O	4/62[X]	—
Notes	A. Rental price does not include cost of magnetic tape units. C. Add time includes indexing and I/O channel reference. K. Magnetic tapes are IBM compatible. N. Analog equipment buffer available. S. Data channel traps may be set by program to ignore or recognize an interrupt. X. FORTRAN, Intercom Translator.																			
S47 AUTONETICS RECOMP II	$2,500[A] (2.5-4.5)	11/58	 1080	9000 950	4K disc 16 fast	40b[F] 1[G]	1.8 none	4	— —	20 15	600[P] 150[P]	—	—	—	0	—	√	I/O	6/60[X]	—
Notes	A. Price does not include cost of magnetic tape units. F. Instructions stored two per word. G. Square root and absolute value instructions included. P. 400 ch/sec reader and 20 ch/sec punch standard, plotter available. X. SALT, SCOPAC (Fortran type).																			
S48 SCIENTIFIC DATA SDS 920	$2,500[A] (2.5-6)	9/62	16	8	2-16K core	24b 1	 MRWC		 —	200[N] —	300 60	300	910	√	1	√	—	I/O	12/62[X]	—
Notes	A. Rental price does not include cost of magnetic tape units. H. Magnetic tape units are IBM compatible. N. Graph plotters and analog conversion equipment are available. X. FORTRAN II.																			
S48a IBM 1401 (card)	$2,500[A] (2.5-3.6)	9/60	230	11.5	1.4-4K core	1a[F] 2	— —	—	— —	800 250	—	600	—	—	3	—	—	—	—[X]	—
Notes	A. Card input-output version of entry S38. X. FORTRAN.																			
S49 RPC 4000	$1,900 (1.8-4.5)	11/60	 1000	17000 10000	8K drum[E] 128 fast	32b 1[G]	— —	—	— —	— —	500[P] 300[P]	—	—	—	1	—	—	I/O	/61[X]	—
Notes	E. Drum offers dual access with two read-write heads operating in two tracks, and eight words of 1000μ access storage. G. The last half of the instruction word indicates the address of the next instruction. Repeat command allows groups of up to 128 words in memory to be operated on by one command at 250μ per word. P. 60 ch/sec reader and 30 ch/sec punch available. X. FORTRAN.																			
S50 SCIENTIFIC DATA SDS 910	$1,700[A] (1.5-6)	8/62	16	8	2-16K core	24b 1	3.5-41[H] MRWC	32	— —	200[N] —	300 60	300	—	√	1	√	—	I/O	12/62[X]	—
Notes	A. Rental price does not include cost of magnetic tape units. H. Magnetic tape units are IBM compatible. N. Graph plotters and analog conversion equipment are available. X. FORTRAN II.																			
S51 IBM 1620	$1,600[A] (1.6-5)	11/60	560 140	20 10	20-100K core	1d[F] 2	7.2-20 none	6	— —	250 125	150 15	—	1401	—	0	√	√	I/O	12/60[X]	—
Notes	A. Price does not include cost of magnetic tape units. C. A 300 character position table is used instead of adder circuits in Model 1 only. Model 2 features normal adder circuitry. Add time assumes a five-character field. F. Variable-word length. X. FORTRAN.																			
S52 AUTONETICS RECOMP III	$1,500 (1.4-3)	6/61	1080	9300 1750	4K disc 16 fast	40b 1[G]	— —	—	— —	20 15	300[P] 150[P]	—	—	—	1	—	√	I/O	/62[X]	—
Notes	G. Instructions stored two per word. P. 10 ch/sec reader and 10 ch/sec punch standard, plotter available. X. AUTOCOM (Fortran-type).																			
S53 CONTROL DATA 160	$1,500[A] (1.5-3)	7/60	12.8	6.4	4K core	12b 1[G]	15-83[H] none[J]	20[K]	— —	1300[N] 100	350 110	150 1000	—	—	0	√	—	I/O	/62[X]	—
Notes	A. Price does not include cost of magnetic tape units. G. Instructions use no address, direct address, indirect address, constant address, and relative address modes. H. CDC Model 606 or IBM 729 tape units. J. Magnetic tape start-stop time may be overlapped with computing. K. Magnetic tapes are IBM compatible. N. 100 and 250 cpm readers available. X. FORTRAN.																			
S54 UNIVAC 1004	$1,500 (1.1-1.9)	2/63	150	8	961 core[E]	1a	— —	—	— —	300 200	—	300[Q]	—	—	—	—	—	—	—	—
Notes	E. Plugboard serves as instruction storage unit. Q. Numeric information only printed at 400 lpm.																			
S55 DEC PDP-4	$1,300[A] (1-)	7/62	16	8	1-8K core	18b 1	15 none	9	— —	200 100	300 64	600[Q]	—	√	0	√	—	I/O	—	—
Notes	A. No rental prices announced. Prices derived from purchase price. Q. Cathode ray tube display with light pen available. Analog conversion equipment available.																			

SOLID-STATE SYSTEMS

System	Central Processor						File Storage: Magnetic Tape		File Storage: Random Access	Input-Output Equipment			Other Features							
	Typical Monthly Rental Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size Instruction Addresses	Thousands of Characters per Second Buffering	Maximum Tape Units	Capacity Average Access Time	Cards per Minute In Out	Paper Tape Characters per Second In Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
S56 PACKARD BELL PB 250	$1,200[A] (1.2-6)	12/60	24	3070 12	2.3-16K delay[E] 16 fast	22b 1	2 none	6	— —	400 —	300[P] 110[P]	500	—	—	1	—	—	I/O	5/62	—
S57 MONROBOT XI	$700 (.7-1)	5/60	9000	12000	1K drum	32b 1	— —	—	— —	15[N] 15	20[P] 20	—	—	—	0	—	—	I/O	—	—

PACKARD BELL PB 250: A. Price does not include cost of magnetic tape units. E. Internal storage is magnetostrictive delay lines. P. 20 ch/sec reader and 20 ch/sec punch standard while plotter and analog conversion equipment are available.

MONROBOT XI: N, P. Facilities for three input and three output devices including teletypewriter, edge-punched card reader and punch, and a 16-key numeric keyboard.

SPECIAL INDUSTRY COMPUTERS (Solid-State)

Banking

System	Typical Monthly Rental Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size Instruction Addresses	Thousands of Characters per Second Buffering	Maximum Tape Units	Capacity Average Access Time	Cards per Minute In Out	Paper Tape Characters per Second In Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
SP1 BURROUGHS B250	$4,200[A] (2.8-6.7)	9/61	777[C]	10	9.6K core	1a[F] 3	— —	—	— —	200[N] 100	1000 100	214	—	—	0	—	—	—	—	—
SP2 NCR 310	$2,450[A] (1.6-6.5)	4/61	12.8	6.4	4K core	12b 1	— —	—	— —	—[N] —	350[P] 110	900	—	—	0	√	—	I/O	—	—
SP3 NCR 390	$1,850 (1.4-1.9)	5/61	11300	1200	200 core	12d 4	— —	—	— —	15[N] 15	400 17	110[Q]	—	—	0	—	—	I/O	—	—

BURROUGHS B250: A. Includes central processor, ledger processor and card reader. C. Add time assumes five-character field. F. Instruction can be up to 12 characters in length. N. Magnetically encoded ledger cards can be read at 180 cpm. MICR documents read at 1560 per minute. Q. 214 lpm on up to three forms. See entry S37 for further data.

NCR 310: A. Price does not include cost of magnetic tape units. A version of the CDC-160 (see entry S53). N. MICR documents read at 750 or 1620 per minute. P. 1000 ch/sec reader available.

NCR 390: N. Magnetic ledger card stores up to 200 characters in magnetic strips. Printed information appears on front of card. Q. Programmable printer allows any columnar arrangement on forms and reports.

VACUUM TUBE SYSTEMS — Still Widely Used

System	Typical Monthly Rental Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size Instruction Addresses	Thousands of Characters per Second Buffering	Maximum Tape Units	Capacity Average Access Time	Cards per Minute In Out	Paper Tape Characters per Second In Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
V1 UNIVAC 1105	$43,000 (40-55)	9/58	44	8 34000	8-12K core 16-32K drum[E]	36b 2	21 RWC	24[K]	— —	120 —	200 60	—[Q]	—[R]	√	0	—	√	O	—	—
V2 IBM 709	$40,000 (28-50)	8/58	24	12 7000	4-32K core 4-16K drum	36b 1	15 MRWC	48	— —	250 100	— —	150[Q]	1401 samo	√	3	√	√	O	/59[X]	10/61[Y]
V3 UNIVAC 1103A	$35,000 (25-45)	3/56	44	8 34000	4-12K core 16-32K drum[E]	36b 2	13 none[J]	12[K]	— —	120 —	200 60	—	—[R]	√	0	—	√	O	—	—
V4 IBM 704	$32,000 (24-)	4/56	24	12	4-32K core 4-16K drum	36b 1	15 none[J]	10	— —	250 100	— —	150[Q]	1401 same	—	3	—	√	O	/57[X]	—

UNIVAC 1105: E. Interlace storage arrangement (address locations on drum spaced according to word times) reduces drum access time. K. Magnetic tapes read in forward and reverse directions. Q. On-line display unit available. R. 300 cpm reader, 120 cpm punch and 600 lpm printer available off-line.

IBM 709: Q. On-line display unit available. X. FORTRAN. Y. COBOL, COMmercial TRANslator (9/61).

UNIVAC 1103A: E. See UNIVAC 1105 (entry V1). J. Magnetic tape start-stop time can be overlapped with computing time. K. Magnetic tapes read in forward and reverse directions. R. 300 cpm reader, 120 cpm punch and 600 lpm printer available off-line.

IBM 704: J. Magnetic tape start-stop time can be overlapped with computing time. Q. 500 lpm printer available off-line and on-line display unit is available. X. FORTRAN.

VACUUM TUBE SYSTEMS — Still Widely Used

		CENTRAL PROCESSOR					FILE STORAGE: Magnetic Tape		Random Access	INPUT-OUTPUT EQUIPMENT				OTHER FEATURES						
System	Typical Monthly Rental / Monthly Rental Range	Date First Delivery	Add Time in Microseconds	Cycle Time in Microseconds	Storage Capacity and Type	Word Size / Instruction Addresses	Thousands of Characters per Second / Buffering	Maximum Tape Units	Capacity / Average Access Time	Cards per Minute In / Out	Paper Tape Characters per Second In / Out	Printer Lines per Minute	Off-line Equipment	Program Interrupt	Index Registers	Indirect Addressing	Floating Point Arith.	Console Typewriter	Algebraic Compiler	Business Compiler
V5 IBM 705 III / I & II	$30,000 (18-54)	3/56	86[C] 119[C]	9 17	20-80K core	1a[F] 1	15-62 RWC	60	— —	250 100	— —	150[Q]	1401 same	—	0	√	—	O	/59[X]	10/61[Y]
V6 UNIVAC II	$28,000 (25-30)	11/57	200	40	2K core	12a 1[G]	25 RWC	16[K]	— —	— —	— —	—	—[R]	—	0	—	—	I/O	/58[X]	11/60[Y]
V7 UNIVAC I	$25,000 (20-30)	3/51	282	242	1K delay[E]	12a 1[G]	13 RWC	10[K]	— —	— —	— —	— —	—[R]	—	0	—	—	I/O	—	/57[Y]
V8 BURROUGHS 220	$17,000 (8-35)	12/58	200	10	2-10K core	10d[F] 1	25 none[J]	10	500M —[M]	300 100	1000 60	150[Q] 1500[Q]	—	—	1	—	√	I/O	/59[X]	—
V9 UNIVAC FILE COMPUTER I / Model II	$15,000 (8-21)	1/58 1/62	8600 3400	900 5000 630	20 core 1K drum[E] 2K core	12a 3	10.4 MRWC	10[K]	1.8M[L] 17.6m	150 150	240 60	600[Q]	samo[R]	√	0	—	—	I/O	—	—
V10 IBM 650	$9,000 (3.7-16)	11/54	700	4800 100	1-4K drum 60 core	10d[F] 1[G]	15[H] RC, WC	6	48M[L] 600m	155 100	60 —	150[Q]	—	—	3	—	√	—	/57[X]	—
V11 BURROUGHS 205	$8,000 (2-17)	7/54	 1700	17000 1700	4K drum 80 fast	10d[F] 1	6 none[J]	10	200M —[M]	300 100	540 60	150[Q]	—	—	1	—	√	I/O	/59[X]	—
V12 EL-TRONICS ALWAC III-E	$3,600[A] (1.6-4)	/55	1000	8000	4-8K drum	33b[F] 1[G]	21 RC, WC	16[K]	— —	100 100	200 60	150	—	—	1	—	—	I/O	—	—
V13 IBM 305 RAMAC Model I / Model II	$3,600[A] (2.8-6.5) (1.8-)	12/57 3/62	 30000 50000	 10000	100 core 2K drum	1a 2[G]	15 RC, WC	4	5-40M 600m 5M 600m	125 100 80 50	60 —	30-50[Q] 150	—	√	0	—	—	I/O	—	—
V14 BENDIX G-15	$1,500[A] (1.5-4)	8/55	 540	29500 1080	2K drum 16 fast	29b 1[G]	.43 RC, WC	4	— —	100 100	400 100	100[Q]	—	—	0	—	—	I/O	8/60[X]	—
V15 RPC LGP-30	$1,300 (1.1-2)	9/56	2260[C]	17000	4K drum[E]	31b 1	— —	—	— —	— —	200 20	—	—	—	0	—	—	I/O	/59[X]	—
V16 BURROUGHS E-101	$875[A] (.9-1,400)	/55	50000	20000	220 drum[E]	12d 1	— —	—	— —	— —	20 13	60	—	—	2	—	—	I/O	—	—

V5 — C. Add-time assumes a five-character field. F. Variable word length can be used as a fixed (five-digit) word. Q. 500 lpm printer available off-line. X. FORTRAN. Y. COBOL, COMmercial TRANslator (9/61).

V6 — G. Instructions stored two per word. K. Magnetic tapes read in forward and reverse directions. R. 240 cpm and 300 cpm card readers, 120 cpm card punch, 600 lpm printer and Unityper used off-line only. X. Math-Matic. Y. COBOL '60, Flow-matic.

V7 — E. Mercury filled tanks are the storage media. G. Instructions stored two per word. K. Magnetic tapes can be read in forward and reverse directions. R. 240 cpm and 300 cpm card readers, 120 cpm card punch, 200 ch/sec paper tape reader; 50 ch/sec paper tape punch, 600 lpm printer and Unityper used off-line only. Y. Flow-matic.

V8 — F. Word size is 10d plus sign. J. Magnetic tapes with addressable blocks can be searched concurrently with computer operations. M. Access time to tape loops is 1–9 seconds (dependent on size of file). Q. Printers buffered for on-line use and can be used off-line. X. ALGOL '58.

V9 — E. In Model II, core memory is used instead of drum. K. Off-line sort-collate unit available. L. Up to ten Randex drums (6 million characters each—385m average access time) may be attached. Q. 800 lpm for pure numeric data. R. 240 or 300 cpm reader and 120 cpm punch available off-line.

V10 — F. Word size is 10d plus sign. G. Address of next instruction indicated in last part of instruction. H. Tapes written in BCD (six-bit) or numeric (four-bit) format. L. Up to four Ramac disc files can store 12 million characters each. Q. Printer can be used off-line. X. FORTRANSIT.

V11 — F. Word size is 10d plus sign. J. Magnetic tapes with addressable blocks can be searched concurrently with computer operations. M. Access time to tape loops is 2–17 seconds (dependent on size of file). Q. Printer buffered for on-line use (CARDATRON) and can be used off-line. X. ALGOL '58.

V12 — A. Does not include cost of magnetic tape units. F. Half and quarter word operations are possible. G. Two, three or four instructions may be contained within one word. K. Magnetic tapes can be searched with computer operations.

V13 — A. Does not include cost of magnetic tape units. G. Input editing, logical decisions and character analysis usually made through the 305 control panel. Q. "Stick" printer prints one character at a time.

V14 — A. Does not include cost of magnetic tape units. G. Address of next instruction indicated in last part of instruction. Q. Analog devices, graph plotter and digital differential analyzer accessories available. X. ALGOL.

V15 — C. Minimum execution time for any instruction. E. Interlace storage arrangement (address locations on drum spaced according to word times) reduces drum access time. X. ACT I (Fortran-type).

V16 — A. Computer now being marketed as E-103. E. Pinboard serves as instruction storage unit.

ERRATUM

Listing S27: Should read 7904 data channels (instead of 7094, etc.)

Listing S42a: Should read $3,800[A]

Listing S51: Should read 560[A]

Listing SP1: Should read 214[Q]