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A METHODOLOGY FOR THE SELECTION OF MICROCOMPUTER SYSTEMS FOR LANDSCAPE ARCHITECTURAL PRACTICE

by

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1. Introduction

A growing number of landscape architects are finding the computer an essential tool to improve office productivity, as well as the quality of professional services. As related professionals implement the computer, landscape architects are finding a certain level of computer expertise necessary to effectively interface with those professionals. Many landscape architects are finding traditional methods to be obsolete, as competitors successfully incorporate the computer into practice.

For years, computers were available only to large businesses and institutions, due to the high expense and level of expertise required for computer system operation. However, the most recent innovations in solid-state electronics have revolutionized the computer industry. Within the past decade, this revolution has impacted nearly every aspect of human activity. Modern microcomputers can be owned and operated by home owners, small businesses, and professionals as well. Businesses and professionals who do not take advantage of these technological advances, may soon find themselves competitively lacking with those who do.

A study of the evolution of computer technology reveals the innovations which have enabled the impact of the computer in modern society.

1.1 Hardware Evolution

Since the origin of calculation machines, computers have become an integral component of human activity. As greater computational power and speed is provided in increasingly smaller and more affordable packages, computers bear a greater impact upon society. The growth of computer technology can be attributed primarily to research and development for military defense, and to vigorous competition within the market place (Wise, 1980).

Mechanical Computers

The first machine developed to aid calculation was the abacus, a set of beads arranged on wires to represent numerical values. The wires represented powers of ten, and the beads, units of those powers. Beads were moved to symbolize addition and subtraction. Multiplication and division were difficult to implement on the abacus. John Napiers designed a method to perform those functions by adding and subtracting logarithms, using an abacus and logarithmic tables. The slide rule was developed as a more efficient means to implement Napiers system. The slide rule was the first example of an analog computer (Hawkes, 1972).

The slide rule provided accuracy adequate for most engineering applications. However, the compilation of mathematical tables was a laborious task. "A mathematician might devote years, or even a lifetime to the production of a particular mathematical table. Mistakes were inevitable, and often cumulative." (Peterson, 1982:15). This problem became a major inspiration for the mechanization of calculation.

Leonardo Da Vinci designed a mechanical calculating machine based upon a series of thirteen cogwheels. Each wheel could be advanced to represent one of ten values. When the tenth position was reached, the wheel would return to the zero position, and the next wheel would be advanced one position to symbolize the processes of addition and subtraction. Da Vinci's design to mechanize the abacus was not realized until after his death.

The 'Pascaline' was the first mechanical calculating machine actually constructed. The machine was designed according to Da Vincis notes, by Blaise Pascal in 1642. The Pascaline performed addition and subtraction, and results were displayed on marked wheels. Although functional, the machine was not accepted by the merchants of the day who could have made use of it. They considered the labor of clerks, a more economical prospect. The clerks feared the machine as a threat to their livelihood. A number of machines patterned after the Pascaline, were built in the years that followed. One of the most successful of these was designed and constructed by Gothfried Wilhelm Van Leibnitz, in 1673. His machine was based upon binary arithmetic. The Leibnitz machine was designed for use by financial managers, surveyors, astronomers, geographers, navigators, and mathematicians (Hawkes, 1972 p.14). The design of calculating machines did not change a great deal until the 1950's, when they could be mass produced. Modern desk computers still use some of the same operating principals of the Leibnitz machine.

Charles Babbage designed two mechanical machines which could perform complex calculations without human intervention, and type the results. The first of these, known as the 'Difference Machine', would calculate the values of polynomial equations. The hand cranked Difference Machine was of such tremendous value that Babbage was awarded a gold metal by the Royal Astronomical Society in 1822. He also designed the 'Analytic Machine', which theoretically would have been able to perform any mathematical task. Although the design was sound, the technology of his age was not adequate to construct the machine. The design, however, closely resembles that of modern computers in that it comprised each of the following:

an input mechanism to accept information,

a processing mechanism to manipulate information

an output mechanism to return information to the user.

Babbage is now commonly considered to be the "Father" of the computer.

George Boole, a lawyer and mathematician, developed Boolean algebra as a tool to formalize thought processes in 1854. His work later became the basis of computer logic design (Cooper, 1982).

Electromechanical Computers

The first machine developed specifically for data processing was known as the Hollerith Tabulator, designed by Herman

Hollerith. The tabulator was designed to store data collected in the 1890 United States census. The machine accepted data which was recorded on punched cards. Numerical values were represented by the presence or absence of holes in defined locations on the cards. The holes were sensed electro-mechanically. The tabulating Machine Company manufactured machines similiar to the Hollerith Tabulator, and sold them to insurance companies, railways, and other large businesses. The company was successful, and later adopted the name International Business Systems (IBM).

Several electromechanical machines were developed throughout the late 1800's. "Probably the single most important stimulus to the development of a more efficient calculating machine was World War II." (Peterson, 1982:18). The English developed a code breaking machine, the 'Colossus', which was based upon binary arithmetic, and originally used relays. The relays, however, could switch from one state to another only five to ten times per second, which was not fast enough to be useful. The relays were replaced by vacuum tubes which could switch states hundreds to thousands of times per second. The Colossus was used by the British to decode German messages.

Two large digital computers were constructed in 1944. Howard Aiken, a Harvard professor, studied the design of Babbage's mechanical Analytical Machine, and set out to construct an electromechanical version of the design. Construction of the machine, the Automatic Sequence Controlled Calculator Mark 1, was financed by IBM. The Mark 1 weighed five tons, housed more than three thousand relays, and multiplied two ten-digit numbers in less than three seconds. The other machine was developed by George Stibitz of Bell Laboratories. The Stibitz machine used relays to count numbers, and could add two ten-digit numbers in two seconds. Neither of these machines operated fast enough for most purposes, due to the slowness of their mechanical parts.

Electronic Computers

The first totally electronic computer, the Electronic Numerical Integrator And Calculator (ENIAC) was constructed in 1944 by Professor John Mauchley, a Harvard professor, and J.P. Eckert. The United States government issued Mauchley a grant of $400,000 to develop a fast machine for the calculation of ballistics tables for weapons. The ENIAC, constructed specifically for this application, could multiply two ten digit numbers in three one thousandths of a second, nearly a thousand times faster than the Mark 1. The increased speed was due to its use of vacuum tubes instead of mechanical relays. The ENIAC housed 18,000 tubes, 10,000 capacitors, 6,000 switches, occupied 3,000 square feet, and required 150 kw of power to operate. Constant maintenance was required during operation, as one tube failed approximately once every six minutes. The ENIAC is considered to be the most significant development in computing history in that it demonstrated that automatic computing was possible.

Although the ENIAC was theoretically capable of solving any mathematical problem, only the program which was 'wired into the machine' could be executed. John Von Nuemann drastically altered the design of the electronic computer by incorporating the ability to temporarily store programs, and alternate between programs automatically without the need to resolder and rewire. This concept was built into the UNIVAC 1, the first general purpose computer by Remington Rand. UNIVAC 1 became famous when it was used to assist Walter Cronkite in analyzing the 1952 elections.

The first commercial electronic computers became available in the early 1950s. The forerunners of the business computer market were IBM, Honeywell, and Burroughs. Throughout the 1950s, there was a dramatic increase in the development and usage of business and scientific computers. Whereas computers had previously been available only to government and large scientific institutions, they were now available to business as well.

Bell Laboratories and International Telephone and Telegraph (ITT) laid the ground work for the development of microcomputers. Semiconductors (materials whose resistance to the flow of electricity can be varied) have enabled the development of solidstate electronics. One of the first innovations resulting from the discovery of semiconductors was the transistor, developed by Bell Laboratories, in 1947. A transistor can operate tens of thousands of times faster than a vacuum tube. Transistors also generate less heat, require far less power, and are much more reliable.

The first transistors were relatively large, although small compared to a vacuum tube. Two hundred transistors could fit into one vacuum tube. As transistorized devices proliferated throughout the 1960s Computer scientists adopted transistor technology as well. Transistors, as well as other discrete components, were mounted upon a printed circuit board and connected by copper traces on the back of the board. Whereas the fastest vacuum tube computers could multiply two ten-digit number two thousand times per second, the new transistorized computers could perform the same feat one hundred thousand times per second.

Computer technology was revolutionized by the discovery of a method to miniaturize the components of a computer to microscopic dimensions. Large scale circuit designs, which may cover an entire drawing board, are photographically projected onto a small silicon wafer commonly measuring one quarter inch square. The silicon wafers are first treated with certain acids which impart positive and negative charges to the silicon. Exposure to strong ultraviolet light catalyzes chemical reactions in the silicon. The acids, triggered by light, etch patterns into the wafer. Components of the logic design, such as transistors, capacitors, etc., are then diffused onto the etched wafer. The original logic design is reduced so drammatically by this process, that individual circuits on the wafer may be distinguished only under a microscope. The completed wafer is called a chip. The chips are equipped with fine gold wires through which information is sent or received, and encased within plastic or ceramic rectangles. The encased chip is called an integrated circuit (IC).

The integration process is referred to as small, medium, large, or very large scale integration, depending upon the number of components implemented upon a chip. The first ICs were created with small scale integration (SSI), in which only a few components were integrated on a chip. The complexity of logic design which could be implemented on a large scale integrated (LSI) chip increased rapidly. By 1969 LSI chips were developed which implemented thousands of devices on a single chip. Very large scale integration (VLSI) was developed throughout the 1970's, which implemented tens to hundreds of thousands of components on a chip.

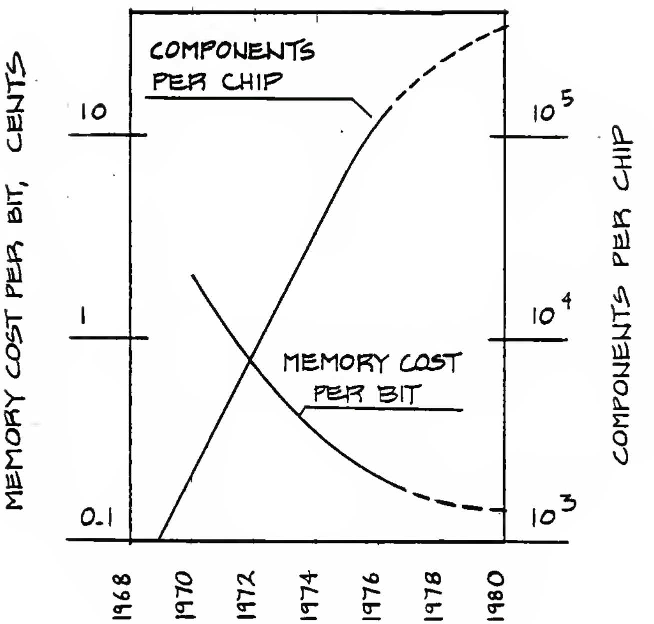
The first SSI circuits could perform a calculation in thousandths of a second. The LSI circuits could perform the same calculation in billionths of a second. The level of complexity provided on a LSI chip was adequate to enable development of the first microprocessor, the Intel 4004. A microprocessor is a central processing unit, the 'brain' of a computer, on a single chip. The complexity of the 4004 was roughly equivalent to that of the ENIAC, however, it was twenty times as fast, thousands of times more reliable, a ten thousandth as expensive, and a thirty thousandth the size. (Cooper, 1982).

Within ten years, the microprocessor made a much greater impact upon society, than large computers had in their first twenty years. (Hoff, 1981). "From 1975 to 1979, microprocessor sales grew at an average compound rate of 188 percent." (Hoff, 1981:18). Microprocessors are being incorporated into a progressively greater number of devices, such as electronic games, automobiles, radios, microwave ovens, vending machines, etc.

Throughout the 1960s, manufacturers have focused upon lower cost, higher speed, higher performance, and smaller devices. The number of components which can be integrated on a chip doubles nearly every year. At the same time, the cost per function has declined. (Wise, 1980). Table 1.1 illustrates the simultaneous increase in capability and decrease in cost which has occured between 1968 and 1980. The progress in device density eventually enabled all the components of a computer to be integrated upon one chip in 1976. The Intel 8048 was the first single chip microcomputer.

Computers based upon microprocessors became known as micro-computers, although the meaning of the term 'microcomputer' has changed as technology has progressed. The first microcomputer store opened in 1975 to sell the first microcomputer kit, the MITS Altair 8800. At last computers were small and affordable enough to be owned and operated by individuals, instead of large businesses and institutions. The first home computer kits were designed for hobbyists who possessed some knowledge of computers. They came as a package of components which the user assembled. The explosive demand for these kits encouraged others to enter the market. By 1977, 300 to 500 computer stores had opened all over the country. (Perry, 1977). Most of the small companies failed, but a few were very successful.

Manufacturers began to develop computer systems which were completely assembled and ready for use. "The days of the tinkerer were ending, and the day of the computer as a 'mind appliance' was beginning." (Perry, 1977:97). The microcomputer was becoming an appliance that anyone could own and use. Companies which once served the hobby market, were now addressing



Graph 1.1

Trends In The Cost And Level Of Integration

In Monolithic Circuits

Adapted From Wise et. al., 1980 (Figure 2) the individuals and small businesses. Because they envied for years the ways in which large businesses could afford to use computers, small businesses became an eager market for microcomputers. Because manufacturers were focusing upon ease of use, more 'plug and go' computers were developed.

By 1979, small business systems based upon microcomputers were beginning to replace large centralized computers. "Within the past decade, the number of microcomputers has grown from a handful to over half a million." (Friedman, 1981:19). As greater computational power is made available in smaller and less costly devices, computers will be applied to perform increasingly greater tasks.

1.2 Software Evolution

The real power of a computer lies not in the capability of the machine, but in the work it is used to perform. Software development has not kept pace with hardware innovation, particularly within the past fifteen years. The most recent breakthroughs in computer technology have occured so rapidly, that it will be years before microcomputer capability is fully realized (Smolin, 1980). Engineers and entreprenuers in the mid 1970's, responding to the growing demand for microcomputers, did not concern themselves with how the machine might be used. The result has been a tremendous gap between the power of modern microcomputers, and the degree of that capability being used effectively.

The key to computer applications is software, or the instrutions required to control operation of the machine. A program is a sequential set of instructions required to instruct a computer to perform a defined task. A computer language is a set of symbols used by humans, to communicate with a computer.

The earliest computer users and programmers had to communicate values and instructions to the computer using the machines own code, represented as patterns of ones and zeros. These codes are referred to as machine code because they are used to communicate directly with the machine. The use of machine code is extremely slow and tedious, as several lines of code are required to command a simple task.

Computer programming became less difficult with the development of languages more comprehensible to the user. The newer languages were easier to use because they were coded in decimal notation, and instruction symbols formed meaningful English words or word fragments. Fewer lines of instruction were required to command the same task. Information coded in more 'user oriented' languages, had to be translated or interpreted into machine code by developmental programs before the machine could operate upon it. Languages which could communicate most directly with the machine, are referred to as low level languages. Those most comprehensible to humans are termed high level languages.

Development of high level languages made the programming and operation of computers increasingly less difficult. The first microcomputers, however, were marketed before high level languages had been developed for them. The developmental programs required to translate most high level languages used on large computers, were too large to fit within the relatively small memories of microcomputers. Use of the earliest microcomputers was limited to hobbiests and computer scientists who possessed a certain amount of computer expertise. Software developers began to design more limited versions of the traditional high level languages for use on microcomputers. The use of computers was then opened to a wider range of programmers and individuals who chose to learn those new languages. A great number of microcomputer programs were written and marketed as 'packaged' or 'off the shelf' software, which individuals could purchase a license to use. Since packaged software could be used by those who possessed no knowledge of programming, they became very popular for use in the home, business, or professional practice.

Manufacturers have more recently begun to focus upon providing useful packaged software with their hardware systems, in an effort to provide readily usable and complete systems to the general public.

The design of programs is becoming less difficult with the innovations of new languages and programming techniques. Languages are being designed for development of software oriented towards particular tasks and application. For example, commonly used functions are built into the newer versions of languages, to alleviate the programming burden of software designers. The more recently developed structured languages enable a more simple and logical problem-solving approach to software development.

Packaged software is now being designed with greater consideration to human usage. The emphasis is on clearly explicit user instructions and data entry techniques which demand less of the user and more of the machine. Self-customizing software is being developed which allows the user the flexibility to adapt packages to individual requirements with no knowledge of programming. Packages currently available are designed to be less machine dependent, so they can be used on a wider range of systems without modification.

As microcomputer hardware becomes more capable, many applications traditionally performed on large computers can now be implemented on microcomputers. Software developers are now focusing on these more sophistocated applications for smaller machines. Manufacturers are also focusing upon upwardly compatible systems which allow microcomputer users to upgrade to larger systems without major software revisions.

Software development, however, still lags behind the increasing capability of computer hardware. As expressed by Hoff, (1980:20)

> "The quantity and complexity of applications are growing rapidly; the human resources needed to develop these applications are not. Unless this impasse is resolved, microelectronics will see its growth limited by the supply of available programmers".

In order to use computers to the greatest advantage, there is a need to identify potential applications and to design systems which integrate the machine and the user to perform more efficiently.

1.3 Problem Statement

Within the design professions, the computer is enabling firms not only to accomplish existing tasks more easily, but previously impossible tasks are becoming feasible. (ASLA,1977). Landscape architects commonly function as master coordinators and problem solvers, collecting and synthesizing large quantities of information, to arrive at design solutions. Information management is the life blood of all land related professions. (Clay, 1980). Computers are well suited to rapid data manipulation.

Computer-aided design processes currently implemented, involve the manipulation of complex data banks, modeling, gaming, and simulation to duplicate, explain, and predict the real world. (ASLA, 1977). Computer technology is increasing the landscape architects knowledge base, and capacity to synthesize information, design, and manage. (McCarthy, 1980).

Until recently, most computer applications to landscape architecture, have been available only on large systems which were not affordable to small landscape architecture firms. As the capability of large computers is becoming available in smaller and less costly systems, a greater number of computer applications are becoming feasable for small landscape architecture firms. Many landscape architects preparing to incorporate computers into their practice, are considering the advantages offered by microcomputer systems, which require a lower initial investment than larger systems. Microcomputers are currently used within the profession to perform accounting, time analysis, cost estimation, plant selection, word processing, and construction calculations. (Rupley, 1981. Computer-aided design and drafting have more recently become practical applications for microcomputers.

Landscape architects within the Kansas City area were interviewed to ascertain the future of computers in landscape architectural practice, i.e. the ways in which computers are currently being implemented, areas of potential application, and factors which currently limit computer implementation. As indicated by the interview results summarized in Appendix A, many landscape architects are attempting to educate themselves about microcomputer systems, such that they may intelligently incorporate these systems into professional practice.

As landscape architects prepare to select computer hardware/ software systems, they face a nearly incomprehensible number of variables to consider. Most of the landscape architects interviewed, expressed a desire to know how to make sense of the information available, and select a computer system which meets the requirements of their practice.

Statement Of Purpose

This research is proposed to develop a method by which landscape architects may identify their data processing objectives, and select a microcomputer system best suited for the accomplishment of those objectives.

1.4 Methodology

1. Landscape architecture firms within the Kansas City area were interviewed to determine the following:

   - the level of interest existing among landscape architecture professionals concerning computer applications to landscape architecture,
   - computer applications currently implemented within landscape architecture offices,
   - computer applications which landscape architects would like to implement.

2. A general knowledge of computer systems was acquired through a literature search, and interviews with computer vendors and professionals. The most pertinent information covered the following areas:

   - computer system components and configuration,
   - computer system selection considerations,
   - computer system suppliers,
   - computer system applications,
   - computer systems analysis.

3. Based upon the information collected, a methodology was designed to enable landscape architects to intelligently select a microcomputer system. The selection methodology prescribes an efficient means for landscape architects to accomplish the following:

   - identify data processing goals,
   - identify specific tasks to be computerized,

- design a schedule for implementation,
- define the tasks to be computerized,
- identify computer system characteristics required to perform those tasks,
- locate suitable system suppliers,
- compare cost and capability offered by suppliers.

4. A hypothetical case study was designed to demonstrate the application of the proposed methodology.

1.5 Justification Of Topic

Landscape architectects interviewed within the Kansas City area were employed either in a landscape architectural firm, an interdisciplinary firm, or within governmental offices. Results of the survey indicated that, in general, landscape architects tend to lag behind related professionals which implement computer systems. Landscape architects employed within large interdisciplinary firms, tend to be less involved with computer applications, than engineers and architects within the same firm. The majority of landscape architecture firms have not yet implemented computer systems. Those which have been using computers, have found a certain level of in-house programming expertise essential to provide the level of flexibility which they considered necessary.

The majority of landscape architecture firms which have not invested in a computer system, have plans to do so. Although most landscape architects are aware of the advantage offered by computers, the hesitation to implement a system stems in part from the lack of knowledge required for system selection, and the lack of available software designed specifically for landscape architectural practice.

The selection methodology proposed within this study has been designed as an aid to landscape architects who are ready to invest in a computer system, but lack the necessary background knowledge to approach the investment intelligently. The selection process requires an understanding of both computer systems, and the work they will be used to perform. The selection approach proposed within this study emphasizes the identification of data processing goals and the definition of applications. Landscape architects are far better equipped to define their work than are computer professionals. A basic knowledge of computer systems will enable the landscape architect to determine computer system configuration and characteristics required to perform desired tasks. This informed approach will make the most efficient use of time, and may prevent many potential errors in system selection. System suppliers are best able to help those who understand their data processing needs, and they appreciate informed customers.

1.6 Statement Of Premises

The use of computers can enhance the landscape architecture profession in the following ways:

- by providing a means to increase speed, efficiency and productivity, effecting a time/cost savings
- by improving the quality of professional services
- by upgrading the credibility of landscape architects among related professionals
- by enabling landscape architects to keep apace with technical progress occuring in related professions

1.7 Use Of The Study

The results of this research are presented within this document in four major sections. Section 1, Introduction To The Topic, provides a brief introduction to the computing industry and a statement of thesis purpose. Section 2, Introduction To Computer Systems, provides a description of computer system components and selection considerations for each component. Section 3, Computer System Selection Methodology, sets forth a methodology for computer system selection and a demonstration of that methodology in the selection of a computer system for a hypothetical landscape architectural firm.

The matrices included within Appendices C, D, and E provide a summary for various aspects of the selection methodolgy as follows:

Appendix C, Summary Of Computer System Selection Considerations, describes the relative importance of each selection criteria for a given set of data processing objectives.

Appendix D, Computer System Specifications, sets forth specifications which describe a system to meet those objectives as well as the specifications of systems proposed to accommodate the objectives.

Appendix E, Computer System Evaluation Matrix, provides a point-by-point basis for comparison of systems proposed by contending manufacturers.

The appendices serve as an efficient means to organize and communicate information compiled as the methodology is utilized for system selection.

The most effective usage of this study may be accomplished in the following manner:

(1) a preliminary review of the appendices to establish a frame of reference,

(2) a thorough study of Section 3, which presents the computer system selection methodology,

(3) reference to Section 2, which describes computer system components, as needed to enhance understanding of the methodology, and finally

(4) review of Section 4, which presents the results of the study.

2. Introduction To Computer Systems

A computer is an electronic machine which manipulates data at high speeds. A computer system comprises the machinery, and the instructions which interface the human user, with the computer. The machine is the physical part of the system, referred to as computer hardware. Software is the set of instructions required to control operation of the hardware. A computer system is capable of accommodating the four processes as follows:

Input: data is input into the system by the user

Process: data is manipulated by the computer

Output: data is returned from the computer to the user

Storage: data is stored for future use or reference

These processes are often represented graphically using the symbols illustrated in Diagram 2.1. The flow charts indicate a step by step process performed by the computer and the user, to solve a problem. A combination of both hardware and software is required to perform each function.

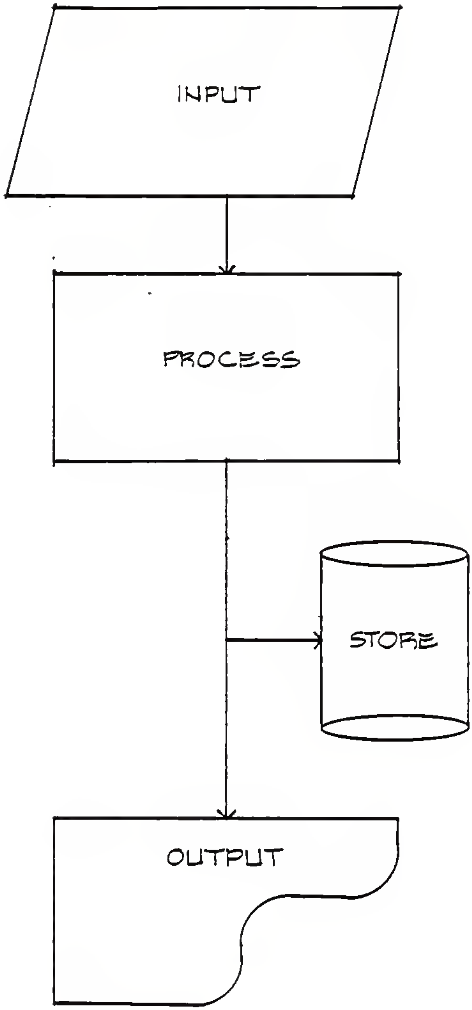


Diagram 2.1

Flowchart Representation Of Computer Processes

2.1 Introduction To Computer Hardware

Each physical component of the system performs one of the four basic processes: input, computation, output or storage. They may be categorized accordingly as follows:

Input Devices:

- keyboards
- graphics tablets
- digitizers
- light pens
- potentiometer devices
- voice input devices

Output Devices

- monitors
- printers
- plotters
- video copiers

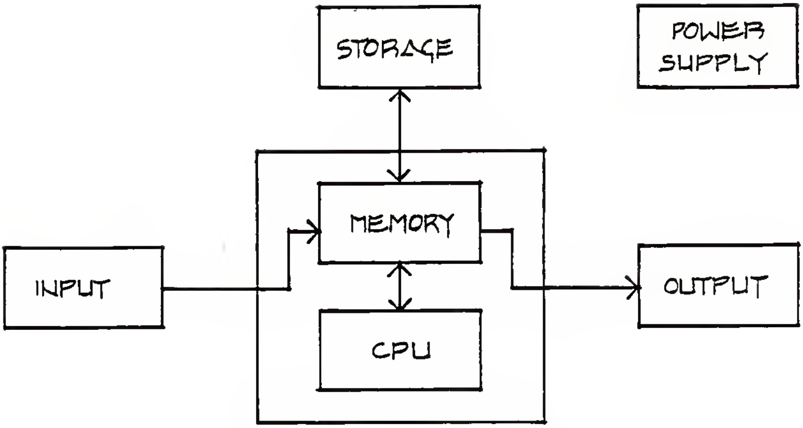
Storage Devices:

- magnetic tape drives
- magnetic disk drives
- semiconductor memory
- bubble memory

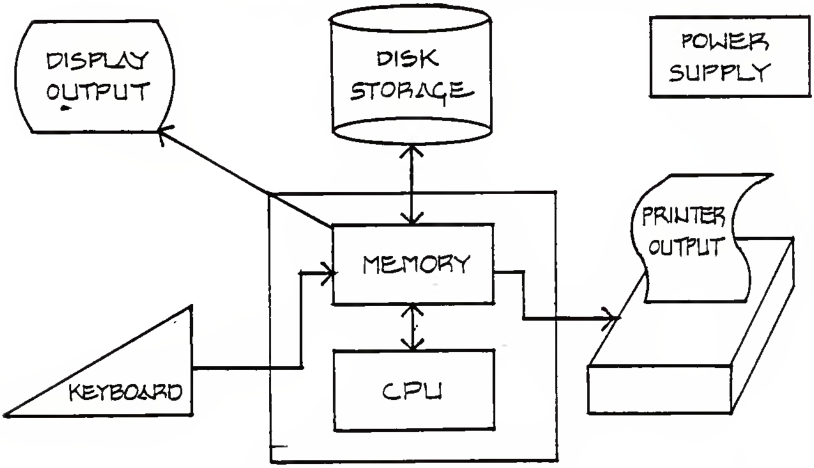
Computation or Process Devices

- computers

The configuration of these devices is illustrated in Diagram 2.2.



Fundamental Diagram Of All Computer Systems



Typical Configuration For A Small Computer System

Diagram 2.2

Elements Of A Computer System

2.1.1 Computers

The computer is the only part of a computer system that actually performs computations, i.e. processes data. All other hardware components are referred to as peripheral devices. The basic constituents of all computers include the following:

central processing unit (CPU)

memory

input/output ports

The configuration of these elements is illustrated in Diagram 2.3 The CPU is that part of a computer which actually processes data. A microprocessor is a large scale integrated (LSI) CPU which is encased within one chip. A microcomputer is a computer which uses a microprocessor as it's CPU. (Osborne 1980:1-1).

The only data processed by the CPU are two voltage levels, represented as the digits one and zero. For this reason, machine code, the language used to communicate directly with the machine, is based upon the binary or base two numbering system. One binary number is called a bit. Combinations of bits used to transmit data are called words. A 4-bit word is called a nibble, an 8-bit word, a byte, a 16-bit word, a half word, a 32-bit word, a word, a 64-bit word, an extended word or long word. Most microcomputers use 8-bit processors. However, 16-bit and 32-bit processors are becoming more prevalent. They are capable of transmitting data at much greater speeds.

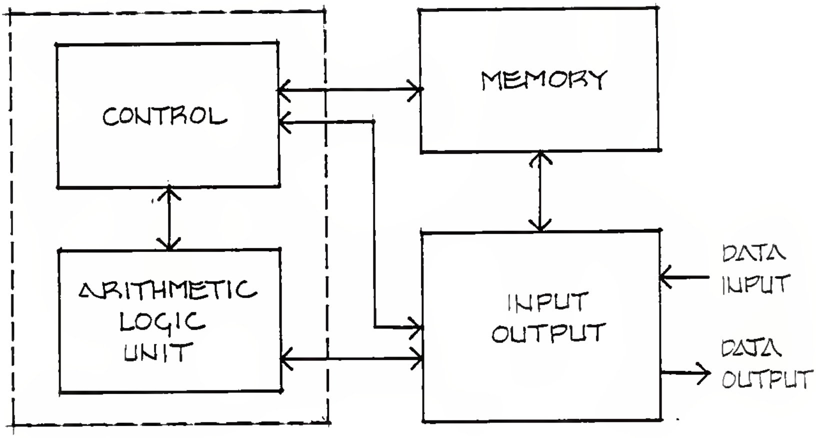


Diagram 2.3

Elements Of A Computer

Adapted From Frenzel (1983:16)

The basic constituents of a CPU include the following:

arithmetic logic unit (ALU)

controller

registers

address and data buses

coders and decoders

The configuration of these components is illustrated in Diagram 2.2. The registers are temporary storage locations for binary numbers which have a fixed length. Each type of register holds data and performs a unique function. The control unit fetches words from memory, interprets their instructions, and routes data to it's appropriate location, so that the instruction can be executed. It is the arithmetic logic unit which actually performs arithmetic and logical operations upon the data. At this level most computers can only add, perform the equivalent of subtraction, perform boolean algebra, and shift data. This repertoire of processes which can be executed is known as the instruction set of the CPU. Some processors also contain multiplication, division, and floating point decimal instructions within their instruction set. These basic functions are said to be hardwired if contained within a processors intruction set. They are combined and repeated to achieve the equivalent of more complex operations. If not hardwired, these combinations must be specified by software instructions. For example: a CPU which does not contain multiplication within it's instruction set will perform multiplication by successive addition.

Data is transferred between registers, memory, and the

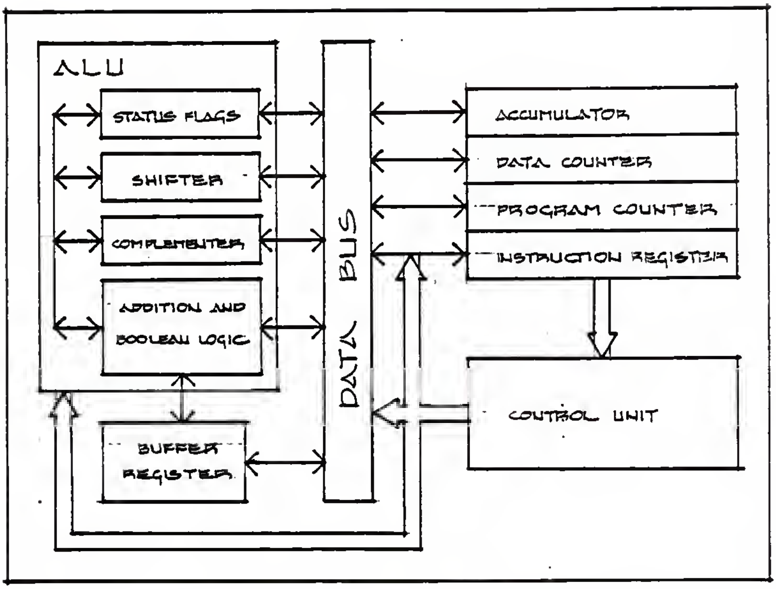


Diagram 2.4

Elements Of A CPU

Adapted From Osborne (1980:4-12)

input/output ports through buses. These are parallel lines which connect the components. Each line carries one bit. Address buses carry signals from the CPU registers to memory and the input/output ports. The words traveling through the address bus designate the location where data is stored. The number of parallel lines in the address bus determine the number of internal memory locations which may be accessed by the CPU. If n = the width of the address bus, then 2^n = the number of memory locations which can be accessed. For example: an address bus which is 16 lines wide can access 2^{16} or 65,536, (64K) memory locations. The data bus carries information to be stored or retrieved from memory. The number of parallel lines in the data bus effects the speed and efficiency of computation. One or more read/write lines are used to signal whether memory will be read from or written to. The internal memory of computers is further described in Section 2.1.4.1.

Selection Considerations

Computers

The computing power of a system depends largely upon the CPU, and the internal memory of the computer. The most important characteristics to be considered are the word length, the memory size and the instruction set.

Processors which have a longer word length are more versatile, and capable of faster data transfer. The word length of a CPU refers either to the number of bits which may be processed by the CPU at one time, or the width of the data bus. In some cases, these word lengths may be the same for a particular computer. If not, they are often both specified. If both word lengths are expressed, the word length of the data bus is expressed first, and separated by a slash from the word length of the CPU. For example: the data bus word length of a 16/32 bit computer is 16, and the CPU word length is 32. If only one word length is expressed, it is always that of the CPU. The data bus width is either equal to or less than that of the CPU. A 'true' 16-bit computer has a both a 16-bit CPU word length, and a 16-bit data bus as well.

The internal memory required of a computer is dependent upon the software to be run, and the amount of information which must be accessable to the CPU at one time. Once having determined this requirement, the following items should be considered:

- the maximum amount of memory which the machine can accept

- whether or not that amount will fit into the main enclosure of the computer, or if an expansion chassis must be added to contain it
- if an expansion chassis must be added, if it is available

These factors are especially critical if future expansion is anticipated.

Hardwired functions within the instruction set can effect computing speed. They execute much more rapidly than those which require iterations of simpler instructions.

Cycle time is a measure of processor computing speed. Turnaround time, or the time required for data input to be processed and output to the user, is much more impacted by factors other than cycle time. Turnaround time is much more dependent upon the efficiency of the software, and the speed of peripheral devices.

Summary Of Selection Considerations

Computers

Total memory capacity

Maximum internal memory required

(internal memory is further described in Section 2.1.4.1)

Availability of expansion chassis, if required

Speed - cycle time

CPU instruction set

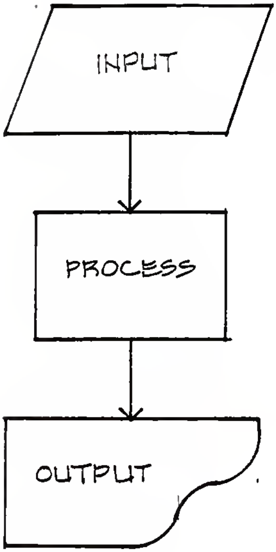
2.1.2 Input/Output Devices

Introduction

Input devices are peripherals which allow users to enter data into a computer system. Output devices return information from the computer system to the user. The input/output (I/O) peripherals connected to a system determine the ways in which the user may interface with the computer.

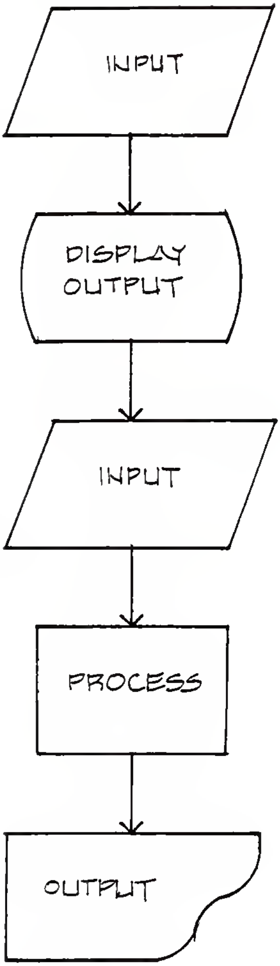
Computer systems may be categorized as either passive, or interactive, depending upon the degree of interaction allowed between the computer and the user during operation. The user can communicate information into the system only during input operations. Within a totally passive system, input occurs only at the beginning of operations. Data is then processed and output independently of human intervention. Interactive systems, however, incorporate the human into the system. Input, computation, and output processes are intermixed throughout operations, allowing a back and forth dialogue between the computer and the user. The contrast between passive and interactive systems is illustrated in Diagram 2.5.

Interactive systems offer much greater power and flexibility to the user. Some of the most useful applications which make use of interactive systems include: text editing, file management, computer-aided instruction, computer-aided design and on-line programming. The interactive capability of a system is determined by the I/O devices connected to the computer. Input/output devices currently available for microcomputers



Passive

System Flowchart



Interactive

System Flowchart

Diagram 2.5

Passive vs. Interactive Systems

include the following:

input devices	output devices
keyboards	monitors
digitizers	printers
potentiomenter devices	plotters
light pens	video copiers
voice input devices	

The most commonly used I/O devices are monitors and keyboards. They are usually connected to a computer, and referred to as a system unit. This arrangement allows simultaneous display of information both input by the user, and output by the computer.

2.1.2.1 Monitors

The display screen, or monitor, provides a means for data display. This includes both textual data, such as letters and numbers (alpha-numeric data) as well as pictoral images, such as line drawings, and continuous tone images. If connected to an input device, such as a keyboard, a monitor can display information entered by a user on the keyboard as it is entered, enabling highly interactive applications. The most widely used monitors are refresh cathode ray tubes, (CRTs), and storage CRTs. Refresh CRTs create either color or monochromatic displays. Storage CRTs are only monochromatic.

Monochromatic Refresh CRTs

The basic constituents of a monochromatic refresh CRT include an electron gun, a focusing structure, an accelerating structure, a deflection system, and a phosphor coated screen. Diagram 2.6 illustrates the typical configuration of these components. The cathode emits a stream of electrons. The electron gun assembly focuses the electrons into a beam, and aims them at the center of a viewing surface. The location of the beam when it strikes the screen, is controlled by the deflectors. As the beam passes between two horizontal and two vertical deflectors, it is attracted and repelled by their relative voltage levels. This control is used to divert the beam along a horizontal and a vertical axis. Two types of deflectors may be used; electrostatic, or electromagnetic. An electrostatic

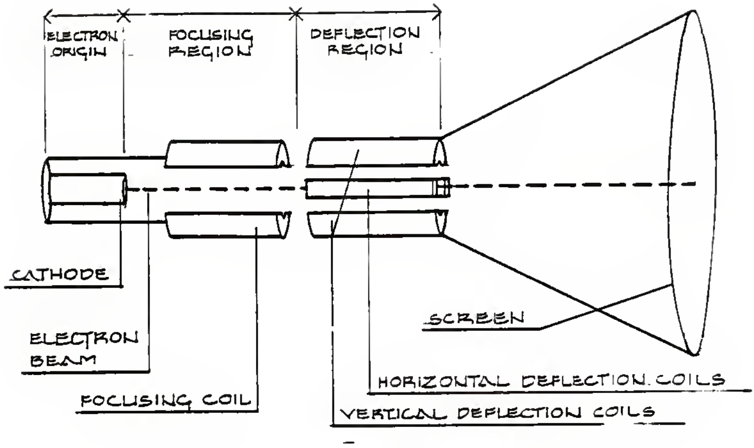


Diagram 2.6A

Basic Electromagnetic CRT

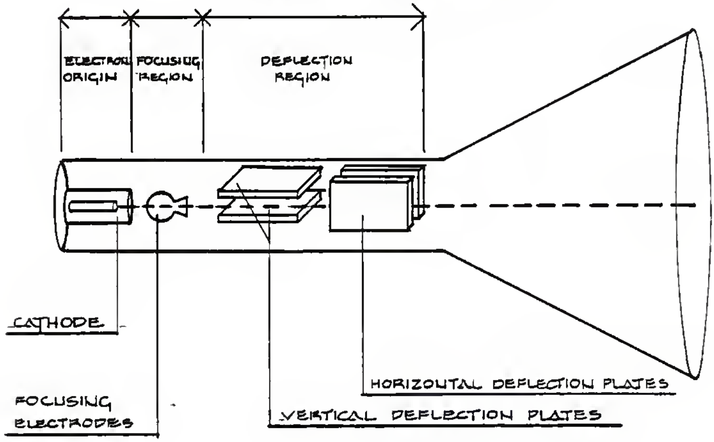


Diagram 2.6B

Basic Electrostatic CRT

Adapted From Lee (1975:6)

CRT, such as the system illustrated in Diagram 2.6B uses two electrically charged plates. An electromagnetic system (illustrated in Diagram 2.6A) uses coils which create perpendicular magnetic fields. Electrostatic systems provide more accurate control, but are also more costly (Lee, 1975).

As electrons strike the viewing surface, some of the phosphor's energy is converted into light, a phenomenon called phosphorescence. The remaining energy is stored in the phosphor, which continues to radiate as energy is converted into light; the phenomenon of flourescence. The length of time during which flouescence occurs, is known as the persistence of the phosphor. More precisely, persistence is measured as the time required for display brightness to drop to 1/10th it's initial value. This should be no greater than 100 milliseconds. If flourescence ceases before the screen receives more energy from the electron beam, the screeen will appear to flicker. The beam must "refresh" most screens 30 or 60 times per second in order to provide a flicker free picture. The type of phosphor which coats the screen will determine the following:

- the amount of energy which can be delivered to the monitor without causing damage to the phosphor,
- the color of light emitted during flourescence and phosphorescence,
- the decay rate or the persistence of the phosphor

Together these factors determine the brightness of a display, and the rate at which it must be refreshed to eliminate flicker.

Phosphors used in CRTs are produced using compounds of calcium, cadmium, zinc, and other rare earth elements. They are identified by a numbering system which uses names such as P1, P4, P7, etc. The phosphor most commonly used for graphic displays is P7. This is a long persistence phophor which leaves a green afterglow.

A CRT which is to be used in an environment with bright ambient light, requires a brighter display. If the refresh rate is not high enough, and the image appears to flicker or warble, this may cause tiredness, headaches, and visual disturbances for the operator, especially if used for long periods at a time.

Screen Definition

The locations on the screen may be defined by either high or low resolution graphics. A high resolution screen is defined as a matrix of screen locations or pixels, arranged in rows and columns as shown in Diagram 2.7. Display information for each pixel is stored within a random access memory, referred to as a bit map or frame buffer. Each pixel corresponds with one or more bits of memory in the buffer. The number of bits representing each pixel, varies with each display system.

An inexpensive frame buffer allocates only one bit of memory per pixel. That bit stores one of two beam intensity values; a one for pixels which are to be lighted, or a zero for those to be unlit. This is adequate for a simple monochromatic display of text and simple graphics. Two and four bits can specify the display of solid areas of grey, or color. A high quality shaded display requires eight or more bits per pixel. Some frame

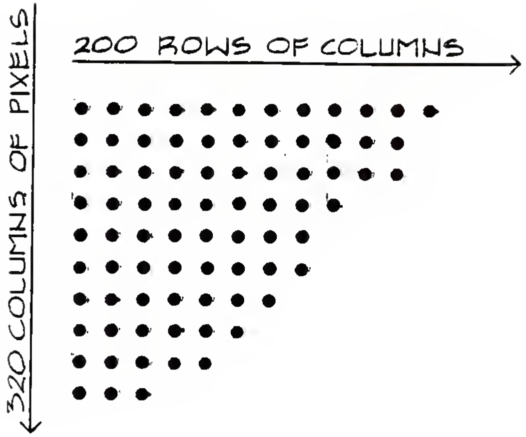


Diagram 2.7A

High Resolution Screen Definition

Division Of The Screen Into Pixels

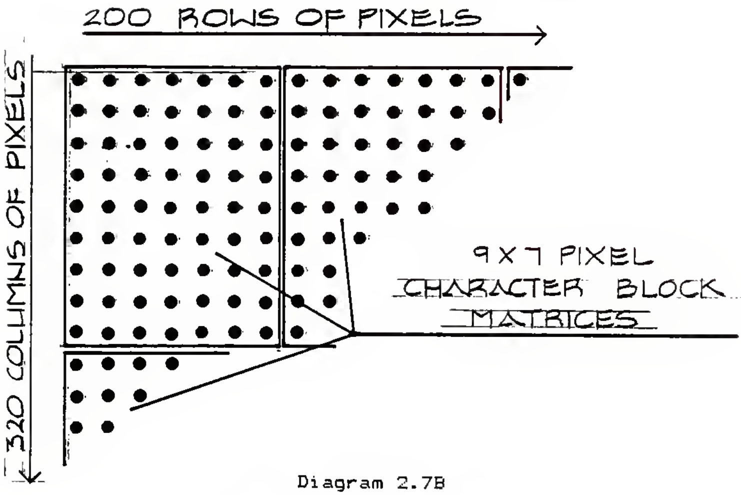


Diagram 2.7B

Low Resolution Screen Definition

Division Of The Screen Into Character Block Matrices buffers store up to 24 bits per pixel. This is useful to display not only a wide range of colors and intensities; it may also store each screen as a stack of planes, each containing a separate image. This enables several types of video mixing. For example: one plane may be used to display a static picture, while another is altered by the operator.

The set of instructions required to create a display are stored in a sequence of memory locations, collectively referred to as the display file. The file usually contains instructions necessary to create characters or vectors on the screen. The display controller is an interface between the computer and the CRT. The controller translates display file information into analog signals which control the electron beam. The display controller also temporarily stores data to compensate for differences in operating speed between components which transmit data. Data flow between the computer, the display controller, and the CRT is illustrated in Diagram 2.8.

Low resolution graphic systems define the screen more coarsely into a matrix of blocks, as shown in Diagram 2.9. Each block is a matrix of pixels. A typical screen may be divided into 25 rows x 40 columns of blocks. Each block is comprised of approximately 64 pixels, commonly arranged in a 9 x 7 matrix. The individual pixels of a block are lighted according to predefined patterns to display characters. The patterns may be stored within a display file which would require a 16-bit word for the display of each character. Textual display is generated more efficiently by a hardware character which performs essentially the same function.

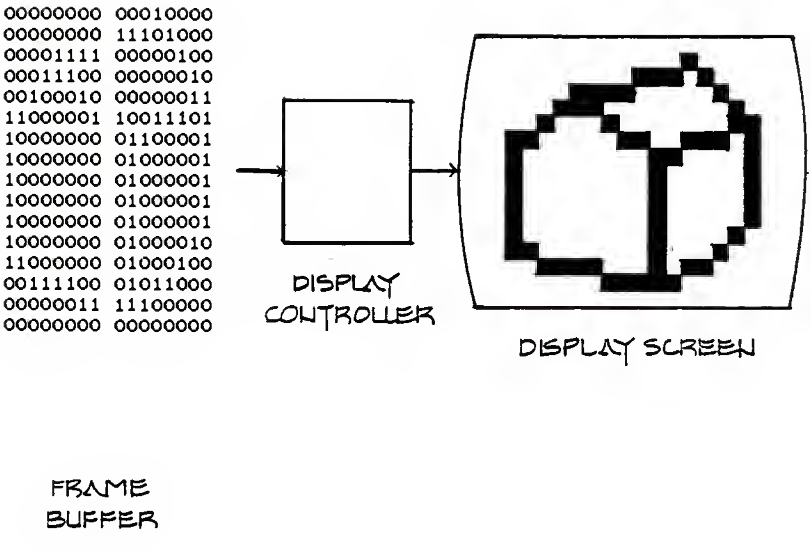


Diagram 2.8

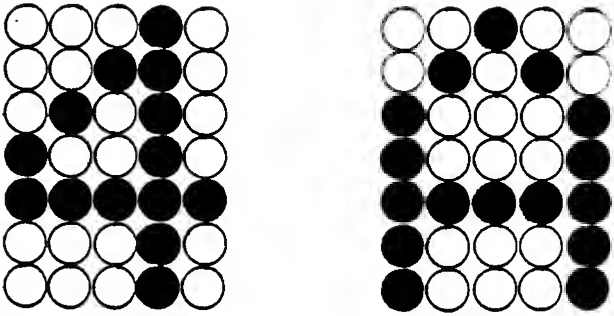
Data Flow Between Frame Buffer And Screen

Adapted From Newman and Sproull (1983:7)

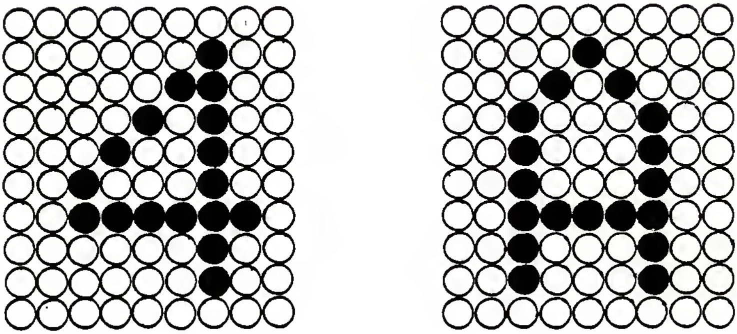
Pre-defined characters may include letters, numbers, and special characters such as mathematical notation or graphic symbols. As indicated in Diagram 2.8, the left column and bottom row of most textual characters are left dark to separate them from one another on the screen. Line drawings may be generated by combining patterns of pre-defined graphics characters, as illustrated in Diagram 2.9. The light intensity of groups of blocks may be specified to create coarse line drawings or continuous tone images.

The number of characters which may be displayed on a monitor is dependent upon the computer. The size of individual characters is dependent upon the screen, i.e. a larger monitor enlarges the size of characters displayed. Screen size is usually designated by the diagonal dimension of the screen in inches. Most computers can generate a display of 24 x 60, 16 x 64 or 24 x 80 rows by columns of characters. Some monitors will also enable a compressed display of 132 characters per line.

Low resolution graphic systems are used to display textual data, as well as very coarse graphic images. High resolution systems create a much more highly resolved display, and are used primarily to display graphic images instead of alpha-numeric text. Some applications require displays which may be implemented most efficiently using a combination of high and low relolution graphics: for example; the lines of a working drawing may require the accuracy of a high resolution system, while the associated construction specifications may be generated more efficiently with low resolution graphics. Some computers have a software switch which allows them to operate in either mode with



5 X 7 PIXEL
CHARACTER BLOCK MATRICES



9 X 10 PIXEL
CHARACTER BLOCK MATRICES

Diagram 2.9

Character Matrices For Refresh CRTs

the appropriate software. This switch can be quite an asset for those applications which require both textual and high resolution graphic display.

The term resolution is used not only to describe the method by which a screen is defined, but also the number of pixels defined on a particular screen. A high resolution screen is one which is defined by a relatively large number of pixels. They produce a clearer, sharper picture, in which connected dots may be small enough to appear as solid lines. Individual pixels on a low resolution screen may be distinguished by the unaided eye. Screen resolution is determined by the size of the frame buffer, the focus of the electron beam, and the characteristics of the phosphor.

A typical high resolution screen displays 100 dots per square inch. A screen which has a higher resolution than this would not appear much different to the user. Screens are typically 9, 10, 12, 13, 14, and 15 inches wide. The height to width ratio of most screens is 3:4. Screen resolution, or the number of addressable points on a screen usually ranges from 34 rows x 64 columns of pixels to 4096 x 4096. The standard number of pixels defined across the row of a screen include 256, 525, 625, 813, 875, and 1023. Since this type of screen resolution measure does not take screen size into account, dots per square inch is more indicative of display quality.

Beam Control

Refresh CRTs direct the electron beam using either raster or vector graphics. Most refresh CRTs are designed to display data using raster graphics. Those which display vector graphics are referred to as vector refresh CRTs. In the case of raster systems, the electron beam path is repeatedly directed across each row of pixels, drawing the picture as a series of scan lines. Beginning at the upper left hand corner of the screen, the beam path moves from left to right across each line. The beam is then turned off and once again positioned at the left of the screen, one or more rows lower. This process is repeated until the entire screen has been scanned. The beam is then repositioned at the upper left hand corner, and the cycle is repeated. A non-interlaced display is one in which every row is scanned in each screen scan. An interlaced display requires two screen scans to produce a display. The first scan includes only odd numbered rows, and the second includes even numbered rows. Non-interlaced displays are scanned 60 times per second, (60 hz), and interlaced displays are refreshed at 30 hz.

A vector refresh system creates a display by drawing a series of continuous lines. Whereas a raster system can only assimilate a line by lighting a series of pixels, the beam in a vector refresh system traces a straight line from a start to an end point. Vector screens may be divided into a screen resolution of 4096 x 4096. Specific points within the screen matrix are used only to specify vector end points. Each line begins and ends with a pixel, but the lines are traced by the electron beam without regard to the pixels between the start and end points. The width of the beam drawn line may or may not be narrower than the pixels which comprise a raster drawn line. However, the vector refresh display appears more highly resolved due to the elimination of the stair-stepped effect created by raster displays. Lines drawn at an angle other than 90 or 45 degrees, appear jagged, as shown in Diagram 2.10. This would probably not reduce the utility of the screen. It may have some importance if photographic methods are used to generate presentation quality hard copies of the screen.

A vector list is the set of x-y coordinates which specify the location of start and end points for a vector display. This list is stored within a display file. An analog vector generator continuously converts this vector list into analog signals. The horizontal and vertical deflectors are provided with a pair of gradually changing voltage levels by the analog vector generator as the vector is being written. Some vector systems refresh the screen at a fixed rate; 30 or 60 hz, regardless of the number of lines in the diplay. Others adjust the refresh rate to compensate for screen complexity. At a certain level of screen complexity, the refresh rate will become so slow that the screen will appear to flicker.

Raster monitors are not as costly as vector refresh CRTs. Frame buffer displays are not quite as well suited to dynamic, interactive graphics as are vector driven displays. A vector system can respond more rapidly to user actions. Raster monitors are capable of producing full color displays.

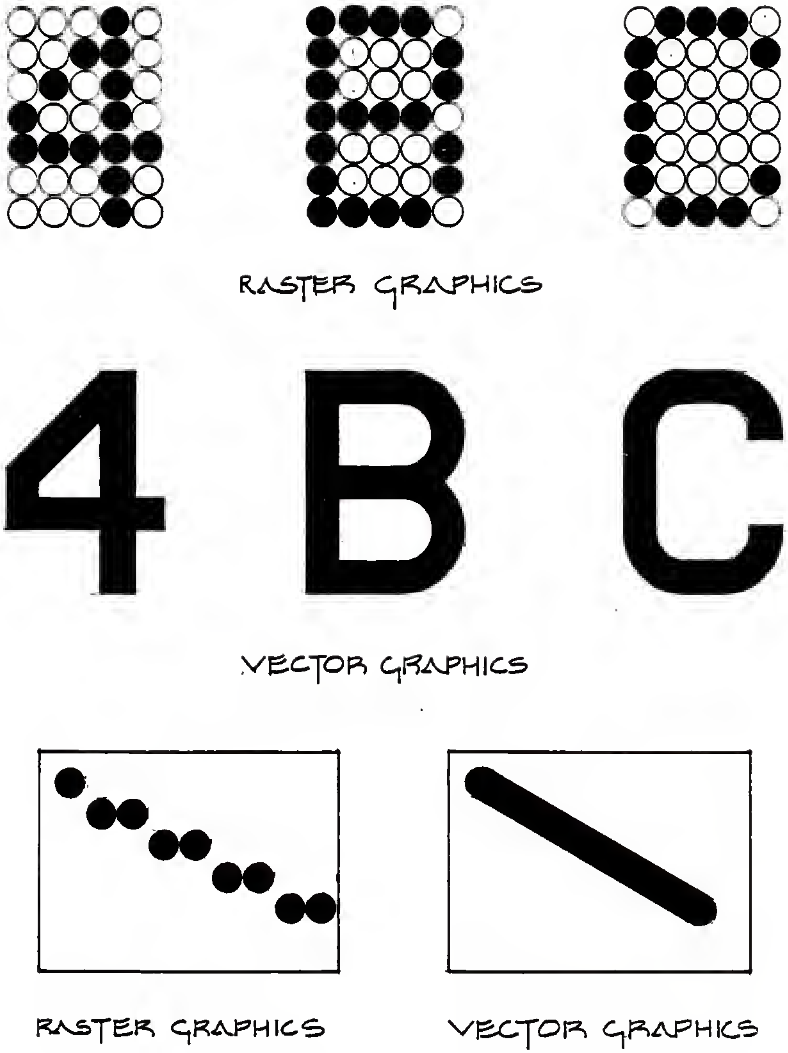


Diagram 2.10

Raster vs. Vector Graphics For Refresh CRTs

Color

Color may be rendered on a refresh CRT using one of two methods. Color raster systems are sometimes referred to as shadow mask CRTs. Color vector systems use a method of beam penetration to implement a color display.

A shadow mask CRT is equipped with a color phosphor coated screen, a shadow mask, and a delta gun, as shown in Diagram 2.11. Each pixel on the screen is composed of a triad of color dots. Each dot displays one of the three primary light colors, red, blue, or green, when excited by the electron beam. In place of the single electron gun used in monochromatic CRTs, a shadow mask CRT uses a set of three guns. They are arranged in a triad, and collectively referred to as the delta gun. Each gun within the delta lights one of the three color dots for each pixel.

The shadow mask is a metal plate pierced with a matrix of holes; one for each pixel. The deflection system operates on all three electron beams simultaneously, to focus them through the same hole on the shadow mask. Since each beam has a different origin within the delta, they strike the screen at a slightly different location. The delta gun and shadow mask are arranged so that each beam is directed to strike only one of the color dots within each triad. If the three beams do not converge through precisely the same hole in the shadow mask, the colors displayed will appear to be edged with a different color. A small degree of misconvergence can render a display illegible. This can be corrected by adjusting the deflectors, but the adjustment is usually costly, and requires a skilled technician.

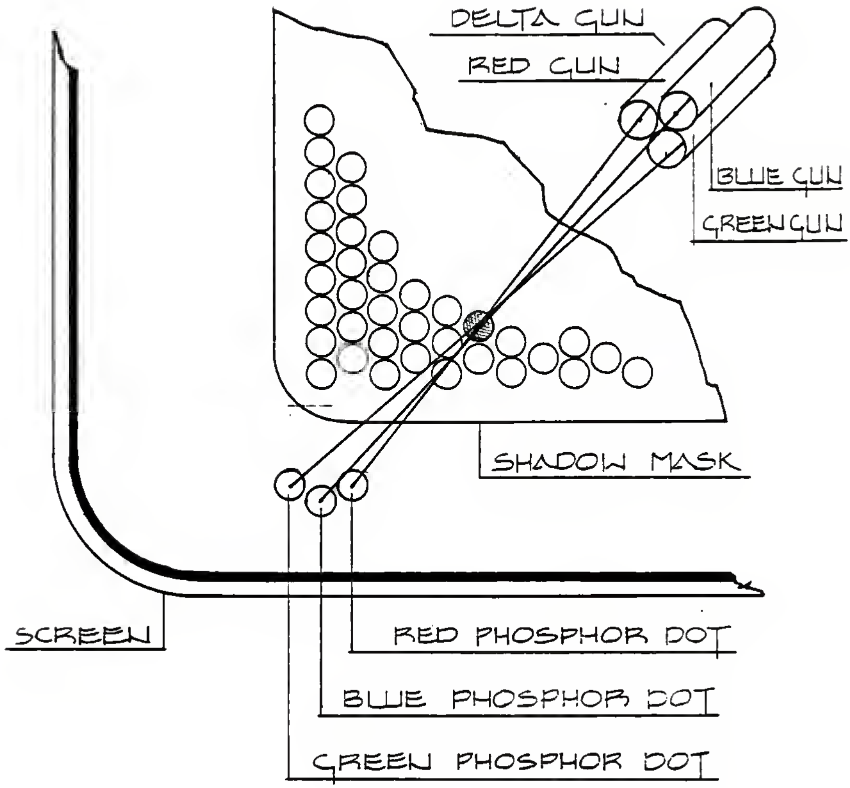


Diagram 2.11

Elements Of A Shadow Mask CRT

Adapted From Rossiter (1980:117)

Some systems are designed to allow an unskilled user to make the adjustment, which can effect a considerable savings for the user.

Each of the three primary light colors may be displayed by only one color of dot within the triad. Secondary colors are rendered by simultaneously lighting more than one color of dot with the appropriate intensity. For example; when the red, green, and blue dots are all lit with equal intensity, the displayed pixel will appear white. If the red and green dots are lit, the display will appear yellow.

An acceptable color display requires a higher quality picture than a monochromatic display. The primary requirements for a high quality color display include accurate convergence adjustment, properly chosen colors, absence of flicker, high resolution, and small color dot size. The set of displayable colors should be easily distinguishable by the user. The phosphor must be of high enough persistence to match the refresh rate with the required range of brightness. The grain of the color dots limits the obtainable resolution of a shadow mask CRT. The efficiency of light output in a color CRT is less than that of a monochromatic CRT because the shadow mask blocks a large portion of the beam energy.

The beam energies required to display the appropriate colors may be stored within the frame buffer. However, this limits the number of colors which may be displayed. Color mapping is a more flexible method in which values within the frame buffer represent addresses to a color map. Within the map, colors are defined by their red, blue, and green components. An 8-bit frame buffer can address a 256 color table. The intensity of each color can be defined more precisley using a color map, enabling a high degree of control over colors displayed. A color map which is stored in read/write memory offers much greater flexibility, in that colors may be defined by a program or user.

A beam penetration CRT uses one electron beam, and a multi-layered phophor screen. Each phosphor layer emits a different color when penetrated by the beam. The speed of the beam determines which layers will be bombarded. A low speed beam will cause only one layer to phosphoresce, while a faster beam will penetrate more layers. This method of color display is shown in Diagram 2.12.

Direct View Storage Tubes

A direct view storage tube, (DVST), differs from a refresh CRT in that displays are stored directly on the screen instead of within a memory. A DVST screen is coated with a highly persistent phosphor, which will hold an image up to one hour after it is written. The configuration of a DVST resembles that of a refresh CRT with the addition of a flood gun, a control grid, and a storage grid, as shown in Diagram 2.13.

The storage grid is a fine-mesh wire grid coated with dielectric, and mounted just behind the screen. The control grid, another wire mesh, is located just behind the screen. The elctron gun emits a relatively high speed stream of electrons, which strike the viewing storage grid at those screen locations which are to be lighted. At those points, the electron beam imparts a pattern of positive charge through the dielectric as

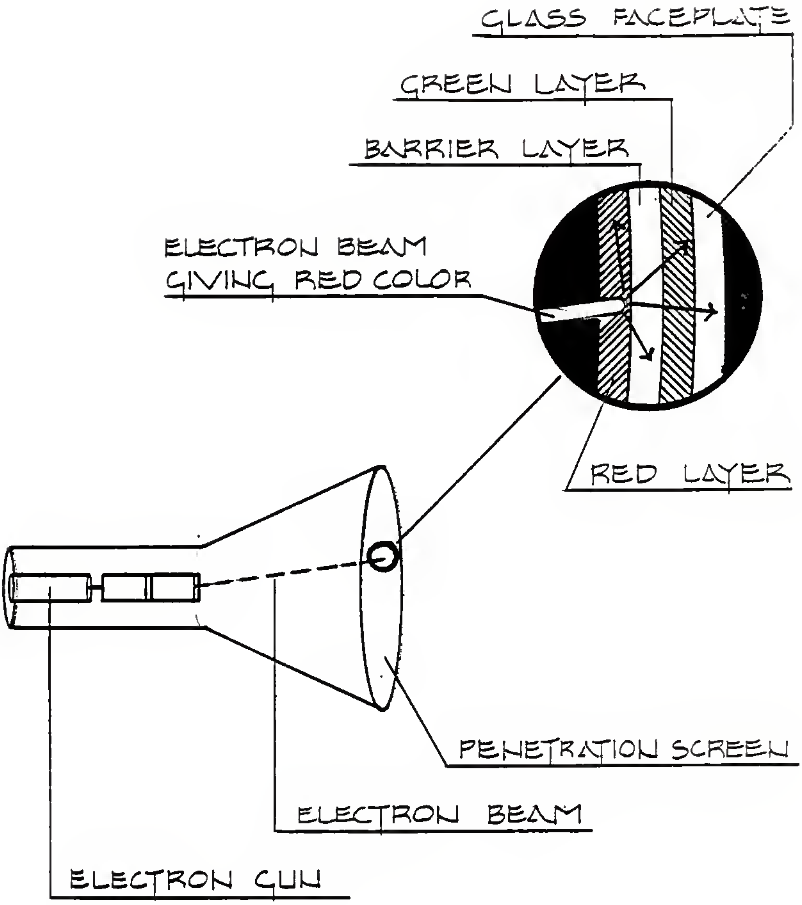


Diagram 2.12

Elements Of A Beam Penetration Color CRT

Adapted From Sharp (1977:39)

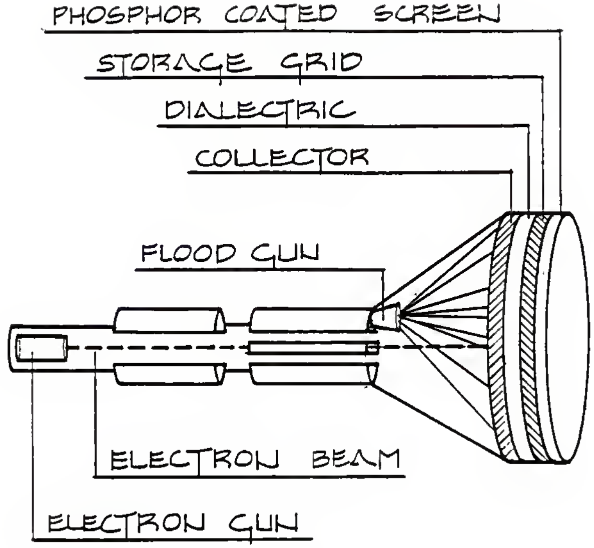


Diagram 2.13

Elements Of A Direct View Storage Tube

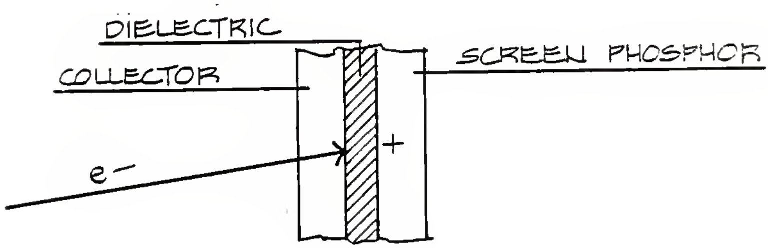


Diagram 2.14

Beam Penetration For A Direct View Storage Tube shown in Diagram 2.14. A flood gun which is situated in front of the deflectors, supplies a continuous and uniform flood of low energy electrons to the collector, which serves to smooth out the flow. This provides a relatively dim background glow to the entire face of the screen. The low energy electrons are attracted to those locations on the storage grid which hold a positive charge. They are accelerated at those points to pass through the grid and strike the phosphor. In this manner, the pattern of positive charge written by the electron beam, is transferred to the screen.

Refresh Vs. Storage Tube Display

Although refresh CRTs are superior to DVSTs in most ways, historically, DVSTs have been more popular due to their lesser cost. However, refresh CRTs are becoming competitive in cost, especially when long term cost is considered. A storage tube must typically be replaced once every three to four years. A refresh CRT usually lasts at least until a computer is replaced with a new model. The one major advantage offered by storage tubes is the high resolution of the display.

A refreshed image is stored within a memory, and may be altered by changing the contents of that memory. Therefore, the image may be duplicated as many times as desired. However, if a DVST image is to be duplicated, it must be scanned on the screen by an interrogation beam each time a copy is produced. Each interrogation further degrades the screen image until the picture becomes blurred. This limits the number of hard copies which may be produced from the DVST.

The ability to alter a display is vital to most applications. Interactive computing often relies upon rapid screen modification to be effective. This is not a problem with refreshed displays, because each pixel of the display is stored within a memory, and may be altered individually. Portions of the screen may be easily edited by changing that portion of memory which holds it's display information. However, unless equipped with a memory, the display of a DVST is stored only within the screen phosphor. In order to alter the screen even slightly, the entire screen must be erased and rewritten. The entire screen must be flooded with a positive voltage which lasts at least one second, and causes an unpleasant flash to the viewer. This difficulty in erasing and editing the screen is the most limiting drawback for the DVST. In some cases, the problem is dealt with at the programming level. To help alleviate the problem, some DVSTs are capable of displaying in a 'write through' mode. In this case the DVST operates like a vector refresh system, continuously writing each vector on the screen, but with insufficient energy to store them in the phosphor. As the image becomes more complex, it may begin to flicker.

The speed of display is important for two major reasons. A refreshed display must be transmited between a memory and a monitor either point by point in the case of raster displays, or a line segment at a time for vector displays. For a given refresh rate, the longer it takes for information to be transmitted, the less data may be displayed. The speed at which the display responds to actions by the user is also important for interactive applications. Raster systems usually display information about ten times slower than DVSTs. The speed of display may be increased by the addition of a processor which performs display functions that would otherwise be handled by the CPU.

The brightness of a refresh display is sufficient to be viewed in normal room lighting, and may be varied over a wide range. The phosphors currently in use on storage tubes produce a low level of brightness which cannot be adjusted by the user. Due to the relatively low accelerating potential applied to the electrons, the DVST display has poor contrast. As small amounts of charge accumulate on the control grid, background glow increases, and the picture degrades. Advantages offered by each type of CRT are summarized in Table 2.1.

REFRESH CRT

- becoming cost competitive with direct view storage tubes (DVSTs) especially when replacement costs are considered.
- has greater life expectancy than
- screen may be copied as many times as desired without degrading display
- portions of screen may be altered without erasing and rewriting entire screen
- brighter display - may be used in normal room lighting
- wider range of brightness - may be controlled by user
- displays both color and black & white
- usually displays raster graphics - sometimes vector graphics

RASTER REFRESH CRT

- displays both color and b&w
- slightly less expensive than a strokewriter

HIGH RESOLUTION GRAPHICS | LOW RESOLUTION GRAPHICS

VECTOR REFRESH CRT

- also called a strokewriter
- displays is monochromatic usually - color is difficult to implement
- lines appear smoother than those displayed on a raster screen
- flicker sometimes a problem for complex drawings
- vector graphics more common for DVST

STORAGE CRT

- historically more economical than refresh CRTs
- picture is degraded each time copied
- more difficult for a programmer to fafilitate screen editing
- display rate 10X faster than that of refresh CRT
- brightness fixed - no shading possible with currently available phosphors
- almost always displays vector graphics
- display requires hooding or low lighted environment for prolonged usage

Table 2.1

Storage Vs. Refresh CRTs

Summary Of Selection Considerations

Monitors

Type of CRT:

- Raster refresh CRT
  - Monochromatic
  - Color
- Vector refresh CRT
  - Monochromatic
  - Color
- Direct view storage tube

Phosphor or display quality

- Persistence of the phosphor
- Brightness
- Refresh rate required
  - Adjustable?

Color for shadow mask CRTs

- Number of displayable colors
- Number of simultaneously displayable colors
- Color map
- User definable colors
- Color dot grain
- Convergence adjustment

Display area

Number of displayable character blocks per screen

- Number of lines
- Number of characters per line

Number of dots per block

Screen resolution

Pixels per screen

Rows

Columns

Pixels per inch

High/low resolution graphics switch?

Displayable character set

Displayable character sizes

Deflectors - electrostatic vs. electromagnetic

2.1.2.2 Keyboards

The computer keyboard is an input device which accepts user input through a set of keys, similiar to those of a typewriter. Most keyboards have additional keys for control and special functions. Each key represents a symbol, which communicates information to the system when depressed. Symbols entered by the operator are interpreted and stored within the computer according to a code, which is referred to as the output code. Equipment and software must use the same output code if they are to be compatible. The most commonly used standard output code is the American Standard Code For Information Interchange (ASCII). The Extended Binary Coded Decimal Infomation Code (EBCDIC), is another popular standard. The output code may be transmitted from the keyboard using either a parallel or a serial interface. Not all keyboards use a standard interface. Since the computer is usually purchased with the keyboard as a unit, use of a standard interface is not critical.

Standard keyboards generate the output code, or character set which is available on most typewriter keyboards. This usually ranges between 64 and 96 characters. Optional characters may include foreign language, line drawing, mathematical, or graphic symbols. Some keyboards generate only upper case letters. The capability to generate both upper and lower case letters is essential for most word processing applications. Some systems transmit both upper and lower case letters to the printer, but only lower case letters to the monitor. This arrangement can be confusing to the operator. Some keyboards generate non-printable characters such as back space or cursor control characters.

There are two ways in which a display unit can communicate with a computer. In full-duplex mode, a key depressed on the keyboard will cause an output code to be transmitted to the CPU, in the form of a unique series of impulses. The CPU then determines which code was transmitted, and echoes that character back to the display. In half-duplex mode, or auto-echo, the keyboard transmits characters to both the screen and the computer simultaneously. Most computers are used in full-duplex mode to insure that characters are transmitted correctly. Half-duplex mode is often used if data is to be transmitted a great distance, as full-duplex mode would cause too much delay. Some displays have a switch which allows operation in either full- or half-duplex mode.

The data rate, or baud rate, is the number of bits which can be transmitted per second. The baud rate divided by ten is usually the number of characters which can be displayed per second. For example; most terminals which operate at 9600 baud, transmit 960 characters per second (cps). Keyboards transmit data at rate much faster than most operators can type, and therefore is not a critical selection consideration.

Keyboard Features

The cursor is a symbol displayed on the screen, which indicates the position where data will next be entered. A terminal which has cursor control keys allows the operator to easily position the cursor on the screen. This is a tremendous aid for editing purposes as well as for graphic input. Cursor movement may also be controlled by other input devices such as digitizers and track balls.

Many keyboards have a numeric cluster, which facilitates rapid entry of numeric data. The cluster is a set of numeric keys arranged like those of an adding machine, and set apart from other keys. Since periods, (decimal points), and commas are commonly a part of numeric data, their presence in a numeric cluster can further speed data entry. A carriage return usually signals the end of a numeric data entry, and should be located within easy reach of the cluster. In some cases, numeric cluster keys are designed to do double duty as cursor movement keys. This shared key arrangement can be tremendously inconveniant for some applications.

Each keyboard has a unique tactile feel and audio response. These factors become important for data entry operations which will occur for several hours at a time. Touch switch keyboards resemble a plastic sheet with keys printed on the surface. The appropriate signal enters the system when each key is touched. The use of such a keyboard requires that the operator hover his hands above the keyboard without resting them, which is very tiring for large amounts of data entry. Although the 'feel' of a keyboard is a matter of personal preference, many operators prefer keys which are slightly dished, and curved toward the user. Some computers have a speaker which emits a beep each time a key is depressed. The audio response provides the user a positive indication when each signal is entered. In some cases, this added confidence enables faster data entry. However, many users find the beep to be quite irritating.

Users which tend to press more than one key at a time, can usually enter data more rapidly on a keyboard which features 'rollover'. If one key is depressed, and then a second before the first is released, a keyboard with rollover will enter both signals. Keyboard arrangement also has a great impact upon speed of data entry. Although the standard QWERTY keyboard layout does not allow the fastest operator speeds, it is the only arrangement familiar to most everyone. The most convenient keyboard layouts group special keys in a separate keypad where they won't interfere with the basic alphanumeric keyboard.

Keyboard Editing Controls

Intuitive control keys are keys marked by symbols which clearly indicate their function. For example; a key marked with an upward pointing arrow, moves the cursor to the top of the screen. Tab sets enable the operator to define locations within rows and columns to which the cursor will skip when certain keys are depressed.

A character insert/delete control enables the operator to add and delete characters at the cursor position. When inserting, all characters to the right of the cursor shift one more position to the right. When deleting, they shift to the left to fill the empty space.

A line insert/delete control enables the operator to position the cursor at a particular row, and then insert or delete lines of data. When inserting a line, all lines beneath shift one row down to make room. Likewise, when deleting lines, all new lines shift one line up.

Split screen control divides the screen into more than one field. One field usually contains data which is protected, or can't be manipulated by the user. The others are active, and can be altered. This reduces the chances of accidentally deleting blocks of data. The ability to partition display memory, allows display of operator instructions or special forms. The user can enter new data without fear of deleting permanent data.

Partial transmit control enables the operator to define a block of data or a portion of the screen to be transmitted to the computer, without having to transmit the entire screen.

Scroll control shifts all the lines up one row when a new line is entered at the bottom of the screen. The top line is then shifted off the screen. This option is usually provided in both the forward and backward directions.

Wraparound control rapidly moves the cursor to opposite sides of the screen, either horizontally or vertically.

Keyboard Display Controls

Reverse video control reverses the intensity values of all pixels within designated areas.

Double-intensity control increases the brightness of designated characters or areas.

Non-display control enables the operator to enter information which will not be displayed. This is useful when classified information, such as passwords are being entered.

Blinking capability allows the operator to specify characters or areas to blink. This is achieved by alternately refreshing characters, and not refreshing others. Blinking capability can be used to draw a users attention to certain areas of the screen which indicate specific information, instructions or requests to the user.

Summary Of Selection Considerations

Keyboards

Output Code:

Character Set:

Number Of Characters:

Foreign Language Symbols:

Mathematical Notation:

Upper/lower Case Letters:

Line Drawing Symbols:

Graphic Symbols:

Function Keys:

Programmed:

Programmable:

Keyboard layout:

Baud rate:

Features:

Numeric cluster:

Half/full duplex mode:

Switcheable line speed:

Rollover:

Tactile/audio response:

Detacheable keyboard:

Keyboard editing controls:

Intuitive control keys:

Character insert/delete:

Tab sets:

- Line insert/delete:

  Split screen control:

  Partial transmit:

  Scroll:

  Wraparound:

Display controls

  Reverse video:

  Double intensity:

  Non-display:

  Blinking capability:

2.1.2.3 Image Input Devices

Image input devices generate a digital representation of graphic images which may be input into computer systems. Digitizers, mice, light pens, and image scanners are the types of image input devices most commonly interfaced with microcomputers.

Digitizers

A digitizer is an input device which converts the path of a shape which is followed by a sensor into digital form. The digitizer consists basically of two parts; a reading surface and the sensor. The reading surface is a flat bed upon which a paper is lain which contains the image to be input. In some cases, the reading surface is composed of glass, and the image is projected onto the glass. The sensor, usually in the form of a special pen, is then used to trace the lines of the image. The sensor interacts with electric signals beneath the reading surface to record the position of the sensor. The locational coordinates are then translated into a digital representation for computer processing.

Data input by a digitizer is usually sent to a display monitor, so that the image may be displayed during the input process. Most systems will allow the image to be stored on auxiliary storage media, and plotted or printed as needed.

Sensor types available for use with digitizers include reticle crosshairs embedded within a magnified glass ring, and pencil sensors. The magnified crosshairs enable higher accuracy, but are somewhat slower to operate. A sensor with an open circle target of .250 " in diameter enables movement of the sensor along a line thinner than a hair. Some sensors are specially designed for the reading of images projected onto a glass reading surface. An example of each sensor type is illustrated in Diagram 2.15. Input speed usually ranges between 18 to 300 symbols or 2 to 30 pairs of coordinates per second. Speed is not a critical selection consideration due to the comparitive slowness of most operators.

Functional software rountines can ease the operation of a digitizer as well as the sophistication of application software required to drive the device. In some cases, the rountines are made available to the user on a menu which is provided on the reading surface. Users may call routines which automatically digitize pre-defined symbols or those which generate certain commands. Typical routines provided for digitizers include the following:

linear and area calculation
output data formating
automatic reversal (generation of a mirror image of one side of either axis.)
determination of angles

Some digitizers provide work surfaces of 40 to 60 inches. The size of the work surface must be capable of accommodating the required drawing size to be input. A reading surface may be used to input drawings larger than itself by the use of software which

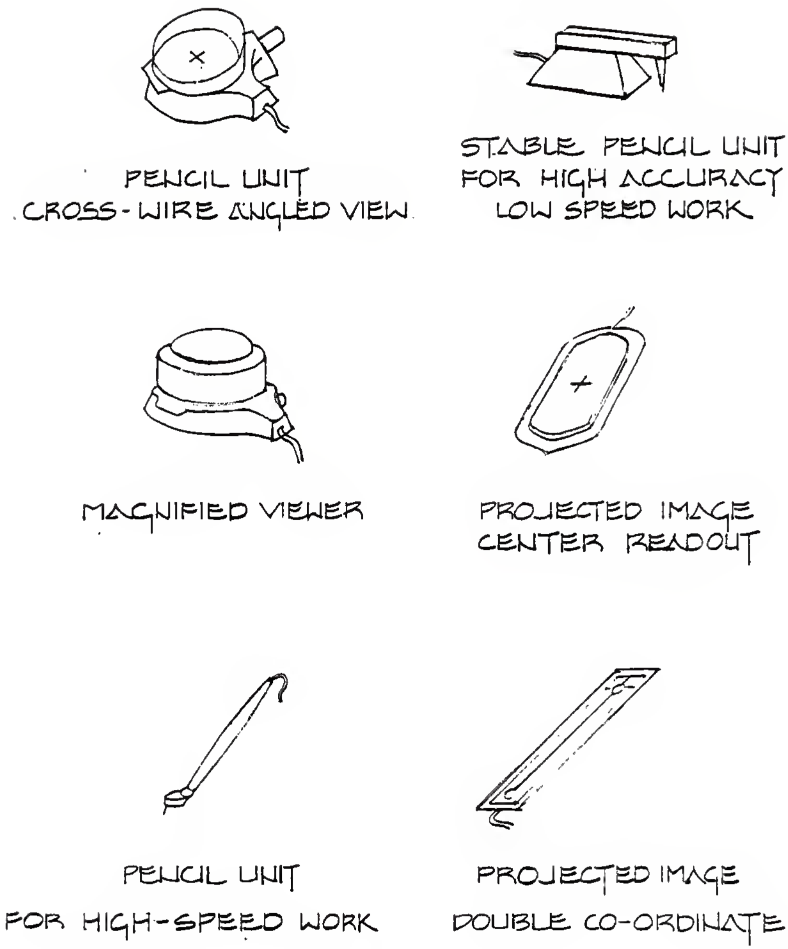


Diagram 2.15

Digitizer Reading Sensors

Adapted From Ralston And Reilly (1983:756) divides the drawing into more than one image, and connects them into a representation of one.

Digitizers are often used to input existing graphic images such as maps, site plans, or engineering drawings. Drawings may than be stored, edited, and output repeatedly as desired. One drawing may be used as a base plan by which to generate several drawings. The computer generation of precise drawings from the input of rough sketches is another common usage which can save the user a great deal of drafting time.

The input of existing original drawings often requires a relatively high degree of accuracy. The tracing of an existing image with a pencil type sensor incorporates the propensity for operator error. Software which contains computer smoothing routines to reduce the number of random errors tends to improve accuracy.

Most digitizers operate in a point mode. A point is input only when a button is pushed or when the digitizer touches the surface at a particular point. The smallness of the increment between points is limited by the size of the sensor. Some digitizers automatically enter points at preset grid intervals or at preset distances along a line. This facility, which must be software supported, provides an efficient means for the entry of curves. Some digitizers allow the user to set the increment size which usually ranges between .002 to .999 inches. Some digitizers operate according to both the metric and the english systems of measurement.

Summary Of Selection Considerations

Digitizers

Reading Surface Size

Type Of Sensor

Speed

Associated Functional Software Rountines

Light Pens

A light pen is a graphic input device used for marking a position on a monitor screen. As the pen is located close to the screen surface, the pen emits a signal. The signal is translated by the CRT control electronics into an x-y address which is sent to the computer. The light pen is used to select items displayed upon a menu, or to alter a stored image which is displayed upon the screen. Use of a light pen is not an efficient means by which to input an existing drawing.

Image Scanners

Image scanners optically scan all points of an imaginary grid superimposed upon an image to be input. The image is usually reproduced on a screen. The projected image can be microfilmed so that hard copy duplicates of the original image can be generated when needed. The input image must be translated into digital form for computer processing. Few image scanners are priced low enough to be practically interfaced with microcomputers at this time.

2.1.2.4 Hard Copy Output Devices

Hard copy output devices are those which produce a permanent copy of computer output. Two types are typically interfaced with microcomputers; printers and plotters. Printers are used primarily to print textual data such as numbers, letters, and special characters. Most printers, however, are capable of producing graphics by printing combinations of characters in patterns to form graphs and drawings. Plotters are designed primarily to plot graphic data such as lines, curves, and graphs. Plotters are capable of producing textual characters, but operate most efficiently as graphics output devices.

Printers

Printers may be categorized according to three sets of characteristics as follows:

Impact vs. Non-impact Printers

Impact devices print by impacting an inked ribbon against print media using a print head much as a typewriter. Non-impact printers print without impressing the print mechanism against the paper.

Fully-formed character vs. Dot-matrix Printers

Characters printed by fully-formed character printers are solid, much as the produced by the character fonts of a typewriter. Dot-matrix characters are formed by patterns of dots combined to represent text or graphics.

Character vs. Line Printers

Character printers produce one line of character at a time and line printers print a line at a time.

Based upon the available combinations of these characteristics printers may be identified according to one of seven categories:

fully-formed character/impact/character printer

fully-formed character/impact/line printer

fully-formed character/non-impact/line printer

dot-matrix/impact/character printer

dot-matrix/impact/line printer

dot-matrix/non-impact/character printer

dot-matrix/non-impact/line printer

Fully-formed Impact Character Printers

Formed character printers operate by firing individual character fonts against an inked ribbon to impress each character onto the print medium. Each character font consists of a solid base which is etched with a fully formed character. Character fonts are arranged radially around a hub which moves horizontally across each print line, and spins to align the appropriate character with each print position. Once properly positioned, a hammer stirkes to impress the character font agaist the paper.

Hubs which hold the character fonts are usually either a ball, a wheel, or a thimble. Ball type heads are spheres with characters embossed around the surface. The ball rotates and tilts to align the correct font with the paper. Wheel types, also referred to as daisywheels, and thimbles heads operate in a similiar manner. A daisywheel is a disk with arms arranged radially from the center. The end of each arm has an embossed character. Thimble print heads are similiar to daisywheels, however the print arms are turned upwards. The elements of each type of print head are illustrated in Diagram 2.16.

Formed-character printers are provided with a wide variety of features which can increase the capability and convenience of the machine. Spinning print heads are usually interchangeable enabling a variety of type styles, sizes, and in some cases, character reading fonts. Some daisywheel manufacturers offer cartridge and drop-in wheels which automatically position themselves. This simplifies the task of of changing wheels, and reduces the opportunity of print element damage.

Some printers have two print wheels which print on the same line simultaneously. Print speed is maximized on printers which can print both right-to-left and left-to-right (bidirectional printing) as well as those which feature a logic seeking carriage return. Printers with a logic seeking carriage return can recognize which margin is in closest proximity to the print head, to maximize carriage return time at the end of short lines.

The ability to specify fractional horizontal and vertical spacing of the print head enables graphic output. The print wheel may be positioned horizontally and vertically in small

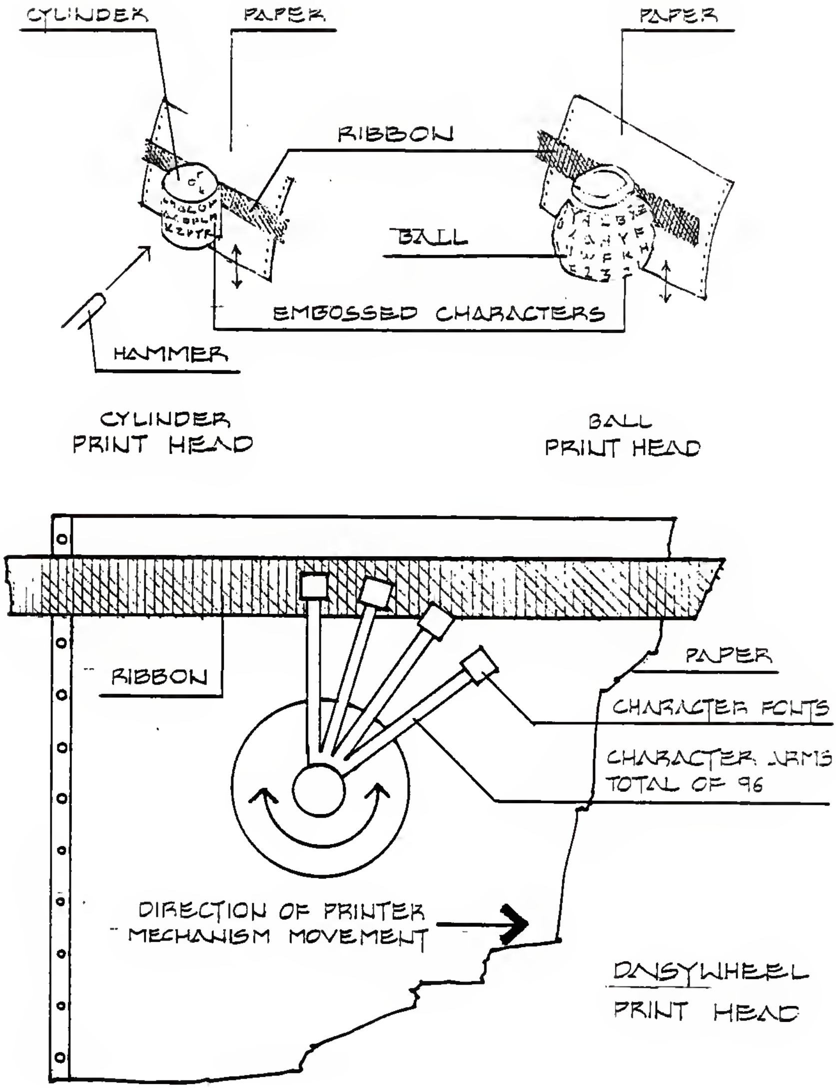


Diagram 2.16

Types Of Print Heads

increments to acheive the equivalent of x-y plotting. Most printers accommodate paper widths of 8 1/2 inches. Some allow widths of up to 16 inches.

Due to the high quality of print produced by formed-character printers, they are often referred to as letter-quality printers. Applications which require output with a professional appearance often require letter-quality printers. Formed-character impact printers can print approximately 50 characters per sec (cps), which is considerably slower than the print speed of most dot-matrix printers.

In some cases, standard typewriters are used as computer printers. The typewriters are equipped with an electronic interface that will accept signals from the computer, and cause the keys to type. Typewriters, however, tend to be more fragile than computer printers and breakdowns are more frequent.

Thermal transfer printers are a type of formed-character/impact/character printer which operate by transfering heated ink onto paper. Wax-imbedded ink on a ribbon is heated to a boiling point and forced onto the print medium. The transfered characters are raised so that they can be felt when touching the paper. The result is a very high quality output. However, over a period of time the print tends to erode.

Thermal transfer printers are one type of thermal printer which produce color graphics and near letter-quality text. Although the printers themselves are relatively low in cost (under $500), as well as the print medium, the cost of the ribbon is high in that it may be used only once.

Fully-formed Impact Line Printers

Line printers operate by the movement of a carrier or drum embossed with print characters to the proper print locations on paper. An entire line of characters are aligned with a line on the print medium. All embossed characters which are in the correct position are impressed against the page simultaneously. The steel belt or drum is rotated to align another set of fonts with that line until the entire line on the page has been printed. The page is then advanced, and the process is repeated.

The embossed characters are arranged on a carrier such as a chain, train, band, or drum. The greater the number of characters embossed on a chain or band, the fewer number of lines may be printed per minute. For this reason, many line printers print only the upper case 64 character ASCII set. The font carriers of many line printers may be changed easily which allows the user greater flexibility.

Line printers are capable of speeds ranging from several hundred to thousands of lines per minute. Typical speeds range from 200 to 1200 lines per minute. Some printers (line/page printers) can print several pages per minute, but the high cost of these printers usually prohibits usage with microcomputers.

Fully-Formed Non-impact Line Printers

Fully-formed non-impact line printers are exceedingly fast special purpose printers of which there are three types available; photographic, xerographic, and laser printers.

Laser printers operate by the direction of a computer controlled laser beam onto an electrically charged rotating drum or belt. Toner particles cling to charged sections, and are then transferred to paper to form a printed page. The print toner is usually fused by heat. Laser printers are capable of speeds ranging between 18,000 and 21,000 lines per minute. The least expensive laser printers range in price from $5,000 to $6,000. The price is expected to drop as some manufacturers develop laser printers for microcomputers.

Photographic printers operate by the optical projection of characters or images onto photosensitive paper or film. The exposed paper or film is developed, and the phototypeset copy is used to make press plates for printing. Projection of the character font is achieved by either a cathode-ray tube with a character generator stored in memory, or by character masks used to optically project selected characters.

Dot-matrix Impact Character Printer

A dot matrix printer forms each character with a defined grid of dots. The simplest of grids is 5 dots high by 7 dots wide. Character matrices are typically composed of 5 x 7, 7 x 7, 9 x 12, or 10 x 9, dots, as illustrated in Diagram 2.17. The number of rows in the character matrix is usually fixed. The number of rows and columns may sometimes be varied to print expanded, or compressed characters. In some cases, the user may define printable symbols. Special software is required to take advantage of this capability.

Each line on a page consists of a matrix of printable rows and columns. The number of rows in a line is equal to the number of rows in the character matrix. The number of columns in a line is equal to the number of columns in the character dot matrix multiplied by the number of printable characters in a line, as indicated in Diagram 2.18. Since all of the dots are small and closely spaced, the characters appear to be solid from a typical viewing distance. The higher the character matrix resolution, the greater the print quality. A 28 x 30 dot matrix produces near letter-quality appearance.

The print pins of a dot-matrix impact character printer are arranged in a single or double vertical column on a print head. The print head moves horizontally across each line of print. As the print head aligns with each column defined within the line, the appropriate pins are fired.

Patterns of dots which comprise each character are stored permanently within main memory. Most print heads are moved bi-directionally to achieve greater speeds. Some printers gain speed through the use of two print heads on the same carriage. Dot-matrix impact character printers operate at approximately 180 characters per second (cps).

Dot-matrix Impact Line Printer

Dot-matrix impact line printers print a line at a time using a horizontal print comb which is 132 print spaces wide. The print comb consists of 132 fingerlike hammers, each with a raised

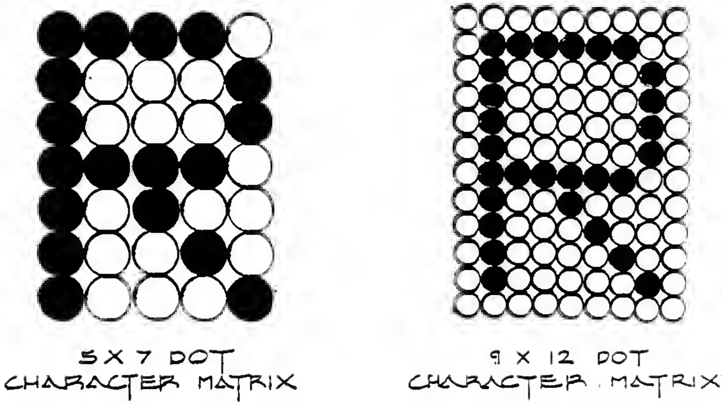


Diagram 2.17

Character Matrices Generated By Dot-Matrix Printers

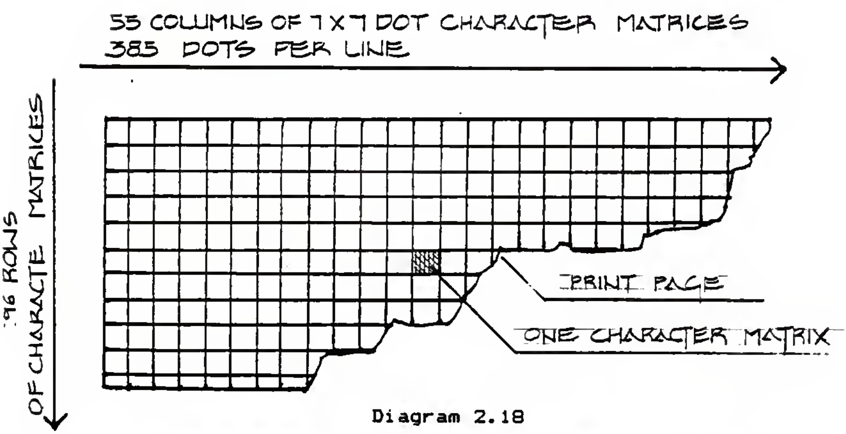


Diagram 2.18

Arrangement Of Character Matrices On A Page dot that corresponds to a print position. The entire comb moves back and forth horizontally to print any of the overlapping 5 dots which constitute a horizontal row of a character matrix. The paper advances vertically one dot position, and the next row of dots are printed. Subsequent rows are printed for all 132 character positions until all 7 vertical dots have been printed for a 5 x 7 dot character matrix and a 132 character line. Dot-matrix impact line printers print at a speed of approximately 300 lines per minute.

Dot-matrix Non-impact Character Printers

THe four types of dot-matrix non-impact character printers currently available include thermal, electrosensitive, electrostatic, and ink jet printers.

Thermal

Thermal printers are dot matrix printers which create images by passing heated print heads over a special heat-sensitive paper. The paper is normally white, but turns a darker color (usually blue) when heated. The printer electrically heats a dot matrix in the desired character pattern. Thermal print heads move horizontally across the paper printing each column of the dot matrix serially. The print pins create dots by burning when pressed against the paper. A thermal print head is illustrated in Diagram 2.20. Thermal print eventually fades when exposed to sunlight or heat.

Electro-sensitive Printers

Electro-sensitive printers operate by the passage of current through the tip of a stylus or nib which arcs to a specially coated paper. The paper is coated with a substance such as aluminum which is sensitive to voltage changes. When a voltage is applied the coating vaporizes, leaving a black mark. Aluminum coated paper is not affected by heat, light, or water. Electro-sensitive printers are usually used to record a monitor display.

Electro-static Printers

Electro-static printers operate by the application of voltage to an array of needles which are used to form dot-matrix characters. The energized needles form charged spots on a dialectric paper as paper unwinds from a roll and passes the needles. When the paper is passed through a toner, the charged spots attract toner particles to form dot-matrix characters. This process is illustrated in Diagram 2.19.

Ink Jet Printers

Ink jet printing devices form dot matrix characters by spraying ink onto paper. Three technologies are employed to spray the ink; continuous jet, drop-on-command, and impulse jet.

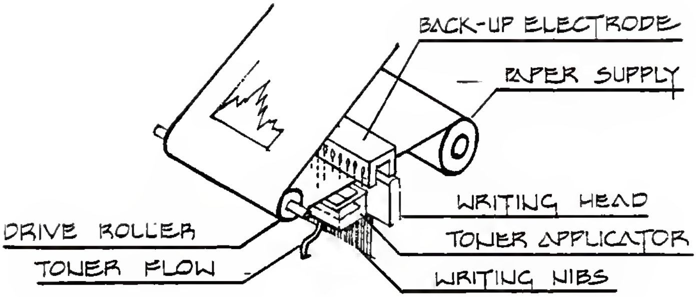


Diagram 2.19

Electrostatic Printing Process

Adapted From Hohenstein (1983:22-22)

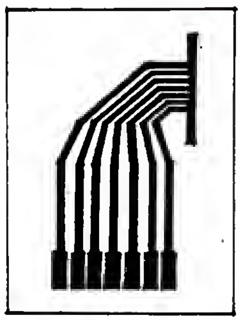


Diagram 2.20

Thermal Print Head

Adapted From Hohenstein (1983:22-20)

Continuous Jet Ink Jet Printers

The basic components of a continous jet ink jet printer include a nozzle, a control electrode, and deflection electrodes. The configuration of these components is illustrated in Diagram 2.21. Ink from a pressurized supply is forced through a nozzle into a tube. As the ink stream breaks into particles within this tube, an electrical charge is selectively imparted to individual particles. Horizontal and verticle deflection electrodes then aim the particles towards the correct position on the print medium by controlled attraction and repulsion. Ink is directed into a reservoir for reuse when aligned with paper positions not to be printed. Some systems cannot use the discarded ink. The paper position aligned with the printing device is controlled either by wrapping the paper around a drum which spins (a drum printer) or by moving the paper past a fixed array of ink jets.

Continuous jet printers produce near letter quality print, and are capable of speeds ranging between 5 and 50 kilohertz (one thousand cycles per second).

Drop-On-Command Ink Jet Printers

A drop-on-command or impulse ink jet printer consists essentially of a pressurized chamber filled with ink, exit orifices, an ink inlet, and a pressure pulsar, as indicated in Diagram 2.22. The pulsar, which is mounted to the back of the chamber, produces a pulse each time a drop of ink is to be emitted. A slight negative pressure in the chamber prevents the

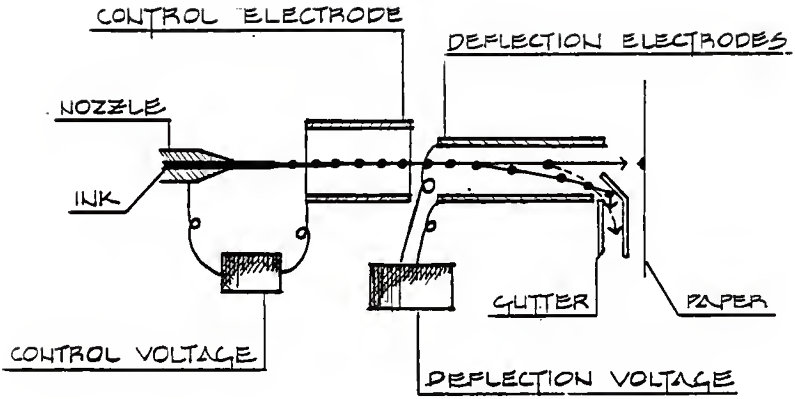


Diagram 2.21

Elements Of A Continuous-jet Ink Jet Printer

Adapted From Duffield (1982:188)

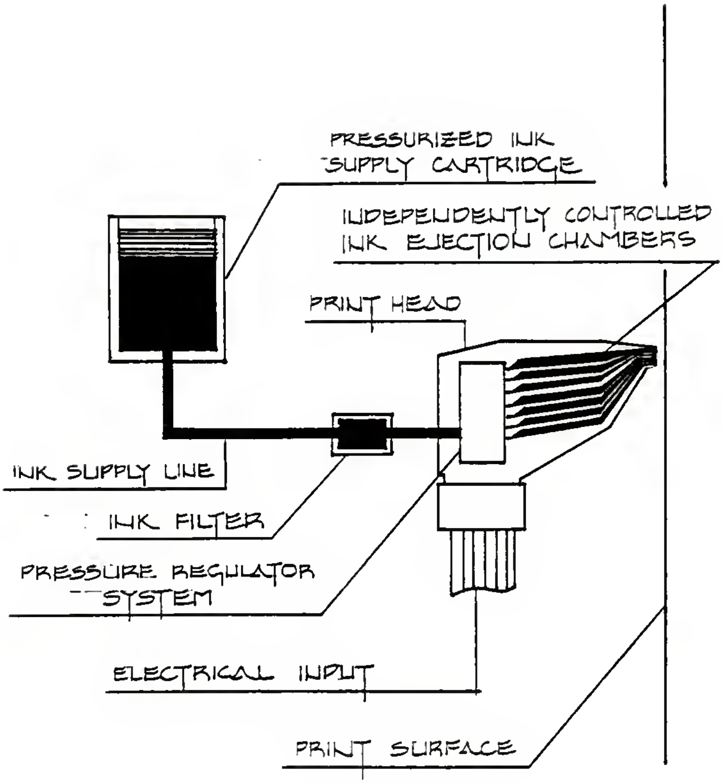


Diagram 2.22

Elements Of A Drop-On-Command Ink Jet Printer

Adapted From Hohenstein (1983:22-23)

ink from flowing. Each drop which is emitted is replenished through the ink inlet. The exit orifices are often arranged into a one column verticle matrix. The matrix is stepped horizontally to print each column of a character matrix. Verticle position on the page is controlled by drum and shuttle mechanisms.

The ink refilling process required for drop-on-command ink jet printers limits potential printing speed which typically ranges from 1 to 2 megahertz (one million cycles per second). Impulse printers tend to be more simpler in design, lower in cost, and more sensitive to mechanical shock. The exit orifice of impulse printers is also larger, which reduces blockages and therefore maintenance.

Intermittent Ink Jet Printers

Intermittent ink jet printers operate by creating an electrical potential between the ink and an electrode which is located at the orifice. Ink drops are pulled through the orifice and guided by the electrodes to the appropriate paper position.

Ink Jet Printers - General

Some ink jet printers emit an array of transparent primary and secondary ink colors. The transparency of the ink enables primary and secondary colors to be overlayed on paper to form hundreds of other colors. Colors displayed on a video screen may be reproduced by an ink jet printer using a process called dithering. Each pixel on a CRT is represented by a 2 x 2 matrix on the hard copy. Five color intensities may be generated for each color by varying the number of dots printed for each pixel between one and four.

Ink clogging has been a problem for ink jet printers. The problem has been remedied by some manufacturers by the provision of inexpensive ink cartridges.

Selection Considerations

Printers

The most critical selection considerations for printers include the following:

legibility or textual/graphic print quality

speed

output character

reliability

simplicity of operation

special features

cost

Legibility

Output devices which produce the highest quality of graphic output include photographic and xerographic copiers, ink jet and laser printers. These printers are best suited to the production of presentation quality drawings. Photographic color copies produce graphics of superb quality on both paper and transparent film. The cost of polaroid material required, however, is approximately $6.00 per copy. The color saturation and accuracy produced by color xerox copiers are excellent.

Fully-formed character impact printers are most appropriate for the production of high quality textual output and are most commonly used for the generation of correspondence-quality documents. Some high-resolution dot matrix impact printers produce near letter-quality print. In general, the print quality generated by impact printers decreases as printing speed increases. Textual output generated by thermal, electrosensitive and electrostatic printers is relatively indistinct and fuzzy. Contrast between characters and the print medium is low.

The major determinants of print quality include the following:

dot resolution

overstrike/doublestrike capability

contrast

distinctness

pitch

uniformity

Dot resolution provides a measure of print quality for dot matrix printers i.e. the higher the resolution, the greater the print quality. The most simple matrix available consists of 5 x 7 rows by columns of dots per character block. Characters of a 5 x 7 block are clearly distinguishable, but print quality is low. Standard character block matrices consist of 5 x 7, 9 x 7, 7 x 8, 11 x 7, 7 x 7, 9 x 9, and 7 x 9 dot blocks. The print quality enabled by 18 x 18 dot blocks approaches that of fully-formed character impact printers. Higher density matrices also enable the generation of lower case letters and special symbols.

Overstrike capability enable printers to overlap the vertical columns of each character matrix as they are printed to achieve a more fully-formed appearance. A Double-strike or multipass feature allows each print position to be printed more than once.[7] The use of this feature creates a darker print which enable bold-faced headings. Some printers can print in either a single- or double-strike mode enabling the generation of correspondence-quality print when desired.

Contrast is dependent upon the blackness of the ink used. The higher the contrast, the greater the readability. Print distinctness is achieved by properly distributed hammer energies. Print which does not appear sharp and clear is often a result of hammers which are not striking all areas of a character font with equal energy which causes uneven character shading, ink spreads, and smears. The distinctness of individual characters should be consistent throughout a page of text. Contrast and distincness are best measured by a visual inspection of printed output.

Pitch is a measure of consistent and proportional vertical and horizontal alignment. Pitch has a great bearing upon print appearance and is usually best estimated by visual inspection. Text which is spaced horizontally proportionately has a more professional appearance. A proportionality spacing feature provides spaces between characters proportional to the width of the characters. In addition to the improved appearance, proportionality spacing also provides room for more characters which effects a paper savings. Characters which align accurately and consistently along the cap, waist, base, and descender lines, as shown in Diagram 2.23 will also have a more professional appearance.

PITCH: the measurement of horizontal character placement, usually measured in 1/72 inch increments. Users who insert a 10-pitch wheel for certain applications for example, want their characters to remain consistently at that pitch throughout the entire document. This is one of the most noticeable textual deficiencies when not carefully controlled.

POINT: the vertical measurement of a character from the capital/ ascender line to the lowest descender line. One point is equal to 0.011 inches. When point control is missing, horizontal lines of print begin o roll awkwardly up and down like a roller coaster across the page. Few print-quality factors can contribute as quickly to negative perceptions of text, and a casual observer can spot even a slight deviance.

CAPITAL AND ASCENDER LINE: the upper vertical point of a printed character that extends above the "waistline". The cap and ascender line for capitals should not extend above the top of lower-case letters with above waist-line stems, such as the lower-case "b".

WAISTLINE: usually 60% of the distance fromn the baseline to the cap on the ascender line, represented by the upper vertical points of the round parts of a lower-case "b", "p", "c", and "e".

BASELINE: the lower vertical point of a character that does not extend to the descender line. The upper-case characters "A", "B", and "C" should all sit squarely on the baseline.

DESCENDER LINE: the lower vertical point for all characters that extend beneath the baseline. The lower-case letters "p", "q", and "y" all extend below the baseline to the descender line.

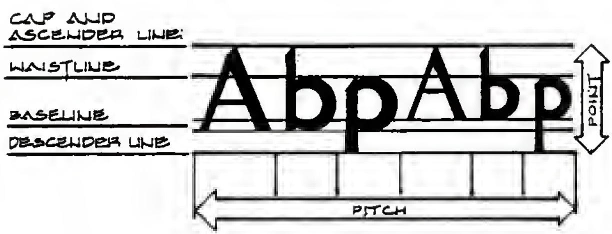


Diagram 2.23

Relative Character Placement Factors Affecting Print Quality

Adapted From Ross (1980:240)

Speed

Printers which offer the greatest speeds for the print of graphic output include ink-jet, laser, photographic color copiers, and xerographic copiers. Plotters are typically slower. Laser printers are the fastest printers available at this time. Print speeds available for dot matrix printers are greater than those for fully-formed character printers. Dot matrix printers are best suited to those printers which require high speed and low cost. Typical print speeds of printers currently available are presented in Table 2.2.

Output Character

The character of hard copy output is dependent upon such features as character set, size, color, and paper type. Hard copy output character must match that required by proposed applications. Some applications require a high degree of flexibility, in which case the printer must offer versatility as well.

Character Set

Most printers are capable of printing the 96 character ASCII set. Many dot matrix printers will print up to 125, 128, 132, 152, or 158 characters. Most of the characters are pre-defined, however, some dot matrix printers provide user-definable characters, and some fully-formed character printers provide user-constructable characters. Pre-defined or constructed characters may include foreign language symbols, mathematical notation, and a variety of type styles. Special characters and graphics symbols for dot matrix printers usually require a at least a 63 (7 x 9) dot character matrix. The number of rows and columns printed by a dot matrix printer may usually be varied to accommodate a variety of sizes, extended and compressed text. Many printers are capable of printing underlined, subscripted, superscripted, boldfaced and italicized text. Such features enable the creation of headings, labels, title blocks, brochures, etc. Some dot matrix printers (usually referred to as graphics printers) are capable of printing high resolution images from the screen.

Most daisy-wheel printers are equipped with a variety of print wheels to provide a wide variety of special characters and styles. Some formed-character printers offer extended character sets with up to 400 characters. Some manufacturers will custom design character fonts to accommodate the application of a particular user. Potential buyers should note that appropriate software is required to support each of these capabilities.

Number Of Printable Columns

The maximum number of characters which may be printed on a line usually ranges from 40 to 198 for most printers. The standard print widths include 32, 40, 80, 96, 132, and 196 columns.

Most applications require a line width of 8 inches or 80 columns. Graphics applications are usually implemented most conveniently on wider paper. An 80 column width will accommodate a standard 8 1/2" x 11" sheet size, and is therefore required for most word processing applications. Columns and charts are often printed most conveniently using a 132 column line width. Some printers allow the user to select from a range of line widths.

Number Of Printable Lines

The number of lines which may be printed per vertical inch usually include 8 and 10, to accommodate standard elite and pica typing styles. Some printers allow other options to enable compressed and extended text, as well as graphics and a variety of styles.

Print Media

The types of media available for printers include continuos paper, such as fanfolded and rolled paper, as well as single sheets. Multiple sheets separated by carbon paper sometimes provided on impact printers enable multiple copies to be printed at once. The multiple print paper is expensive, messy, time consuming to decollate, and the copies are usually of poor quality. The use of xerographic methods to reproduce single copies produced by a printer usually renders prints of better quality at less cost. Ink jet, electrostatic, and thermal printers are not capable of producing multiple copies. Printers which print on transparencies can be used on overhead projectors to generate graphic or textual output which can be adhered to reproducable drawings.

Most printers move paper through the printer using either a friction feed, a pin platen, or a pin tractor feed. Friction feed devices hold paper between a platen and rollers by friction, much as an ordinary typewriter. Paper is advanced as the platen rotates. Friction feed devices can be used to feed either single sheets or rolls of paper and are typically used on slow speed printers.

Pin platen feed devices are used to advance continuous forms which have perforations along the outer edges. Pin platen feeds are less costly than pin tractor feeds and also less flexible in that pins are mounted directly on the platen and cannot be adjusted to accommodate more than one size of form. Pin platen feed devices may be used to feed either rolls or fan-folded paper.

Pin and tractor feeds are used to advance paper which has perforated tear-off margins. Wheels situated on each side of the platen have spokes or pins which can be aligned with the perforations. As the wheel turns with the platen, the paper is advanced. Pin and tractor devices are usually used to feed fan-folded paper, either single- or multiple-ply.

A rear mounted tractor enables printing close to the paper tear off point which enables a paper savings. Front mounted tractors are more common, and easy to adapt to an installed printer.

Reliability

Due to the electro-mechanical nature of printers, reliability is a critical factor in printer selection. Printers tend to break down more frequently than other computer system components as they are subject to vibration and wear. When break-downs occur, the problem is most commonly mechanical in nature. When preparing to purchase a printer, buyers should ensure that the machine is well engineered and that service is readily available. Some of the points which may be checked for an inspection of printers in operation include the following:

- well constructed paper guides which do not appear as though they may break easily,
- rollers which keep the paper straight
- ribbon advance mechanisms which move smoothly
- durable covers

Ease Of Operation

Optional features provided on some printers such as drop-in print cartridges, self-test functions, self-diagnostics and acoustical buffering can tremendously effect ease of operation. Some daisy-wheel manufacturers offer drop-in cartridges which automatically position themselves. This feature simplifies the task of changing wheels and reduces the opportunity for damage to the print element.

Printers which can perform self-diagnostics can increase the speed of repairs and mechanical adjustments. Some printers provide diagnostic displays or alarms which inform the operator of disorders such as paper jams, ribbon faults, paper-out etc. Printers equipped with a paper-out alarm and an automatic paper-stop diminish the chance of losing hard copy during unattended print operations. Diagnostics for disorders which cannot be corrected by the operator should provide the technician an accurate account of the problem. Printers which perform a self-test function prior to operation, enable the user to detect poential problems before print operations.

Printers which provide acoustical buffering may be preferable if print operations will be performed in an environment in which loud noise would be distracting. Impact printers produce the greatest amount of noise. The noise level of printers can be reduced by the use of acoustical padding or foam which is placed throughout the print cabinet. Table top or pedestal mounted printers do not offer any acoustical buffering.

Cost

Printers are often the most expensive component of a microcomputer system accounting for 15 to 20% of the total system cost. The retail cost of printer supplies ranges from 5 to 8 cents per copy, often exceeding the purchase price of the printer. (Hope, 1982).

Buffering

Throughout printing operations, the computer is usually idle 95% of the time due to the discrepancy between the speed of data transmittal and print speed. Data is not usually communicated directly from the computer to the printer as data is transmitted from the computer at higher speeds than the printer can accommodate. The computer baud rate is humdreds of times faster than the maximum print speed. For this reason, data is usually first transmitted to a buffer for storage until the buffer is full. Data is then transmitted to the print mechanism, one character at a time, at a speed which the printer can accommodate, referred to as the print speed. The speed of data transmittal can often be set for both the computer and the buffer.

Printers with buffers that can accommodate only one or two lines of data at a time will 'tie up' the computer throughout the printing process. Those with buffer capacities upwards of 8K can be used to free the computer for other tasks during print operations. This can affect a great time savings for the user. The process can be accomplished either by a buffer transfer or by direct memory access (DMA).

Most microcomputer systems require that all of the processing power of the CPU be devoted to the appropriate output device during print or plot operations. Systems with either buffer transfer or direct memory access capability can enable the CPU to operate upon other data during print or plot operations. Systems with a buffer transfer will request the CPU to halt all other processing while a peripheral buffer is loaded with print or plot instructions. A buffer transfer also loads required main memory contents into the peripheral buffer. The data transfer is performed by the CPU instead of the peripheral MPU. Once the data transfer is complete, both processors may operate upon their independent tasks. DMA operates in a similiar manner with the exception that the peripheral processor in a DMA system performs the data transfer while the CPU is halted.

Systems capable of DMA or buffer transfer must have a buffer memory within the peripherals which make use of these capabilities. DMA capability must be provided within both the computer and the peripheral. Buffer transfer capability is enabled within the programming language implemented upon a particular system. Very few printers and plotters provide DMA.

General Selection Consideratons

Printers

Dot matrix impact printers are the most popular printers on the market owing to the speed, low cost, and flexibility enabled by these machines. Legibility and character appearance falls short of that produced by typewriters or fully-formed character printers. However, correspondance-quality dot matrix printers produce print quality which approaches that generated by fully-formed character printers. Dot matrix printers are best suited to applications requiring high speed, low initial cost, or flexibility where the highest possible print quality can be sacrificed.

Fully-formed character printers produce excellent print quality, low speed, and cumbersome graphics capabilities. They are best suited to applications which require textual output with a professional appearance, such as required for correspondence and contract documents.

Thermal printers are most popular for portable systems. The primary advantage offered by thermal and electrostatic printers is speed, which is enabled by the non-impact nature of operation. The paper required by these special methods is more expensive than that required by impact printers and ink jet printers. Characters are typically indistinct and fuzzy, and the contrast provided is low. Ink jet printers are popular for applications which require printed color graphics.

Photographic color video copiers produce superb print quality both on paper and transparent film. Xerographic copiers produce good print quality as well, however, the image size is limited to approximately 6" and the initial cost is quite high.

Laser printers exceed the capability of other types of printers on the market in terms of speed and print quality. The cost of laser printers is just now beginning to fall within a range practical for usage with microcomputer systems.

Summary Of Selection Considerations

Printers

Type

Legibility

- Dot resolution
- Overstrike/double-strike
- Contrast
- Distinctness
- Horizontal pitch/proportionality spacing
- Vertical pitch
- Uniformity

Speed

Output Character

- Number Of Printable Characters
- Foreign Characters
- Graphic Characters
- Print Styles
- User Definable/Constructable Characters
- Mathematical Notation
- Sizes
- Characters Per Line
- Lines Per Vertical Inch
- Colors
- Paper Types
- Paper Feeds
- Multiple Copies

Reliability

Ease Of Operation

Cost

Direct Memory Access (DMA)

Buffer Transfer

Digital Plotters

A digital plotter is a hard copy output device which produces pictorial images on paper from computer generated information. Plotters operate by moving a plotting tool or a beam of light in two dimensions over a plotting surface. Plotters are commonly used to generate high resolution drawings for architectural, scientific, and engineering applications such as pert charts, schematic diagrams, plan, profile, isometric, and perspective drawings. The use of plotters to generate integrated circuit diagrams and semiconductor fabrication is common throughout the semiconductor industry. Plotters most commonly produce plots on paper or microfilm. The plotting tools of some plotters are equipped with rubylith cutting heads which are used to cut patterns in base substances such as cloth or metal during manufacturing processes.

Plot data is provided either by a digital computer, or an image input device. Plotters may operate either on-line or off-line. Those which operate off-line utilize a plotter controller to coordinate the actions of the plotter and an input device. Most plotters which may be interfaced with microcomputers can operate only in an on-line mode. The types of plotters most commonly interfaced to microcomputers at this time include flatbed and drum plotters. Lasergraphic and microfilm plotters are usually controlled by mainframe or minicomputers.

Drum Plotters

A drum plotter has a cylinder upon which a plotting medium such as paper, is mounted. The drum rotates backward and forward as the plotting tool, usually a pen, moves laterally over the plotting surface. The drum rotation provides movement along one axis, while the plotting tool provides pen movement along the other. A third mechanism controls the lifting and lowering of the pen. The plotting paper is usually provided in a roll. The width of the medium usually ranges between 8" and 17". The length of each plot is limited only by the width of the roll, unless the rolls can be spliced, in which case the plot length is unlimited.

Flatbed Plotters

A flatbed or table plotter moves a pen in two dimensions over a flat and fixed plotting surface. The writing mechanism is comprised of a writing tool assembly and a carriage. The carriage moves along one axis and the writing tool assembly along the other. The tool assembly is lifted and lowered to either write or not write.

The plotting medium is held to the plotting surface often by a vacuum, which is supplied from beneath the surface. The medium is not usually moved until a plot is completed. The plotting surface is usually held in a horizontal position, however, some plotters can tilt the plotting surface from a horizontal to a vertical position at any angle between 0 and 90 degrees. Size of the plotting surface, a major determinant of plotter cost, usually ranges from 11" x 17" to upwards of 100 square feet. Plotting surfaces of plotters typically interfaced with microcomputers usually measure less than 24" x 36". Flatbed plotters produce output on a wide variety of plotting media such as paper, mylar, and vellum.

Selection Considerations

Plotters

Drum plotters are more compact and less costly than flatbed plotters and plotting operations can proceed for long periods of time without attendance as generated plots may be at least as long as a roll of plot paper. Drum plotters are best suited for applications which require large quantities of output in cases where accuracy is not critical. Flatbed plotters are generally more accurate and versatile than drum plotters and also more costly.

Incremental plotters move the pen across the media in a rapid succesion of small steps. Each step consists of movement in one of between two and eight directions depending upon the plotter. Curves plotted in an incremental plotter have a stepped appearance. The length of individual steps determines the resolution of the plotter, those with smaller steps producing the most highly resolved and less jagged drawing. Plotters which move the plotting tool in smaller increments usually operate more slowly. Plotters which can operate in a vector mode are capable of drawing a line from point to point without taking a series of small steps resulting in a much higher quality of output.

Plotters which have a velocity control feature enable the pen to change direction without first coming to a stop. The writing tool decelerates and accelerates adequately to negotiate the change in direction without coming to a full stop. The velocity optimization features enables faster plotting speeds.

Types of media which may be used on most plotters which may be interfaced with microcomputers include vellum, mylar, transparencies, etc. Sheet size and working area is usually specified in inches. The sheet size of drum plotters usually ranges from 8" to 17" x the length of the paper roll. The sheet size of flatbed plotters may range anywhere from 11" x 17" to the size of a small room. Plotter pen types include rapidiograph ink, felt tip, and ball point. The number of pen widths and colors which may be used is limited by the number of pens which the carriage will hold.

Positioning accuracy and repeatability is measured in inches. Repeatability is a measure of how closely the pen can be returned to a given point repeatedly upon command. A high degree of repeatability ensures that intersecting lines and circle shapes will meet exactly. A repeatability of .005 inches is considered adequate for most landscape architecture applications. High resolution ensures that curved lines will appear smooth and straight lines will appear consistently straight. A resolution of 1/1000th inch is considered high. Speed is a measure of pen axial or diagonal pen movement in either steps or inches per second. An automatic pen capping feature prevents pens from drying out between periods of usage. A pen damping feature gently lowers the pen to the media which improves line quality.

Summary Of Selection Considerations

Plotters

- Plotter Type
    - Flatbed
    - Drum
- Incremental vs. Vector
- Data Source
    - Key
    - Auxiliary Storage Media
    - Image Input Device
- Plots On-line/Off-line
- Type Of Plotting Media
- Size Of Working Surface
- Sheet Size
- Pen Type
    - Rapidiograph Ink
    - Felt Tip
    - Ball Point
- Number Of Pens
- Resolution/accuracy
- Repeatability
- Speed
    - Steps Per Sec (Stepping Rate)
    - Inches Per Sec
        - Axially
        - Diagonally

Features

Velocity Optomization

Work Surface Orientation

Automatic Pen Capping

Pen Damping

2.1.4 Storage Devices

Introduction

At the most basic level, computers can process only one word of data at a time. The remaining data to be processed must be stored. Information is stored within a hierarchy of memory types, each with attributes appropriate for their location within the system. The most critical memory characteristics are speed, capacity, and cost. Speed, or access time, is the time required to locate and read a word from memory. Speed is usually measured in microseconds (msec), or nanoseconds (nsec). Storage capacity is usually measured in bytes, kilobytes (2^{10} or 1024 bytes), abbreviated K, or megabytes (2^{20} or 1,048,576 bytes, abbreviated MB. Each memory type requires a unique balance of attributes.

The top of the memory hierarchy is represented by high speed semiconductor memories which can be accessed directly by the CPU. These high speed memories are referred to as either work store, main, or internal memories, and they are contained within the computer itself. Since they can be accessed most directly by the CPU, they are used to store data and instructions which require the most immediate or frequent processing. Due to the high cost per byte of high speed memories, storage capacity is relatively low.

The bottom of the memory hierarchy is represented by slower memories which exist within peripheral devices instead of the computer. These auxillary storage devices are referred to as mass store. Information stored within mass store must be transmitted to the computer before it can be processed. The cost per byte of mass store is usually low, and therefore the storage capacity relatively high. Mass storage is used to store large quantities of data with relatively low processing priority.

Memory locations may be accessed by one of two methods: random access, or sequential access. A random access device is one in which all locations require an approximately equal amount of time to access, and can each be accessed directly by the CPU. Locations within a sequential access device must be accessed by first proceeding through a series of sequential locations. The time required to access each location varies. Sequential access devices may be either direct access sequential devices (DASD), or serial access sequential devices (SASD). Locations on a DASD are usually accessed by moving a read/write head directly to specified locations on a storage media. Locations on a serial access device are accessed by moving a storage media past stationary read/write heads until the appropriate location is reached.

2.1.3.1 Work Store Memory

Work store, or main memory, usually consists of an array of addressable cells which may be read from or written to directly by the CPU. To enable the processor to operate as rapidly as possible, it is essential that the work store have rapid access capability. Main memory is usually based upon semiconductor technology to achieve maximum reliability and speed. Semiconductor memories are not usually used to store large blocks of data due to their expense, and inability to hold their contents at power down. However, the cost of semiconductors is decreasing, thus making potential use more affordable.

A semiconductor memory consists of two functional blocks; the memory cell array, and the peripheral circuitry. The memory cell array is a square matrix of memory locations arranged in rows and columns as shown in Diagram 2.24. Each location has an ad-dress, and stores one word of information. Each word is comprised of an equal number of cells or bits, which is referred to as the word length of the memory. The number of words, or addressable locations within a semiconductor memory, is referred to as memory capacity. A 4K x 16 bit memory contains 4K or 4096 memory locations, and has a 16 bit word length. Some manufacturers express the total capacity as 4096 x 16 bits or 8K bytes. The arrangement of words in a typical high speed memory is shown in Diagram 2.24. Most 8-bit computers can address a maximum of 64K bytes. The maximum internal storage capacity of most 16 bit computers is 1 megabyte, and 32 bit computers can access 16 megabytes of main memory.

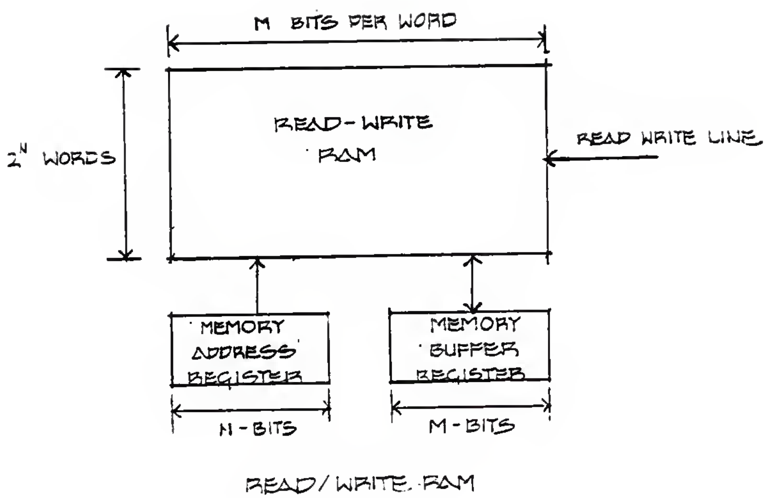


Diagram 2.24

High Speed Memory

Adapted From Bartee (1977:278)

The CPU communicates with the memory through a memory address register, a buffer register, and a read/write line. The computer sends the address of the memory location to be addressed to the address register. A 1 or 0 is sent through the read/write line/s to indicate whether data will be read from or written to that location. In the case of a read operation, the data at the specified location is sent to the buffer register from the memory. If a write operation is signaled, then data to be written into memory is sent to the buffer register, either from an input device, or another memory.

Static vs. dynamic memory

A semiconductor memory may be either static or dynamic. Information within a static memory does not 'fade away'. Each static memory cell has two transistors. By activating one or the other, a 1 or 0 may be represented. These values are held until altered by an external current, or until the power is turned off. Information within dynamic memories fades constantly. Each cell has transistors which may represent either a 1 or 0, depending upon a charge which turns the transistor on or off. Dynamic memories require less space and power than static memories, but unless recharged, the data is lost. Special refresh circuitry is required to recharge dynamic memories at least once every two msec. Applications which require frequent read operations, such as graphic displays, make the most efficient use of dynamic memories. The memory must be read constantly anyway, so special refresh intervals aren't necessary. For applications which do not require the memory to be read at least once every two msec., the refresh circuitry must set aside intervals to refresh the memory. In this case, if less than 4K bytes of work storage are required, a static memory would be more efficient. In general, static memories are preferable for small applicatons. Static memories have fewer control lines, and are therefore easier to interface. Applications which require a work store of greater than 4K bytes, are performed most efficiently using dynamic memory, which uses less power.

Volatile vs Nonvolatile Memories

The majority of main memory is referred to as read/write memory, because it allows both storage and retrieval of data and instructions. Read/write memories are more typically referred to as RAM, an abbreviation for random access memory. Read/write memories are volatile in that they do not hold their contents when the power is off, so programs must be loaded before processing, and unloaded to mass storage before the power down. Read/write memories are usually used to store a variety of programs.

A portion of main memory consists of read-only memory, abbreviated (ROM). Information may be retreived from a ROM, but users may not store information within them. Data and instructions are stored permanently within ROMs by the manufacturer. Read-only memories are random access memories as are 'RAM' memories. ROM memories do not lose their content at power down, and are referred to as non-volatile. ROM memories always perform the same set of instructions, and are therefore used for fixed applications. Permanent storage of frequently used instructions within read-only memories, eliminates the need to pass those instructions through the memory hierarchy each time they are accessed by the CPU. Both RAM and ROM are true random access semiconductor memories.

Most read-only memories are programmed by the manufacturer. However, some varieties of ROM may be programmed by the user. A programmable read-only memory (PROM), permits the user to store data and instructions using a utility program and a special device called a PROM burner, blower, or blaster. Once programmed, the contents of a PROM cannot be altered. If a user requires pérmanent storage of instructions not available in masked (preprogrammed) ROMs, then a PROM may be required.

An erasable PROM, or EPROM, is a PROM which can be erased by exposure to ultra-violet light, and rewritten. An electrically alterable ROM, or EAROM, is a ROM which may be programmed, erased, and reprogrammed repeatedly, using the computer itself. No special programming device is required. EEPROM, or electrically eraseable programable read only memory, is an alternate term used by some manufacturers to designate an EEPROM. EEPROMs or EAROMs may be used just as RAM is used. However, they do not lose their contents at power down. The process of writing to an EEPROM or EAROM is also somewhat slow, requiring approximately 10 msec to write a word. These memories are usually reliable for approximately 10,000 write operations.

Speed

The speed of a semiconductor memory is referred to as memory cycle time, which is comprised of access time plus read recovery time. Access time is the time required for a memory to present valid data at the memory output pins after it receives a valid memory address, or more simply, this is the time required to read a word from from memory. Read recovery time is the time required for the internal sequencing circuitry to recover and enter another access cycle. Since static RAM has no sequencing circuitry, access time is equal to memory cycle time. Read recovery time effects the memory cycle time of dynamic memories only if byte after byte will be accessed in rapid succession, and even then is practically negligible. For applications which do not access memory in this manner, read recovery time is equal to 0, and access time will determine memory speed.

If memory is to be used as an input/output buffer, in which fast bursts of data will be transmitted, total memory cycle time will determine speed. In these cases, the peripheral circuitry surrounding a dynamic cell array, can slow memory cycle to twice the access time. When determining memory speed, additional buffers and control circuitry on a microprocessor card must be taken into account. The peripheral circuitry of a RAM consists of decoders which locate the memory address. One address decoder divides the cell array into a series of row select lines, while the other divides it into column select lines.

Summary Of Selection Considerations

For Work Store Memory

Total memory capacity x memory word length

RAM - Random Access Memory

ROM - Read Only Memory

PROM - Programmable Read Only Memory

EPROM - Erasable Programmable Read Only Memory

EAROM - Electrically Alterable Read Only Memory

Memory speed

Access time

Upgrade potential

2.1.3.2 Mass Storage

Mass storage is used to hold blocks of information too large to fit into work store, but accessed with enough frequency to require rapid access. Data must be read from mass store into work store as it is needed. Media used for this purpose are mass storage media, which can store the content of a computer's memory after the power is turned off, in a form that can be read directly back into work store. Floppy disk, hard disk, magnetic tape, and bubble memories are the most commonly used mass storage media for microcomputer systems.

Floppy, or flexible disks, are an efficient direct access storage media, with rapid access capability. Magnetic tape, on the other hand, is a serial access media, which may have to be wound several hundred feet for one location to be accessed. Whereas digital signals may be stored directly on floppy disks, they must be slowed and converted to audio signals prior to recording on home cassetes. As microcomputer applications are growing more sophistocated, greater memory capacity, reliability, and faster access speeds are required. Most professional applications require the capability of floppy disks or bubble memory. Most sophistocated database management, and engineering graphics applications require hard disk storage, which is becoming cost competitive with floppy disk systems.

Floppy Disks

Floppy disks are paper thin flexible plates, coated with a magnetic oxide, which contains magnetic dipoles. The dipoles align in one of two directions to represent binary values. Most disks are about the size and shape of a 45 rpm record. The disks spin inside a jacket at a speed of approximately 300 or 360 rpm. The jacket provides handling protection, and is equipped with a special liner that entraps dirt that may otherwise harm the disk. A typical floppy disk is illustrated in Diagram 2.25.

Data is stored on concentric tracks which are accessed by a radially moving read/write head through a slot in the jacket. The read/write head records and senses data much like the record playback head of a tape recorder. The head is moved to the proper track by a stepper motor. Each track is divided into 10 to 26 sectors. The sectors usually store data serially in blocks of 128 bytes x 8 bits. Sectors are separated by headers which contain several bytes of preamble data on some systems. Header data may include drive, track, and sector identification. Other systems utilize an addressing system to store this information within an operating system. Hard sectored disks have coding holes to indicate the beginning of each sector. The holes are recognized by photoelectric sensors. Sector locations on soft-sectored disks are determined by reading data on the disk. In this case, the read/write head and system software determine which sector is passing the head as the disk spins. Hard-sectored disks are more reliable because error rates are reduced. Disks are inserted into drives which spin and transfer

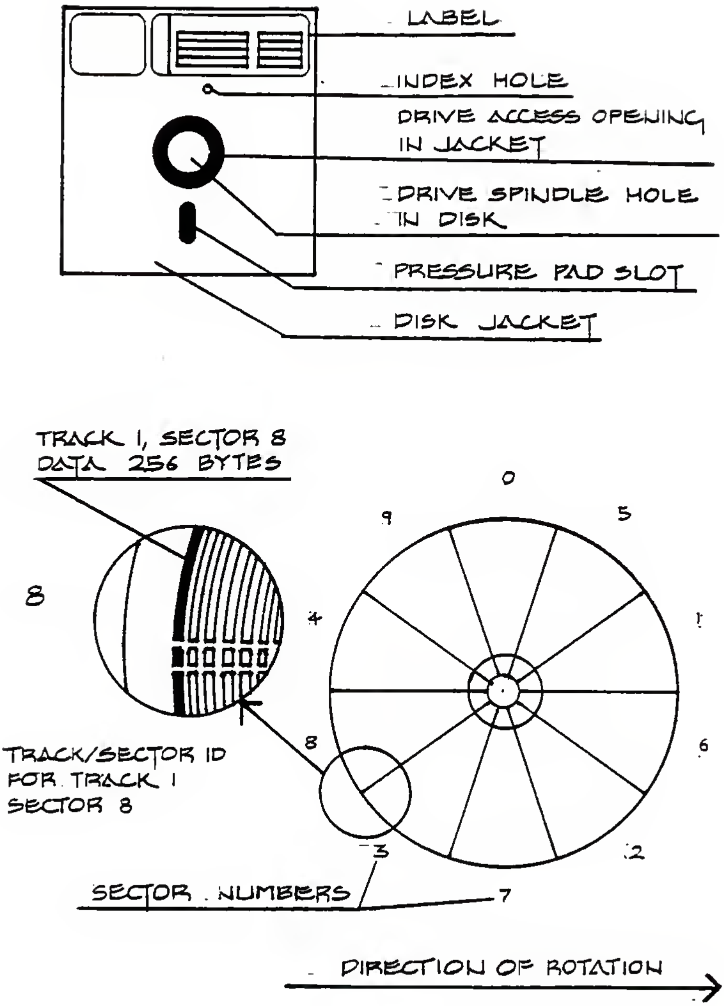


Diagram 2.25

A Floppy Disk System

information to and from the disk.

The components which comprise a disk system include the disk drives, the controller circuits, and the disk operating system (DOS). The primary factors to be considered in the selection of a disk system include memory capacity, speed, operational features, compatibilty, upgrade capacity, and cost.

Disk capacity is dependent upon disk size, recording density, track density, and the number of sides used. Available disk sizes include 8", 5 1/4", and sub 5", also referred to as full-, mini-, and microfloppy disks, respectively. Total storage capacity usually designates unformatted storage, which is the total number of bytes which can reside on a disk. Formatted storage capacity indicates unformatted capacity less bytes required for headers. Total disk capacity ranges from approximately 70,000K to 1 MB at this time.

Recording density is the density of bits recorded on a disk. Density is usually specified in bits per inch (bpi). Disks with double recording densities, called double density disks, can store twice as much information as single density disks. Double density disks allow higher rates of data transmittal, because more data can be sent and received at one time. Track density is the number of tracks on a disk. Track density is specified both as tracks per inch (tpi), and tracks per side (tps). Most disks have either single or double track density. A single density minifloppy disk has about 48 tpi, and a double density, approximately 96 tpi. A disk which has both double recording density, and double track density, is referred to as a quad-density disk. However, these are not too common. Microfloppy disk systems occupy much less space, but yet have 7/8ths the storage capacity of minifloppies, which is near equal to that of a full floppy. By doubling either recording density, or track density, a cost savings is effected. Although double density disks are more expensive, half as many are required, and less time is spent changing disks.

Single-sided disks are those which are recorded on only one side. Double-sided disks are recorded on both sides. Double-sided disks may be accessed either by double-headed drives, or by flipping a disk to access both sides with a single head. Double-headed drives have a read/write head for both sides of the disk. Flipped disks are used in single headed drives by turning a regular disk over. Some drives will allow regular disks to be accessed, regardless of the direction they are facing. These flippy disk systems are less costly than double headed systems. However, flipped disks are less reliable. Only one side of most disks are checked by the manufacturer to ensure reliable reading and writing. The disk jacket is designed to entrap dirt as the disk spins. When the disk is flipped, and spun in the opposite direction, the dirt loosens. This may be a potential cause of read/write errors, or may clog the read/write head. Double-headed drives are usually considered to be a more sound investment than flippy disk systems. Disk capacity is usually specified in terms of K or M bytes of unformatted storage.

Disk access time is the time required for a read/write head to be positioned at a specific disk location, ready to read or write data. Disk access time is comprised of track-to-track access time plus latency. Track accesss time is the time required for the head to move from one track to another. This is typically in the order of 3 msec. Latency is the time required for the proper location on a track to become positioned under the read/write head once the head has been properly positioned. This is typically 15 msec. Floppy disk systems currently available are capable of accessing approximately 500K bits per second (Attikiouzel, 1983). The rotational speed of 5 1/4" and sub-5" disks, has been standardized at 300 rpm. Full floppy disks rotate at 360 rpm. Maximum latency is considered to be the time required for 1/2 a revolution. The data transfer rate is the amount of time required to transfer 1 bit from the disk drive to the controller. These rates are standardized at 250K bits per second for single density drives, and 500K bits per second for double density drives.

Read/write heads are usually positioned within disk drives by one of three mechanisms; lead screw, split band, or spiral cam. Each of these mechanisms are represented in diagram x. The reliability of a drive is effected by the head positioning mechanism. The lead screw positioner is accurate, but wearing of it's ball bearings can limit reliabilty over a period of time. Track-to-track access time for lead screw positioners is usually around 6 msec. The split band positioners are the most reliable mechanisms with a track-to-track access time of approximately 3 msec. Spiral cam mechanisms are used on 5 1/4" drives with a track density of 48 tpi. The spiral cam mechanisms cannot operate with accuracy adequate for 96 tpi drives. The cams are inexpensive, but unreliable. Cam mechanisms are plastic disks embedded with grooves. As the grooves wear, the system becomes susceptible to positioning errors.

Most disk systems are operated either by a brushless AC spindle motor, or a DC motor. AC motors are usually used in 8" disk drives. A solenoid loads and unloads the spinning disk onto the head to read or write data. Once this access function is completed, the disk is unloaded. Smaller drives usually use DC motors. The read/write heads are constantly in contact with the disk. The motor spins the disk only when data is to be read or written.

The read/write heads, and disks used in a head-load solenoid, (AC) drive, do not receive as much wear, and last longer. However, the solenoid itself is subject to failure. A stray magnetic field may sometimes be created when the solenoid couples into the head, which can cause soft errors. Disk drive failures are categorized as either hard or soft errors, and mechanical or electrical failure. A soft error is a read error that is recovered in a specified number of recovery attempts. If more attempts are required, it is called a hard error. Soft errors are usually recoverable. In th case of a hard error, the storage device must be repaired prior to further usage. Soft errors typically occur at a rate of 1 in 10^9 bits. Hard errors occur at a rate of 1 in 10^{12} bits. A hard landing of the disk onto the heads may damage both the disk and the drive. AC systems are also expensive, and must be adjusted periodically. DC motors, commonly used for 5 1/4" drives, require far less power to rotate the disk. The DC motors tend to last longer because they function only during read/write operations. Since the heads are in contact with the disk at all times, they do not have to be loaded and unloaded by solenoids.

The number of disk drives required, depends upon the amount of memory necessary to hold the data and programs which must be accessable to the computer, (on line), at one time, and the storage capacity of the disks. For most applications, it is crucial to make back up copies of disks. Duplicates will ensure that essential data is not permanently lost in the case of damage or wear. Copying with a single drive can be quite inconveniant and time consuming. Data must be transferred in blocks small enough to fit into the computers's main memory. Two drives enable fast copying and double storage capacity. One drive is often used to store programs, while the other is used to store on line data.

When selecting a disk system, it is essential to ensure that the components are compatible. The size of the drive must match the disk size. Full floppy disk drives cannot read 5 1/4" disks. Recording density of disks and drives must also match precisely. However, the number of tracks on the disk must be equal to or smaller than the number of tracks to which a drive can read or write. This is applicable only if track spacing is the same. A 35 track drive cannot be used to read a 40 track disk. The disk sectoring system must also match that of the drive. Single-headed drives can read one side of a disk recorded by a dual-headed drive. However, it can't read the reversed side, because all data would be reversed.

Software usually controls disk formatting, indexing, copying, back-up, reading and writing, and arranging files to fit on a disk most efficiently. For some computer systems, there exists only one compatible disk operating system (DOS). But most offer a choice. The most standard DOS's are CP/M, MS DOS, and PC DOS. If given a choice, it is most important to ensure compatibilty with the complete hardware system and other software to be used. Ease of use is also a critical selection consideration in most cases.

Disk control circuitry usually controls the following functions; drive-select, motor-on, read/write head stepping, track start indication, and write enable. Some indicate index sector and write protect as well. Some disk controllers have advanced features which reduce the disk operating system requirements. Some of the more common features are described in greater detail below:

write protect: In order to protect data stored on a disk, a write protect switch recognizes a tab which is placed on the disk to prevent more data from being written onto the disk.

daisy-chaining: This enables several drives to be connected to one controller, which addresses the individual drives to transfer data.

industry-standard interface: This allows drives supplied by different manufacturers to be controlled by one controller.

software security: Security may be enhanced by a ready switch which signals the following:

- the drive door is closed,
- the door has been reclosed following media insertion, indicating that the media has been disturbed,
- the drive is ready, and has been selected,
- index pulses have been detected

disk in place switch: This verifies the presence or absence of of media before an access is attempted, which prevents inappropriate media access, and reduces overhead costs.

motor start: This centers the media when a disk is inserted into the drive, which eliminates disk pinching. (Williams, 1982:341).

Upgrade potential is also an important selection consideration for disk systems. One should ensure that both software and hardware will be able to handle anticipated increased capacity. For example, if the recording density of a 1 MB disk is doubled, so that the new disk capacity is 2 MB, the data transfer rate would double from 250K to 500K bits per second. The controller must be capable of recovering data at this rate. If upgrading from a single-sided to a double-sided system, one must ensure that both the operating system and the hardware can handle double-sided disks.

Hard Disks

Hard disks, also referred to as rigid disks, are metallic plates coated with magnetic oxides. They too, are read and written to by magnetic heads as the disk rotates. Some are encased singly into a plastic cartridge which slips into a disk drive. Multiple hard disks which are stacked within a plastic encasement, are referred to as disk packs. Individual disks within a disk pack are called platters. Rigid disks are referred to as either fixed, removeable, or fixed/removeable. Removable disks may be removed from their drive and placed in a protected environment. This enables improved data security and back-up. Fixed disks can store more data, and are less expensive. Fixed/removeable packs have one removable, and one or non-removeable disks. Primary selection considerations for hard disk systems include capacity, speed, compatibility, upgrade potential, and price.

Memory capacity is determined by disk size, number of disks, number of tracks, and recording density. Sizes currently available range from 5" to 14". The number of disks in a pack range from 2 to 4. The number of tracks on a disk range from 100 to several thousand. Bits are recorded on a track at a density of 500 to 7000 bits per inch. Some disks have more bits on the outer tracks than on the inner track, due to the difference in circumference. Others have the same number of bits on each track. Generally, hard disk storage is most efficient if an on-line capacity of more than 500K is required.

Most rigid disks rotate at a speed in the vicinity of 3,000 rpm. **Access time** is the time required for a read/write head to read a word from memory once presented with a memory address. Access time is comprised of **seek time** plus **latency** (rotational delay). **Seek time** is the time required to position a read/write head on a specific track. This usually ranges from 50 to 200 msec. (Mullin, 1982:282). **Latency** is the time required for the specific track location to reach the read/write head, once the head has been positioned. For example: a disk speed of 2400 rpm, would have a maximum latency of 25 msec., and an average latency of 12.5 msec.

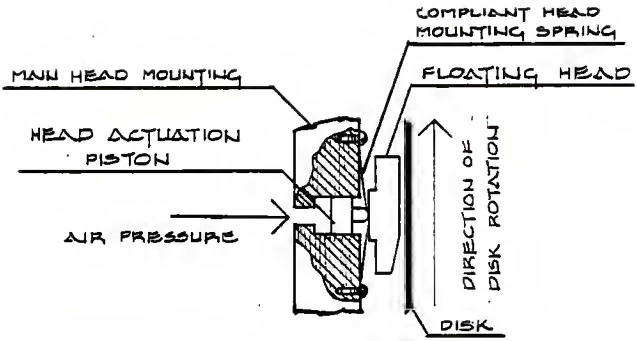
Access time is largely dependent upon the type of read/write head used , and the type of motor used to position the head. The read/write head may be either fixed or moveable. A fixed head system has heads fixed in position on each track. Moveable head systems have one or more pairs of heads for each pair of adjacent disk surfaces. Moveable head systems are not as fast as fixed head systems, due to the amount of mechanical movement required. Head spacing in fixed head systems is about 8 to 16 heads per inch. By interlacing groups of heads, track densities of 30 to 60 per inch may be achieved. Although fixed head systems are faster, moveable head systems read more tracks per inch. The head moving mechanism is costly. If a fixed head system can accommodate the memory capacity required, it provides both a faster, more reliable, and more economical means of data storage.

Most read/write heads used on hard disk systems are of a type called flying heads. As the disk rotates, a thin layer of air rotates between the disk and read/write heads. This prevents wear on the disk surface. Compressed air is blown into a mechanism which forces the head within the correct proximity of the disk, as illustrated in Diagram 2.26.

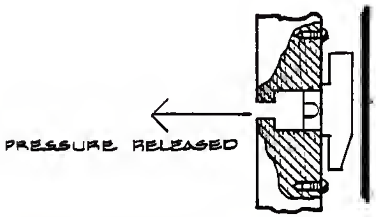
Winchester technology disks offer superior storage capacity, and lower cost per byte. The disks are constructed of a magnetic material similiar to that of conventional rigid disks. However, they are highly polished to allow the head to skim closer to the disk. These systems are designed to operate at precise tolerances. A minute particle can disrupt the movement of the head across the disk. For this reason, the disks must be sealed within the drives, and cannot be removed without destroying the data stored on them. The biggest problem with Winchester technology disks, is data security and back-up.

Access time is also effected by the type of motor used to control the read/write heads. The motor is usually one of two types; a stepper motor, or a rotary voice coil. Stepper motors are less expensive, but slower and less precise. Stepper motors perform adequately for single user systems, but the data access rate decreases if more than two terminals are included. Rotary voice coils provide higher access rates for multi-user systems.

The most recent development in hard disks are 3.9" disks, which are graphite coated thin metal alloys. This film offers several advantages over ferric oxide used to coat regular disks. The 3.9" disks may be recorded at densities 2.5 times greater than regular disks. Conventional storage media have an uneven thickness and soft surface which can be damaged if the head accidentally comes into contact with the disk (a head crash). Graphite coated disks are a thousand times harder than regular



HEAD SHOWN IN OPERATING POSITION



HEAD SHOWN IN RETRACTED POSITION

Diagram 2.26

Elements Of A Hard Disk Read Write Head

Adapted From Bartee (1977:329)

disks, offering much greater durability, and less sensitivity to head impact. The thin metallic coating doesn't need to be sealed, and is less susceptible to contamination. Conventional disks must be protected by a fluid lubricant which attracts dust particles. This requires that the disks go through a purge cycle before used to eliminate contamination. Some 3.9" disks are coated with a layer of quartz or saphire for further protection against head crashes and corrosion.

Intelligence is provided with some disk systems. Some of the most useful features include speed matching, self diagnostics, and local error checking and corrections.

Magnetic Tape

Magnetic tape is a serial access mass storage media, which has relatively large storage capacity, low cost, and operates at a slow rate of access. The principal components of a magnetic tape system are the tape, the read/write system, and the switching and buffering system.

Magnetic tape is a thin layer of plastic coated with a magnetic oxide. The tape is passed through magnetic read/write heads which align the magnetic dipoles to represent ones and zeros. Data must be read serially, and cannot be randomly accessed. The tape must be moving at a certain speed before the read/write process can occur. The tape cannot be started and stopped rapidly enough to read one byte of data at a time. For this reason, blocks of data are usually read from the tape and stored within buffers, where they may be accessed by the CPU, one byte at a time. Since the tape may need to be stopped between blocks, the blocks are separated by enough space to allow the tape to accelerate and decelerate. This gap is called the interblock or interrecord gap. The most common tape widths for microcomputers are either 1/8" or 3/16". Most tape has seven channels. Each channel typically stores one byte of data. Reflective metallic material is fastened to the tape at the beginning and the end. These markers are read by photo-electric cells to indicate the beginning and end of a tape.

The tape transport is comprised primarily of the read/write heads, and the mechanism which moves the tape past the heads.

The read/write system includes the amplifiers and translators which convert analog signals from the tape, to digital signals for the computer. The switching and buffering system is the equipment necessary to select the correct tape mechanism to store information to be read from or written to the tape.

Operating speeds to be considered in the evaluation of a magnetic tape system include stop/start, read/write, fast forward, rewind, and gap search. Stop/start time is the time required to accelerate the tape to a speed sufficient for reading and writing, and the time required to bring the tape to a full stop. Stop/start time is often less than 5 msec. Read/write, fast forward, rewind, and gap search measures indicate the speed at which tape is moved past the read/write head during these operations. Read/write speeds range from 12.5 to 250 inches per second. (Bartee, 1977:338). The data transfer rate is measured in bits per second (bps). Capacity is measured in terms of total unformatted storage. Packing density is specified in bits per inch.

Magnetic tape may be mounted on reels, in casettes, or in cartridges. Cassettes are used most commonly for microcomputer systems. The type of tape used in high quality home cassette systems, is of sufficient quality for computer usage. However, cassette systems designed specifically for computer usage, (digital cassettes), are much better suited to professional applications. Recording densities are higher than those of home cassetes, and speed approaches that of floppy disk systems. The digital cassette systems are more rugged than diskette systems, however their cost begins to approach that of floppy disk systems, which operate much more efficiently. Tape cartridges, which resemble large cassettes, contain more tape, and are more difficult to mount. Since the tape is sealed in a cartridge, it is protected from contamination.

The complexity of the interface required for a cassette system depends upon the number of features incorporated. All cassettes have read and write circuitry which allow them to load and unload blocks of data. Home cassettes have manual controls. Digital cassettes are controlled directly by the computer. If equipped with manual controls, the cassette must be turned on and off at the beginning and end of data blocks to be transmitted. This process is impractical for most professional applications.

Most applications require full motor control features, which are typically equipped on digital cassette systems. A cassette rewinds ten to twenty times faster than it reads or writes. For this reason, the magnetic heads cannot recognize identification codes written at normal speeds to find a particular block of data when the tape is moving at high speeds. Some cassette controls assign a code to the beginning of each file or record, which can be read by the cassette electronics when passed over at high speeds. These markers enable much faster access times. Data transfer rates for magnetic tape cassette systems range from 300 to 1500 baud, for home cassettes, and from 2400 to 5200 baud, for digital cassettes. These rates are equivalent to between 30 and 520 bytes per second. Data transfer rates for floppy disk systems typically range from 250K to 500K bits per second.

Two cassette recorders, and a cassette interface with a motor control can comprise a file management system. One cassette may be used as an input device, the other an output device. Data blocks can be read from the input cassette, edited by the operator, and stored in the output file.

Selection Considerations

Mass Storage Devices

Magnetic tape cassettes are the most inexpensive mass storage devices, and compare favorably in terms of performance. A cassette system costs slightly less than a 5 1/4" floppy disk system, and is capable of an average access time of .50 msec., as compared to .20 msec. for a 5 1/4" floppy disk system.

Hard disks offer larger total storage capacities, and faster data access than floppy systems. However, the purchase price of a hard disk system is higher. Recently though, the cost of hard disk systems has dropped substantially, and they are being incorporated into many small business systems. The added storage capacity and speed is especially important for applications which require large amounts of data to be on-line at one time. For example; if the computer was used to perform the computation for road alignment, earthwork estimation, and cost estimation, on an individual basis, the necessary data and programs could probably be stored on one or two floppy disks. However, if all of these operations were to operate interactively, hard disk storage may be required. Projects which require several users to access the same data base, or project information, may require hard disk storage. Each user within a network in which microcomputers share a hard disk, may access central project data stored on the disk. Individual users may be equipped with their own floppy disk systems on which they can download programs and data as needed. The terminals may also be used to provide back-up for information stored on hard disk. The number of users which may access a single drive usually ranges from 1 to 60.

Hard disk systems with fixed read/write heads offer the greatest memory capacity, the best performance and reliability, and the lowest cost per byte. The storage capacity of these hard disks ranges between 5 MB and 80 MB. Back-up for these systems can be a tremendous problem. Floppy disks provide a slow and inconveniant means of backing up data, while magnetic tape lacks random access capability, and reliability.

Floppy disks have historically offered the advantages of removeability and low cost over hard disks. Removeable hard disk cartridges now offer the high memory capacity, performance, and reliability of hard disk storage, as well as the removeability and low cost of floppy disks. Whereas a sub-5" floppy disk can store approximately 1 MB, a 3.9" hard disk cartridge can store 6.38 megabytes. Average access time for the cartridge is 75 milliseconds, which is 1.5 to 3 times faster than that of floppy disk systems. Data transfer rates for 5 1/4" cartridges is on the order of 5 MB per second as compared to a rate of 1/4 MB per second for full floppy systems Hard disk cartridges provide better interchangeability between drives, and they allow flexible formatting. For example, the number of bytes stored within each sector may be defined by the user. The cartridges are also more durable, which enables them to be mailed and used in portable systems. The difference in cost is greater for the media than for the drives. A floppy disk drive costs slightly less than a hard disk cartridge drive, but one cartridge is equivalent to 10 floppy disks in price. The cost per byte is less for cartridges. The exception to this is the cost of 3.9" cartridge systems, which are becoming cost competitive with floppy disk systems. Whereas floppy disk technology has peaked, small hard disks are at the beginning of their production cycle.

Summary Of Selection Considerations

Mass Storage Devices

Floppy Disk Systems

Media

- Size
- Single/dual sided
- Track density
- Recording parameters
  - Recording density
  - Data transfer rate
  - Total storage capacity
- Format

Drive

- Dimensions
- Weight
- Disk speed
- Seek time or track-to-track access time
- Latency
- Average access time
- Head loading time
- Error rate
- Head life
- media life

Features

- Write protect

Daisy chaining

Software security

Disk-in-place switch

Motor start

Summary Of Selection Considerations

Hard Disk Systems

Removeable or non-removeable media

Pack or cartridge

Fixed or moveable heads

Number of disks

Number of disk surfaces

Media

- Size
- Recording density
- Data transfer rate
- Total storage capacity
- Format

Drive

- Dimensions
- Weight
- Disk speed (rpm)
- Track-to-track access time
- Latency
- Average access time
- Head loading rate
- Error rate
- Head life
- Media life
- Motor type

Summary Of Selection Considerations

Magnetic Tape Systems

Packing density

Total storage capacity

Inter-record gap

Operating speed

- Read/write speed
- Maximum start/stop rate
- Total speed variation
- Access times
- Data transfer rate

Type of read/write head

Features

- Fast forward
- Rewind
- Gap search

2.2 Software

Software is the set of instructions required to control operation of computer hardware. **A computer program** is a set of instructions which command the computer to perform a step by step procedure to solve a problem. Programs are collectively referred to as software. **A programming language** is a set of symbols used to communicate instructions to the computer. Three types of software are required to instruct a computer to execute a defined task; **application, system, and programming and developmental software.**

Applications are the tasks which a computer is employed to perform, such as accounting, statistical analysis, or market forecasting. Applications are the reason for which a computer is purchased. Programs designed to perform specific applications are referred to as **application software.** System software comprises the 'behind the scenes' software which manages the resources of a computer system and enables application programs to be entered and executed by the computer. The operating system is active at all times that a computer is running. **Programming and developmental software** comprise the languages and language translators which enable humans to communicate with a computer.

2.2.1 Programming And Developmental Software

A programming language is the set of symbols used to communicate a program to a computer. A series of languages are usually used for this purpose. At the highest level are languages consisting of symbols and procedures easily understood by users. Lower level languages consist of symbols which are more closely related to instructions actually executed by the computer.

The highest level languages are comprised of symbols which resemble mathematical or spoken language symbols. Most application software is originally written in a high level language, to ease the task of the programmer. The program, expressed in a high level language, is called a source code. The source code is usually entered into a computer with the aid of an editor. The editor is a utility program which allows the user to enter symbols which create a file of text. Most editors will display a file of text on the screen, and provide commands which allow the user to search for words, change text, rearrange the order of text, etc.

The lowest level language is machine code, which consists of the binary digits one and zero (binary code). Machine code can be operated upon directly by the CPU. A program expressed in binary code is called an object code. Source codes are are translated into object codes generally by one of two processes, depending upon which high level language was used for their coding. Programs may be either compiled or interpreted.

A compiled program is translated first into assembly code by a developmental program called a **compiler**. **Assembly language** is a system of mnemonics which symbolize machine code. Alphabetic symbols are used in place of binary digits, so the code is more intelligible to programmers. Each symbol of source code generates one or several lines of machine code. Another developmental program, called an **assembler**, translates the assembly code into machine code or the object code.

Most compilers have built in assemblers, which convert source code directly into machine code. The source code is entered in its entirity before the translation process begins. Once the program is compiled, a listing of the source code may be printed by a printer, or displayed on a monitor. Any syntax errors, (language rule violations), contained within the source code, will also be displayed. The editor may be summoned to correct the errors. Once corrected, the program is ready to be executed and tested for logic errors. The compiler then makes the entire program ready for execution as a whole. A utility program, called a **linker**, calls appropriate subrountines from a library of frequently used instructions, and links them correctly into the object code. Another utility program called a **loader**, searches available memory space, to determine where the object code is to be loaded for execution, and then loads the code. Since the entire program is translated prior to execution, the execution process is relatively fast.

An **interpreter** is a developmental program which single-handedly accomplishes the tasks of a compiler, a library of subrountines, a linker, a loader, and an editor, as these sub-programs are contained within the interpreter. As each line of source code is entered at the keyboard, the interpreter reads the line, and encodes it so that the program may be read quickly at execution time. If a syntax error exists in the source code, the built-in editor will display the error as soon as the error is entered. The user may then make the necessary corrections before proceding to the next line. This line at a time editing capability, and rapid display of results, is the primary advantage of using an interpreted language, especially for interactive computing.

A compiler produces an object code which can be stored, summoned, and executed repeatedly, without being compiled again. Once the code is tested and proven error free, no further translation is necessary. The compiled program does not need to be entered or compiled on the target machine, (the machine on which the program is executed). An interpreted program must be translated each time it is executed, and the interpreter must be present on the target machine. This requirement slows the run time of an interpreted program. Interpreted programs often run 20 times more slowly than compiled programs. The difference in run time can effect a major difference in time and cost for frequently used and/or long programs.

Aside from slower execution, interpreted programs require a greater amount of memory than compiled programs. However, the developmental software associated with some compiled languages requires more memory than does an interpreter, if not provided on circuit cards. Since the compilation process requires access to a larger number of utility programs,(editors, libraries, linkers, loaders, etc.), compilation would be quite inefficient on a system using a magnetic tape cartridge for mass storage. For this reason, interpreted languages are often favored for computer systems without rapid access mass storage. The most popular compiled languages for microcomputers include FORTRAN, C, and Pascal. The most commonly used interpreted languages are BASIC and APL.

Language Selection

The selection of programming languages to be implemented on a particular machine should take into account the following considerations:

- structured programming facilities
- readability
- file handling capability
- portability
- speed at run time
- arithmetic precision
- built-in functions
- user-definable functions

A structured programming language enables the programmer to develop a program in blocks, or modules, which are later joined to form a complete program. This facilitates the practice of top down design, an efficient problem solving methodology, in which the most important decisions are made first, and designed into a program at a high level of detail. Program design procedes downward through a hierarchy of decision making to the lowest level of detail. The top down approach both optimizes programming time, and renders programs which most accurately address the problems they are intended to solve. A program which is structured in modules is easier to understand by someone other than the author, and also easier to debug.

Readability is the ease with which a program can be read and comprehended. Some languages which enable users to write programs most easily, are difficult to read. Those which facilitate structured programming tend to be the readable. Readability becomes of greatest importance when programs must be understood, used, and maintained by those other than the author.

Portability, or transportability, is the ability of a language to operate on more than one machine and operating system. Inspite of considerable effort to standardize languages, most popular languages exist in several versions. Portability becomes most important as hardware becomes obsolete, and a user wishes to upgrade. Portability should also be considered if application software is to be sold, or purchased.

File handling capability is provided within some languages in varying levels of sophistication. If not provided within the programming language, file handling must be provided within the operating system, if to be employed by a user. If file handling is provided within the operating system instead of within the programming language, software portability is more limited. "A file is space set aside on a mass storage media, to hold a program or a related set of data." (Deakin, 1983:104). Factors which effect file handling capability include the following:

random vs. sequential file access

maximum allowable file size

number of files which may be open simultaneously

data types which may be used within a program

maximum array size

The most critical file handling capabilities include the following:

file creation

file deletion

transfer of data to and from a file

change within a file

transfer of a file to another storage device

The arithmetic precision required of a language depends upon the application performed. The precision available on a particular system depends both on the machine, and the programming language which is implemented on the machine. Limitations to be considered include minimum and maximum integer values, and word length.

Speed at run time is heavily affected by whether the language is compiled or interpreted. Although an interpreted language may save programming time due to the ease of correcting syntax errors, run time is considerably slower than that of compiled languages. Therefore, programs which are to be run less frequently, or intended for short term use, may best be written in an interpreted language, where run time is not a critical factor. Long programs which are to be used with frequency, where run time is critical, may best be written in a compiled language.

Programming languages which provide user definable libraries allow users to create a library of commonly used functions. This facility can eliminate the need to repeat these functions each time they are required within individual programs.

Built-in Functions most critical to the proposed applications include trigonometric functions such as sine, arcsine, cosine, arccosine, tangent, arctangent, as well as natural logarithms, exponentiation, decimal degree conversion, and random number generation.

The following pages contain a brief summary explaining the attributes of several popular programming languages.

Assembly Language

Assembly language is best suited for programs which place heavy demands on the resources of the computer. Assembly programs require much less memory than those coded in higher level languages. Run time is also considerably faster. The difference in speed may be of some importance for interactive applications in which the computer must respond rapidly to input. In most cases, the speed gained by coding in an assembly language, is relatively insignificant, however, compared to other factors which effect speed, such as operating speed of peripheral devices.

Assembly language also allows the programmer to control some aspects of a computer system otherwise out of reach using higher level languages. The programmer may exercise more direct control over interfacing peripheral devices, and system software.

An understanding of assembly language incorporates greater insight into the inner workings of the computer, which enables the design of more efficient programs. Portability is zero, as both assembly language and machine code are totally machine dependant. Programs written in assembly language , however, may take advantage of the unique attributes of each machine. The coding of a program in assembly language, is a highly tedious and difficult task, and therefore may be ideal for programs which aren't likely to be changed. Several lines of assembly code are required to command each task, which may require only one line in a higher level language.

Cobol

COBOL, an acronym for Common Business Oriented Language, which became available in 1960, is the best known commercial language. Until recently, COBOL has been available only for mainframe and minicomputers. COBOL has more recently become available for microcomputers. The language is quite capable of handling large data bases of character oriented data, and contains powerful commands useful to business type applications, such as 'sort', and 'inspect'. COBOL is the only language which is required to be tested for conformance to a standard definition before being purchased by the federal government. For this reason, the language is quite transportable. There are a large majority of professional programmers that know COBOL.

COBOL is not well suited for programming system software components, or for scientific and statistical applications. The symbology of the language is very cumbersome in that mathematical notation is spelled out using words. For this reason, COBOL is not an ideal programming tool, but may be a suitable language for packaged business programs.

FORTRAN

FORTRAN, an acronym for formula translator, was developed in 1957 primarily for mathematical, scientific, and engineering applications. FORTRAN was the first widely used programming languge. The arithmetic precision of FORTRAN is high, as well as the capability to maniupulate large numbers and perform complex calculations. The language is not well suited to applications which require extensive database management or input/output, such as is needed for most business applications.

FORTRAN is relatively weakly structured, and hence not very readable. Most versions of both FORTRAN and BASIC make extensive use of the famous GOTO statement, a method of controlling a program's reaction to decisions. Use of the GOTO statement leads to jumping around within a program, which diminishes readability. More structured languages provide alternatives to the GOTO statement, and may be more easily read in a line by line fashion. FORTRAN compilers are highly efficient, and programs execute very rapidly. FORTRAN 77, a FORTRAN version implemented on several mini- and microcomputers, is well structured, and has an ANSI standard.

BASIC

BASIC, an acronym for Beginners All-Purpose Symbolic Instruction Code, was developed in 1965, and used extensively within the education system. For this reason BASIC has become the best known language, accounting for the proliferation of programs available in BASIC. Much of the attraction to BASIC is due to it's ease to use and learn, as well as it's interactive capability.

Being an interpreted language, BASIC is highly inefficient and slow at run time. However, compiled versions of BASIC are available. BASIC is the most weakly structured language available, and therefore the most unreadable. Edsger Dijkstra, a notable figure in the field of computer science states in his assessment of BASIC programmers: "It is nearly impossible to teach programming to anyone with a prior exposure to BASIC." (Luehrmann, 1984:152).

Although the arithmetic precision provided in most versions of BASIC is fairly high, file handling capability is weak. Many do not consider BASIC's ease of use, a justifiable reason to tolerate it's poor performance. Several extended versions have been developed to improve the capability of the language. For this reason BASIC is not very portable.

Pascal

Pascal was originally designed in 1971 as a tool to teach programming techniques to beginners. For this reason the language contains clearly defined guidelines which allow highly structured programming. Pascal is beginning to replace FORTRAN and BASIC in many educational institutions as an introductory programming language, and for this reason may become the most widely used language within the next few years. "Studies at the Universtiy Of California at San Diego, have shown that programmers who learn Pascal as their first programming language, have little difficulty learning other languages." (Stasiowski, 1983:18). "As much as 70% improvement in programmer productivity has been realized by using this modern language." (Stasiowski, 1983:19).

Pascal is slightly more complicated to learn than BASIC in the beginning stages. However, once past the initial difficulty, Pascal is easier to work with, especially if designing programs to perform more complex applications. The highly structured nature of the language renders it to be very readable. Although several versions of Pascal are available, there is an ANSI/ISO standard Pascal, which renders the language more portable. File handling techniques available in Pascal are weaker than those in FORTRAN. This is considered to be a weak spot in Pascal.

Pascal is a compiled language which executes fast and efficiently at run time. Arithmetic precision is highly dependent upon the machine on which Pascal is implemented. Larger machines usually provide FORTRAN's double precision.

C

The C language is the most powerful language currently available for microcomputers. C has the power provided in some low level languages in that it can address registers of the CPU. C is operative with UNIX, a highly powerful operating system. The language is highly structured and readable once a user has gained familiarity with it's use. There are many more commands available in C, than in any other high level language avaliable for microcomputers. Like assembly language programming, the use of C provides insight into the machine. There is only one standard C language, so it is highly portable amongst computers on which C can be implemented. Since the language makes available so many more commands, it is complex to learn initially. C is an ideal language for systems programmers, or those with complicated applications. C executes more efficiently than other languages, but at a scale unnoticeable to most users.

2.2.2 System Software

System software is the collection of programs which enable the hardware to perform tasks instructed by user commands or application software. "System software affects the speed and efficiency of a computer system as much as does the hardware." (Deakin, 1983:47). The programs which comprise system software are categorized as either system or utility software.

2.2.2.1 Operating Systems

"An operating system is a set of programs which manage and allocate the resources of a computer system." (Rinder,1983:38) Those programs are usually designed to operate with a particular processor. Most of the operation of the CPU is controlled by the operating system, which is stored within main memory while the computer is operating. The most important fuctions performed by the operating system (OS) are listed below:

- The OS keeps track of data locations both within the computer, and on peripheral storage devices.
- The OS moves data and instructions between the hardware components such as, main memory, the CPU, and peripheral devices.
- The OS allocates memory space for data and instructions.
- The OS schedules the sequence of instructions processed.

A few of the file handling commands typically provided within the operating system are listed below:

- create a file
- delete a file
- save a program on disk
- display of a directory of programs on a disk
- dump certain memory contents on a peripheral device
- indicate the amount of free storage space remaining on disk
- load a program into memory and start running it
- list the contents of a file on a printer or CRT
- rename a program or data file
- display and informative message to the user when an error occurs in hardware or software

  (Smolin, 1981).

The complexity required of an operating system must vary according to the number of users, the hardware configuration, and the type of tasks performed. One of the major determinants of computer system cost, is the ability of both hardware and software to accommodate more than one user at a time. Operating systems available generally provide one of four levels of sophistication; single-user/single-program, single-user/multi-program, multi-user/multi-tasking, and multi-user/multi-program systems.

Single-user/Single-program Systems

The operating system accommodates one computer and one user. That user is able to access one program at a time. This represents this most simple type of operating system.

Single-user/Multi-program Systems

The operating system accommodates one computer and one user. However, the user is able to access several programs at once. Although the CPU can process only one word of data at a time, the process occurs in much less time than that required to enter or display data. While these slower operations are occuring, the CPU uses it's free time to process information from other programs. The CPU operates so rapidly that it appears to the user as though more than one program is being processed at a time.

Multi-user/Multi-tasking Systems

The oeprating system enables more than one user to access the same program on a single computer which has more than one terminal. The operating system of a multi-user system must be able to keep track of the location of programs and data used by each operator. The OS must log users on and off the system, and resolve conflicts between users competing for the same resource. The OS must also protect the data of each user from interference by another.

Multi-user/Multi-program Systems

The operating system allows more than one user to access several programs on a single computer, using more than one terminal. In this case, the OS must also coordinate the programs being used. (Rinder, 1983).

As the number of users increases, the operating system requires more time to keep track of the computer resources. 'Thrashing' is the inefficient activity of an operating system which spends more time keeping track of resources, than is spent by the CPU to process data. The result of thrashing is a slow response time to each user. The maximum number of simultaneous users for most small computer systems is no more than five. In order to maximize the efficiency of a computer system, the sophistication of the operating system must be carefully matched to data processing requirements.

Selection Considerations

Operating Systems

The most important selection consideration for an operating system is that it be capable of performing the tasks required by the intended applications. The capabilities and peripheral devices required for a computer system must be determined prior to selection of the operating system which can provide the necessary support. The operating system must be compatible with the hardware and software to be used, and must support the number of simultaneous users required. In addition, the usefulness of an operating system may be measured by the degree of portability, speed, and efficiency provided.

Operating systems are stored either in ROM or on disk. Operating systems stored on disk (referred to as disk operating systems (DOS)), are loaded into RAM prior to system operation. Disk operating systems are easily substituted which allows the user a convenient means to switch from one operating system to another. Disk operating systems, however, reduce the amount of user available RAM, a disadvantage which can be overcome with the purchase of more RAM. Operating systems stored within ROM are difficult, sometimes impossible, to replace, but they require no RAM. Some computer systems offer the advantage of both types of operating system storage by enabling the user to command a ROM operating system to give system control to a disk operating system when requested by the user.

If application software is to be provided in pre-written packages, one must ensure that the operating system supports those packages, necessitating, of course, that the application software be chosen prior to the remainder of the system. Some computers operate with only one operating system, while others can operate with several. Some operating systems can support a wide range of applications software, which renders a computer system to a large number of potential applications.

The most standardized operating systems such as CP/M, or MS DOS can usually operate on all computers which use a particular CPU. These standardized operating systems support a large number of application programs which avails the user to a wide range of potential applications. Application software packages written for use with a particular operating system will operate on machines that use that operating system only if compatible with other components of the computer system such as storage devices, storage media, etc. A greater number of programmers are familiar with standard operating systems.

Operating systems intended to support software which is to be written or modified by the user, should support the preferred programming languages. The number of simultaneous users, and the type of tasks to be performed must be carefully matched to the capabilities of an operating system. These considerations will be a major determinant of cost. Single-user/single program systems generally range in price from $1,000 to $20,000.

The operating system must be compatible with the peripherals used. Operating system programs which control operation of peripherals are called drivers. Most operating systems are machine dependent, meaning they are designed to operate with a particular processor. Operating systems can usually run on processors which are similiar in design. Those which are transportable can operate on more than one type of computer. Application software is at least as machine dependent as the operating system which it is designed to operate with. If the computer is to be connected to a computer network, the operating system must be able to support the connection. In some cases, additional hardware may be required as well.

The method of data access utilized by the operating system effects the speed and efficiency of it's performance. Information may be retreived either serially or randomly. Random access operating systems usually retreive data by keyed values. Those systems are referred to as either index sequential access, or keyed sequential access systems. Serial access operating systems may be used to access data on random access storage devices. However, this combination does not take advantage of the potential speed offered by the storage device. Random access software is not usually compatible with serial access storage devices.

The most popular machine independent operating systems available for single user systems are CP/M, UCSD-p, and MSDOS. Apple DOS, IBM's PC DOS, and Radio Shack's TRS DOS are probably the most widely used single user brand dependent operating systems. The most popular multi-user systems are UNIX, and MP/M. Oasis is an operating system which runs on both single and multi-user systems.

CP/M

The CP/M operating system was developed by Digital Research Inc. The system requires 32K of main memory, and is the most popular operating system for single user systems. Some versions of CP/M support multi-user systems. The standard version can operate on any computer which uses a Zilog Z80, Intel 8085, or Intel 8080 processor chip as it's CPU. CP/M is compatible with a wide range of software as well. The greatest advantage of using CP/M is it's popularity. There are a large number of application programs available to run on CP/M, as well as programming consultants familiar with the system. This is helpful if software is to be traded or modified. Inspite of it's popularity, CP/M is not the most efficient or well designed operating system available. CP/M is difficult to learn initially for those who want to design their own application software.

UCSD-p

The UCSD-p system offers the greatest program portability of the single-user systems and can also operate on a large number of computers. USCD-p was first developed to support Pascal, but at this time supports FORTRAN and BASIC as well. UCSD-p provides many facilities which are normally found on operating systems for larger computers. The system is marketed and supported by SoftTech Microsystems, Inc. in San Diego.

MP/M

MP/M is much like CP/M, accept that the system can support multi-user environments, and data security features are provided. MP/M operates on the Intel 8085, 8080, and the z-80 family if processors. The MP/M-86 version runs on the Intel 8086, and 8088 processors for 16-bit computers. MP/M is marketed by Digital Research Inc.

Unix

Unix, until recently, has been available only for mini-computers. With the recent development of more powerful 16-bit computers, Unix has become available for some smaller systems. Unix requires 256K bytes of internal memory, and is capable of handling multi-user and multi-tasking systems. The full Unix system provides many useful user facilities, such as; data handling capability, text editing, and typesetting commands. UNIX supports the C programming language, and is used primarily on the mc68000 family of microprocessors. UNIX was developed by Bell Laboritories for use on digital equipment, and is marketed by Western Electric.

OASIS

The OASIS operating system is available on both 8-bit and 16-bit microcompters, and can accommodate both single and multi-user systems. This is especially advantageous for single-user systems which will eventually be upgraded to multi-user systems. The OASIS system contains many features used in multi-user business environments, such as; password control, user accounting, data security, and data integrity. Data integrity is a facility which protects the data of one user from interference from another. OASIS is marketed by Phase One Systems, Inc. of Oakland, California.

2.2.2.2 Utility Software

Within this study, utility software is defined as the set of programs which provide facilities that ease the task of the user to enter data and run application software. An operating system is essential for the processing of application software, whereas utility software only adds convenience. This is the definition intended by most system programers although the term has taken on a variety of definitions throughout the computer industry. Utility programs alleviate the need for commonly used processing facilities to be included in application software. Some of the most useful utilities include sort, merge, library, trace, edit, and copy functions.

The sort function commands the computer to search through a file and arrange data according to a user specified key. Special features to be considered for this type of function include the following:

maximum number of sort keys available
length of sort keys
ability to specify ascending or descending order

A library is a set of frequently used functions which may be summoned either by the operator or by commands within a program. The use of library functions removes the need to repeat all the commands required to command those functions each time they are needed. The library should include those functions most often used for a particular application.

An editor is a program which allows a user to create and enter a file of text using an interactive input/output device. The file is usually displayed upon a monitor. The text may easily be altered by commands which create, delete, or move a line, a character, or a block of text. Editors may be provided either within a language translator, or as a separate utility.

A trace facility is a helpful programming tool used to detect logic errors within a program. The trace shows the programmer what the computer is doing as a result of each program instruction.

The ability to copy the contents of one storage medium onto another is essential to provide a means of back-up in case of equipment failure, or human error. If this facility is not provided within the oeprating system, it should be provided as a utility.

Summary Of Selection Considerations

System Software

Required application software support

Required hardware support

Preferred programming language support

Required telecommunication support

Required number of simultaneous users and tasks

- Single-user/single program
- Single-user/multi-program
- Multi-user/multi-program
- Multi-user/multi-program

ROM vs. disk storage

Method of data access (random vs. sequential)

Portability

Speed

Essential utilities

- Sort
- Merge
- Library
- Trace
- Edit
- Copy

Required upgradability

Cost

2.2.3 Application Software

Introduction

Applications are the jobs which computers are used to perform. Tasks which are implemented on computer systems usually involve repetitive steps which can be well defined in logical terms, and are performed with enough frequency to justify the cost of computerization. The most common computer applications are business related tasks such as inventory control, cost estimation, and accounting. Programs designed to perform specific applications are collectively referred to as application software. Appendix A presents a summary of project types typically undertaken by landscape architecture firms, as well as individual tasks involved in those projects. Each task varies in it's suitability for computerization.

The selection of application software is usually the most challenging aspect of computer system selection. Success or failure of a computer system is highly dependent on the application software used. In general, the more the user is involved in program design, the more useful the program will be for the user. The design of application software usually entails the steps defined below.

1. **Problem Definition**- User needs are defined in an accurate and thorough description of the tasks which the computer is to perform for the user. The success of the implementation is highly dependent upon the accuracy of this description.

2. **System Design**- All programs, input, output, and data files required for the implementation are identified. Functional relationships between these components are identified. The system design is often expressed using a series of flow charts.

3. **Data Description** - All data prescribed within the system design are described in detail, i.e. variable type, format, minimum and maximum values, etc.

4. **System Specifications** - Computer system charactersistics required to implement system design are determined.

5. **Documentation** - A users guide is developed which describes to a prospective user, how the program is to be used. If documentation is developed at this early stage, the program designer is more apt to accommodate user needs in the program.

6. **Program Design** - Program design begins with a high level algorithm. Design proceeds through the development of increasingly lower level algorithms, each a more detailed version of the one which precedes it.

7. **Coding** - The lowest level program design is expressed in a computer language.

8. **Testing** - The program is checked for errors, and errors are corrected.

9. **Conversion** - Data to be used for an application is entered into the data files.

10. **Operation** - The new computerized system usually operates in tandem with the non-automated system until proven error free.

Application software may be obtained in one of three ways:

1 - Programs may be written in-house

2 - A custom programmer may be employed to write software tailored to the needs of a specific user

3 - Programs may be obtained in pre-written packages

Software Written In-house

When software is written by those employed by the firm in which it will be used (in-house), the author/s commonly proceed through all the steps within the software design process, from problem definition through system operation. In most cases, the user is the most qualified candidate to design the system, as there is often more for a professional programmer to learn about the application, than there is for the user to learn about programming, for either to produce useful software.

The advantages of software development in-house are especially significant to the landscape architecture profession. The design process which landscape architects step through as a matter of daily professional practice closely resembles the top down design approach employed by most professional computer programmers. Top down design involves generating a solution to a problem at a very high level of detail in the initial stages, and defining the solution at progressively lower levels of detail as the problem solving process progresses. This approach ensures that each detail of the solution will meet the broad objectives of the program, or the landscape design, as the case may be.

Most landscape architects are well practiced at this approach and therefore have already developed the basic thinking processes required for good computer programming. Aside from this logical thought process, the other skills required for good programming are the ability to write and to understand basic arithmetic. Most landscape architects have developed these skill as a matter of professional survival, and are capable of both learning a programming language and writing well structured programs. Once having acquired this skill, the landscape architect need not restrict computer usage to those applications originally planned. The needs of the firm and individual projects may be addressed as they change.

Landscape architects are commonly faced with widely dissimiliar project types. Site design solutions must usually take into account a wider variation of factors than design solutions developed by related professionals. Landscape architects must maintain a high degree of flexibility to optimally address the needs of individaul projects. Software designed to assist the practice must be adaptable. Otherwise, the computer may restrict instead of enhance the quality of professional services. In-house programming capability is one of the best ways to ensure the software flexibility required.

The level of programming expertise required to design useful software, depends upon the complexity of the application. Those which involve sophisticated graphics and data base management may require a more extensive knowledge of programming techniques.

Customized Software

Custom programming may be the only source of software available to firms which cannot afford the time required to acquire programming expertise in-house, and have applications for which there is no available software. Custom programmers may be contracted to design software which is tailored precisely to the needs of their clients. The time and cost required varies according to the experience of the programmer, and the complexity of the application. The cost will be considerably less for those applications for which the consultant has a master program. Otherwise, software must be developed from scratch.

A master or skeleton program is often developed for applications which have been undertaken by the consultant previously. A skeleton program contains the basic logic required to perform the task. The programmer then only need to design the specific details which will suit the program to the unique needs of individual clients. Software which must be developed from scratch requires more time and expense, and is usually more error prone.

Firms which contract the services of custom programmers will need to work very closely with the consultant to ensure that the software will meet the needs of the application. The process involved in custom design is summarized below.

1. Request For Proposal (RFP) - The user submits a Request For Proposal to potential custom programming firms. The Request For Proposal includes a general description of the applications to be

addressed.

2. Consultant Is Selected - Proposals submitted by potential consultants are collected, and compared. A consultant is selected.

The remainder of the software development process procedes as described for the development of programs written in-house. The more closely the user works with the consultant, the greater the chance of success. Designation of a steering commitee to direct the software design process may serve to maximize user involvement.

The following factors should be considered in the evaluation and comparison of proposals for programming services. Proposals will contain information concerning the supplier, the general approach to system design, and the contract.

1 - The more past experience the supplier has had in dealing with an application, the lesser the cost, and the greater the chance of success.

2 - The design approach should address the requirements stated in the Request For Proposal.

3 - The supplier should be willing to provide references. The recommendations of references can offer valuable information concerning the services offered by the consultants.

4 - The consultant should be able to communicate well with the client, preferably demonstrating a background understanding of the tasks at hand.

5 - Costs to be considered include the following:

1 - the initial cost, which should include the cost of

planned modifications,

2 - allowance for the cost of unanticipated modifications,

3 - the cost of on-going program maintenance. If the supplier is not under contract to maintain the program, the user must have access to the original source code and documentation.

6 - The contract should state a cost for only the first few phases of the design process. Based upon the time expended on this initial phase, cost estimates may later be projected for the remaining services. This will help avoid the problem of underestimated cost, which can pressure the consultant into taking short cuts which would not benefit the user. A higher than actual cost estimate is preferable to a low estimate. The first phases estimated should include the problem statement, and the system specifications, unless otherwise are provided by the user.

7 - The contract should state that the product of the first phases included in the cost estimation will be the property of the user. If the system specifications are not satisfactory, the user then has the option of changing suppliers.

8 - The time schedule proposed by the supplier must be compatible with the requirements of the client, allowing for some contingency.

Packaged Software

Packaged or 'canned' programs are pre-written programs which have been patented by the author. Licenses to use packaged programs are marketed through computer dealerships, mail order catalogues, software houses, etc. Once the program license has been purchased, ownership of the program itself remains with the author. Buyers may purchase a single processor license, which grants the right to use the program on a single computer. Legally, a separate license must be purchased for each CPU on which the program is processed.

The design of packaged programs is usually generalized to accommodate the needs of a wide range of users. If the package does not meet the requirements of a specific user, the buyers may either alter their method of operation, or find a way to alter the program. If the supplier is not under contract to make the alterations, the users must make sure they have access to the source code and the documentation to customize and update the packaged program as required.

Packaged programs are usually the least costly type of application software, provided the package meets the user's requirements. The cost of pre-written packages is usually borne by several users. Packages are also usually well tested and more reliable due to the experience contributed by a large number of users. Most packages currently applicable to the landscape architecture profession, address the needs of the practice in a piece-meal type fashion. Programs are designed to perform portions of many of the tasks listed in Appendix A. The cost of more comprehensive, or integrated software which performs sets of those tasks is usually prohibitive. Nonetheless, there are a number of programs available which perform useful work for landscape architects. One should at least acquire a general knowledge of packaged programs on the market before selecting the most suitable programs. The awareness of available options may prevent duplication of effort and unnecessary programming expense.

Some software packages are designed to a be self-customizing to meet individual needs through the use of paramaters which the user may specify. Little or no programming knowledge is required of the user to make use of such self-customizing programs. Such packages present the user complex programming facilities as well as flexibility. Self-customizing packages may provide the key for applications represented by markets too small to attract the efforts of professional programmers, but which require development of individualized sophisticated software.

Packaged programs are designed for either general purpose, or industry specific applications. General purpose software performs tasks useful to almost any type of business. Industry specific programs address tasks which are common among specific businesses. Industry specific software is designed to accommodate the unique needs of a particular business or profession, i.e. architecture, medicine, or the construction industry.

General Purpose Software Packages

The wide market for general purpose software has resulted in an abundance of reliable programs which are useful to most types of business. General purpose programs are sometimes marketed as part of a turnkey system, that is, a computer system which includes all of the hardware, software, and vendor support required for system operation and maintenance. The most popular types of general purpose software include those which perform data base management, word processing, and accounting applications.

Data Management Systems

Data management systems also referred to as information management systems, are programs which control the storage, retrieval, selection, and sorting of data. The basis of a DMS is a data base, a collection of computerized data files. Data bases usually contain large quatities of data which are stored on mass storage media. A data management system combines utility functions with the data base. The utilities enable the user to create and modify application programs. Routines typically provided within a DMS enable the user to perform the following functions:

1 - select data from the data base,

2 - arrange and display data according to a specified format

3 - define relationships between selected sets of data,

4 - display, plot, or print defined relationship

Data bases are used most effectively to store information which is accessed frequently, i.e. text, plant characteristics, design and construction standards, or cost data. Data bases are also used to store information pertaining to specific projects such as site characteristics, design alternatives, job accounting, or construction specifications. If used to store graphic coordinates, data bases may be used to generate design and construction drawings. Such applications require a highly sophisticated data management system. The advantages of utilizing a data base for the storage of information include the following:

1 - Large amounts of data may be stored and retreived by the user in a rapid and efficient manner.

2 - Data may be referenced according to keys, and therefore need not be duplicated.

3 - Relationships between data may be defined and quickly represented to the user.

Many data management systems are designed to be self-customizing, so that the user may define both data to be stored, as well as relationships to exist between sets of data. Data management systems available for 8-, 16-, and 32-bit microcomputers enable a user to design and create an application program. Due to the level of programming expertise required to write a DMS from scratch, a self customizing packaged DMS can be a highly useful and cost effective tool to most businesses.

The electronic spreadsheet is one type of self-customizing, or paramater driven data management system. Data is presented to the user in a format consisting of rows and columns. The user may define the data to be entered, and the relationships to exist between rows and columns of data. Most spreadsheets may be adapted to a variety of applications.

Word Processing Software

Word processing is probably the most widely marketed type of general purpose package. A word processor allows the user to create a file of text which can be stored, manipulated, displayed, and copied at the user's command. Most enable the user to add, delete, alter, and move text within a text file. Packages which either contain file handling capability or interface to a data management program, provide a highly useful tool repeatedly producing documents from a common bank of data, but which must each be individualized in a unique manner. Information to be included within documents may be stored within a database, a master file, or series of files. The word processor may then be used to selectively draw that data, and arrange it to create a unique file of text, in a cut-and-paste fashion. Contract documents, construction specifications, reports, proposals, and letters are produced most efficiently in this manner.

Accounting Software

The most commonly used general purpose accounting packages are those which perform general ledger, accounts payable, accounts receivable, payroll, and inventory. The software capability required varies with the size of the business, and the number of transactions to be handled.

Industry Specific Packaged Software

Industry specific packages currently available which are applicable to landscape architecture include those which perform job costing, project mangement, landscape construction calculations, and computer-aided design and drafting (CADD).

Job Costing Packages

Job costing software provides mangement valuable information concerning resources expended on a project. A package may be used to generate a project history for each job. This job file may be used to store time and cost expended on each aspect of a job. Some packages handle client billings, payment, and balance due in addition. Aside from the accounting service provided, the project histories may serve as a basis for projection of future cost estimates.

Site Engineering Calculations

A number of programs available perform the calculations involved in the solution of site engineering applications, being quite useful as calculating operations are time consuming and repetitive. Many of these types of programs are provided on chips for programmable calculators as well. The development of such programs requires a relatively low level of programming expertise, and can usually be developed cost effectively in-house. The use of electronic spreadsheets further simplifies the task of in-house programming for site engineering calculations.

Software which performs a larger share of the site engineering design process in a more comprehensive manner will be of even greater use in practice. For example; programs can be designed to perform each of the site engineering processes for a particular site in such a way that the user can quickly see the impact of each aspect upon another. To data, integrated software of this nature is more often addressed specifically to the needs of engineers and architects, and the cost is high.

Computer-Aided Design And Drafting

There exists a tremendous potential for microcomputers to assist landscape architects in the design process. Much of the design process can be defined in logical terms, and is practiced with enough frequency to justify the cost of software development. Time expended upon the design processes is often cut short in practice due to time and cost limitations. As a result design potential of alternative solutions is left undiscovered. If the logical and mechanical aspects of the design process are computerized, a greater number of potential solutions can be generated, leaving the landscape architect more time to concentrate on the creative aspects of the design process.

The computer can be employed to produce and weigh design alternatives against a defined set of objectives in the time required to produce one alternative manually. The computer can also enable the user to observe the impact of several aspects of each design simultaneously, effecting a time/cost savings and enhancing the final product.

Several available design and/or graphics packages perform small parts of the design process utilized within landscape architecture practice. Graphics packages which produce sophisticated displays are much easier to find than those which are useful. To be of practical use, a graphics package must relate to those aspects of design which are to be expressed graphically, such as site layout, contour maps, etc. Graphics packages capable of displaying a user defined site design are scarce and expensive.

CADD systems which perform a large portion of the design and drafting process, in an integrated fashion, are usually available for large computer systems, and range in price from $50,000 to $3,000,000. Most of these packages are designed specifically for use in large architecture or engineering practices. Typical tasks performed by CADD software applicable to landscape architecture include the following:

design

- schematic planning - bubble diagramming
- space design and analysis
- generation of design alternatives
- master planning
- production of working drawings
- generation of construction specification

graphics

- production of 2D and 3D drawings
- orthographic projection
- axonometric drawing
- texturing
- coloring
- mapping
    - cities
    - counties
    - states
    - natural resources
    - public and private utilities
    - landuse
    - property management

Small landscape architecture firms will most likely find the comprehensive CADD systems to be beyond economic feasibility for quite some time to come. Those firms may either write the software in-house, which would also involve considerable expense, employ a professional programmer, or adopt a self-customizing design and /or graphics program to their application. Of more practical use to landscape architecture firms at this time are self-customizing graphics packages which provide the user a set of pre-written graphics functions which may be called as needed within user written programs. The graphics functions may be combined to produce graphics required for specific applications by those who possess a modest knowledge of programming. Such programs vary greatly in the type and sophistication of graphics rountines provided. Functions typically provided include the following:

drawing a line

drawing curves

drawing shapes

dimensioning

coloring

texturing

scaling or rotation of images

Most packages will allow a user to call and combine these routines as needed to create a graphic display. The user may store frequently used displays or plots within files to be called as needed. For example; a library of construction details may be created to be plotted as required to generate a complete drawing.

Selection Considerations

Packaged Software

The features to be considered in the selection of packaged softare are innumerable. Most importantly, a package should meet the requirements of the intended applications as closely as possible. A number of factors effect software efficiency and ease of use. The most critical of these factors are listed below.

Documentation

Documentation is the description of a program and instructions explaining it's use, both in printed documentation, and within user guides displayed on the screen. The following areas should be covered within the documentation:

- how to initiate and terminate a program
- how to perform all rountine functions
- descriptions of each error condition and possible operator responses
- how to procede in case of abnormal termination
- description of safeguards built into the system to prevent loss of data

Whenever the software supplier makes a change in the documentation which effects a user, the user should be provided with new documents or inserts for old documents which describe the change.

Integration

One of the most useful and sophisticated features provided within packages is the ability to transfer data between programs. This eliminates a great deal of data entry operations. The ability to transfer data between programs, such as spreadsheets word processors, and graphics generators, enables much more comprehensive data processing.

Mouse/Window

Packages which operate with mouse/window capability represent one type of integrated software package. A mouse/window software system consists of several integrated programs which may be accessed in a back and forth type fashion. As with other integral packages, data may be moved from one program to another so that several packages may be used simultaneously. The screen is sectioned into windows which may each be used to display data generated by the user or different programs. The cursor is positioned on the screen using a mouse type input device. Use of the mouse can replace the keyboard. For example, a system which contains word processing, graphics, and database software could be used to generate reports which contain both graphic and textual information or for the production of construction details and proposals, lettered and dimensioned appropriately.

Menu

Menu driven software displays to the user a set of optional commands from which may be selected. Otherwise, command words must be typed on the keyboard each time a particular action is called for.

Ease Of Modification

Packages which need to be altered should be provided with a copy of the source code. Programs which are well structured are most easily understood and modified.

Error Processing

A good program filters out user errors as is possible. For example: a program may check to see if the user has entered alphabetic characters in numeric fields, or values outside of their designated bounds. Error checking capability can save the user a significant time.

Exception Processing

Exceptions include power failures and computer malfunctions. If a failure occurs, a program should be able to recover without damage to existing files.

3. Computer System Selection Methodology

3.1 Introduction

The individual components which comprise a computer system include the following:

Hardware

- Computer
- Input devices
- Output devices
- Storage devices
- Communications devices
- Interfaces
- Enhancement boards
- Auxiliary equipment

Software

- Application software
- Programming and developmental software
- System software

Documentation

Vendor support

Section 3 sets forth a methodology by which potential buyers may select a complete computer system which will meet the data processing requirements of a particular user. The most appropriate selection methodology is dependent upon the combination of hardware and software suppliers chosen to furnish the system.

3.1.1 Hardware Manufacturers

Most microcomputer manufacturers only manufacture a portion of the computers which they market. The remaining components and peripheral devices are purchased from other manufacturers and assembled into a working system. The major companies usually manufacture a larger portion of the systems which they market. The term 'original equipment manufacturer' has taken on several interpretations throughout the computer industry. Originally the term designated manufacturers which actually manufacture all components marketed by the company. Regardless of whether or not a computer system is purchased from an original equipment manufacturer it is most important to ensure the availability and willingness of the supplier to provide necessary maintenance for the entire system. The types of microcomputer manufacturers which presently dominate the market include the following:

1 - mainframe manufacturers which also manufacture microcomputers,

2 - minicomputer manufacturers which also manufacture microcomputers,

3 - manufacturers which manufacture microcomputers only,

4 - turnkey suppliers, and

5 - systems houses

Mainframe Manufacturers

The most successful mainframe manufacturers (IBM, NCR, Burroughs, and Univac) manufacture computers and business equipment. Mainframe manufacturers usually market microcomputer systems through their own sales offices, along with software and vendor support. In some cases the microcomputers are marketed through computer stores such as Computer Land or Computer World, or through department stores such as Sears. Software available for microcomputers marketed by the major companies consists primarily of general purpose packages. In the event of a hardware supply shortage, contractual obligations with retail outlets are met prior to those with individual buyers in which case buyers dealing with a department store may have a shorter waiting period. The manufacturer can offer the buyer a recommendation concerning the optimum vendor through which to purchase a computer system. The following outline sets forth the advantages and disadvantages of purchasing a microcomputer system from a mainframe manufacturer.

advantages

1 - Mainframe manufacturers usually offer a wide range of peripherals enabling the buyer to purchase a larger portion of a complete computer system from a single supplier. The greater the number of suppliers contracted to supply system components, the greater the chance of difficulty encountered in securing system maintenance. In cases where a number of suppliers have provided the various components of a computer system, there is often a

tendency to blame a malfunction on components supplied by another vendor in attempts for suppliers to escape the responsibility of maintenance. This 'pass the buck' syndrom can result in time delays for the user.

2 - Investment in a mainframe manufacturer involves less risk for the buyer due to the size and reliability of the major companies as compared to a smaller and less stable supplier.

3 - Hardware and software provided by mainframe manufacturers is usually well proven.

4 - Vendor support provided by mainframe manufacturers is usually more extensive than that of minicomputer and strictly microcomputer manufacturers, baring some notable exceptions such as Radio Shack and Apple.

5 - Mainframe manufacturers usually offer the user a greater number of financing options (rent, lease, or purchase) than do smaller companies.

Disadvantages

1 - Due to the relatively high level of vendor support provided by mainframe manufacturers, the cost of microcomputer systems is usually higher than that offered by smaller companies. The additional cost may be justified only if the user actually required the support.

2 - The range of application software designed for use on most microcomputer systems manufactured by the major companies is comparitively limited. The most notable exception to this is IBM.

3 - The number of plug-compatible components available for microcomputers manufactured by the major companies is usually less than that provided for those muanufactured by smaller companies. Plug-compatible components are those which may be connected to and operated on computers manufactured by a variety of suppliers.

Minicomputer Manufacturers

Minicomputer manufacturers which also manufacture microcomputers include Digital Equipment Corporation (DEC), Wang, Data General, General Automation, and Microdata. Minicomputer manufacturers most often market their microcomputers through their own sales offices. The advantages and disadvantages offered by microcomputer systems provided through these types of manufacturers are summarized in the following statements.

advantages

1 - Microcomputer systems provided by minicomputer manufacturers are generally less costly than those produced by mainframe manufacturers.

2 - Application software provided for microcomputer systems produced by minicomputer manufacturers is usually more abundant than that provided for those produced by mainframe manufacturers.

3 - The number of plug compatible components available

for microcomputer systems manufactured by minicomputer companies is usually greater than that for systems produced by mainframe manufacturers.

Disadvantages

1 - Microcomputer systems produced by minicomputer manufacturers are usually provided with less vendor support than those produced by the major suppliers.

2 - Minicomputer manufacturers more typically do not offer the buyer as much assistance in the selection or provision of application software as is provided by the major companies. Minicomputer manufacturers more commonly provide the user a list of software firms, leaving the user to locate required application software.

Microcomputer Manufacturers

Computer manufacturers which manufacture only microcomputers usually offer the least costly systems and the lowest level of vendor support. Microcomputer systems produced by these smaller companies are usually marketed through computer, department, or discount stores. Tandy Radio Shack is an exception to this trend in that Tandy microcomputer systems are marketed through their own retail outlets. Most computer stores offer hardware components as well as software packages 'off the shelf'. The buyer is often left to select and interface system components into a working system without a great deal of vendor assistance.

advantages

1 - Microcomputer systems manufactured by strictly microcomputer manufacturers tend to be the lowest priced microcomputers available.

2 - The greatest number of plug compatible components are available for microcomputer systems manufactured by the less major companies.

3 - The greatest number of application software packages are available for these brands.

disadvantages

1 - System maintenance is often more difficult when computer system components are provided by more than one vendor, which is often the case when microcomputers are purchased from smaller, microcomputer only manufacturers. The problem may be avoided to some extent if each vendor is contracted to provide maintenance, and the responsibilities of each are clearly set forth.

2 - Vendors of microcomputer systems provided by microcomputer only manufacturers provide less assistance to the buyer in selection of a complete working system. The buyer must assume greater responsibility to ensure compatibility between components.

Turnkey Suppliers

Turnkey suppliers, also referred to as business system suppliers, provide both hardware and software required to perform a particular set of applications as well as the vendor support required to implement and maintain the system. System support usually includes system assembly, documentation, training, installation supervision, as well as hardware and software maintenance. A fully running system is turned over to the user to be operated by in-house personnel. In the event that available software does not meet user requirements, custom programming is sometimes provided by the turnkey supplier. Turnkey systems are based upon both mini- and microcomputers. Radio Shack and AVL Eagle provide turnkey systems based upon microcomputers, while Cado and Qantel turnkey systems are both based upon minicomputers. The following summary indicates the advantages and disadvantages of turnkey systems.

advantages

1 - The buyer of a turnkey system can be assured that all system components will operate together successfully.

2 - Turnkey suppliers provide a high level of system support to the buyer.

3 - The amount of investment risk is minimized to the buyer of a turnkey system.

4 - Potential buyers of turnkey systems can usually observe the proposed system in operation by other users prior to

purchase.

disadvantages

1 - The cost of turnkey systems is much higher than those with equivalent hardware and software components, but less support.

2 - Hardware and software options provided by turnkey suppliers are usually quite limited. This may not be a problem if the turnkey system happens to meet the buyer's requirements, or if custom programming is provided.

3 - Turnkey systems often accommodate only a narrow set of applications.

Systems Houses

Hardware vendors, software suppliers, or consulting firms, in some cases, operate in the capacity of systems houses. Systems houses are contracted to select both the software and hardware to accommodate applications specified by users. A systems house will assemble an entire or a partial system as the buyer requests. The buyer, for the most part, is totally relieved of the responsibility for system selection, however, the cost of this type of service is high. Buyers which require custom programming services may be sufficiently fortunate to locate a systems house which will enter an agreement with the buyer to offset the cost of services. For example, in the event that a user wishes to address an application which has not yet been accommodated by available application software, and the systems house is convinced that there is an adequate market for the application, then the systems house may enter a contract with the buyer which specifies that the systems house will research the user's requirements, and develop software which will accommodate the application. As the software is marketed to other users, the original buyer is compensated for his input in developing the system. This arrangement provides a means by which users may acquire the benefits of custom programming services for which the expense could otherwise not be justified. Such an arrangement can be especially beneficial to those with highly unique applications, such as landscape architects.

3.1.2 Software Suppliers

The three primary sources of application software are the user, custom programmers, and packaged software. Programs developed within the business or institution of the user, are said to be written in-house. Staff members whom are knowledgeable of the intended applications, in some cases, may acquire the programming expertise required for software development. Otherwise a programming professional may be contracted to develop the application software. The choice depends upon the time required by either to accomplish the programming task, and the value of that time. The most ideal candidate for a software developer is one who possesses knowledge both of the intended applications, and of computer programming.

The services of custom programmers may be [illegible] rate of approximately $45 per hour (Long, 1987). Custom programmers operate through software houses, hardware suppliers, and systems houses. The number of packaged software suppliers is so great, that it would be impossible to learn, let alone analyze the product of each. Software suppliers are not usually known to general public. Computer dealerships commonly have catalogues which list software suppliers and available packages. Trade magazines, user groups, and professional associations also provide a means by which to locate industry specific packages. The most thorough and up-to-date summary of software available for landscape architectural practice is provided by Design Compudata, edited and published by Frank A. Stasiowski. The catalogue, which is updated yearly, provides a brief description of both hardware and software as as well as consultants available for the design professions. Applications covered within the catalogue include engineering, project management, scheduling, budgeting, cost estimating, and CADD.

Methodologies

Based upon the available sources of hardware and software, there exists essentially five methods by which potential buyers may select a complete computer system.

Hardware And Software Provided By One Vendor

Case 1 - Turnkey System

All system components are supplied by one vendor, who provides both the hardware and software, training, documentation, and system support required for to install and operate a complete system. The vendor commonly answers questions as necessary, ensures that the system is running properly, and provides system maintenance for a specified period of time.

case 2 - One Vendor - Varying Support Level

One vendor provides all system components. The level of support may vary from none to that of a turnkey system.

Hardware And Software Provided By More Than One Vendor

Case 3 - Software Supplied In-house, Hardware Provided By One Or More Vendors

Case 4 - Software Provided By Custom Programmer, Hardware Provided By One Or More Vendors

Case 5 - Software Provided As Pre-written Packages From Independent Software Suppliers, Hardware Provided By One Or More Vendors

The remainder of this section outlines basic selection methodologies most appropriate for each case. The recommended steps need not necessarily be followed in the sequence set forth, as the purchase of each system presents a unique set of circumstances. For example, most firms will find that more than one case applies if more than one application is being computerized. The suggested methodologies are intended to serve as guidelines.

Subsequent sections within this study provide a more detailed description of each step proposed within the following methodologies. The procedures involved in each methodology are essentially the same, but vary in their sequence, and in the degree of detail in which they are practiced. The methodologies have been designed to maximize user involvement in the selection process, improving the probability of obtaining a system which will meet the user's requirements.

Case 1 Turnkey System If Using Packaged Software

1 - Identification of data processing goals	user
2 - System design	user (little detail)
3 - Data design	user (little detail)
4 - Development of computer system specifications	user
5 - Develpment of request for proposal for supplier	user
6 - Supplier selection	user
7 - Hardware and software selection	user and supplier
8 - Customizing if any	user and supplier
9 - Testing	user and supplier
10 - Computer system implementation	user and supplier
11 - Operation	user

Case 2 - Turnkey Supplier If Custom Programming

1	- Identification of data processing goals	user
2	- System design	user
3	- Data design	user
4	- Development of evaluation criteria for supplier	user
5	- Development of request for proposal for supplier	user
6	- Supplier selection	user
7	- Hardware selection	user and supplier
8	- System design	user and supplier (greater detail)
9	- Data design	user and supplier (greater detail)
10	- Documentation	user and supplier
11	- Program design	user and supplier
12	- Coding	supplier
13	- Testing	user and supplier
14	- Computer system implementation	user and supplier
15	- Operation	user

Case 2 - One Vendor, Varying Level Of Support

1	- Identification of data processing goals	user
2	- System design	user
3	- Data design	user
4	- Development of computer system specification	user
5	- Development of request for proposal for supplier	user
6	- Supplier selection	user
7	- Hardware selection	user
8	- System design	user (and supplier) (greater detail)
9	- Data design	user (and supplier) (greater detail)
10	- Documentation	user (and supplier)
11	- Program design	user (and supplier)
12	- Coding	user (and supplier)
13	- Testing	user (and supplier)
14	- Computer system implementation	user (and supplier)
15	- Operation	user

The procedure matches that of case 1 accept that the supplier is less involved in the process, depending upon the level of vendor support provided.

Case 3 - User Programming, One Or More Hardware Suppliers

1 - Identification of data processing goals	user
2 - System design	user
3 - Data design	user
4 - Development of computer system specifications	user
5 - Development of request for proposal for hardware suppliers	user
6 - Hardware selection	user
7 - Documentation	user
8 - Program design	user
9 - Coding	user
10 - Conversion	user
11 - Operation	user

Case 4 - Custom Programming, One Or More Hardware Suppliers

1	- Identification of data processing goals	user
2	- System design	user
3	- Data design	user
4	- Development of criteria for custom programmer	user
5	- Development of request for proposal for custom programmer	user
6	- Custom programmer selection	user
7	- System design	user and systems analyst (greater detail)
8	- Data design	user and systems analyst (greater detail)
9	- Determination of hardware requirements	user and systems analyst
10	- Development of evaluation criteria for hardware	user and systems analyst
11	- Development of request for proposal for hardware	user and systems analyst
12	- Hardware selection	user and systems analyst
13	- Documentation	user and systems analyst
14	- Program design	user and systems analyst
15	- Coding	coder
16	- Testing	coder
17	- Computer system implementation	user and consultant
18	- Operation	user

Case 5 - Packaged Software, One Or More Hardware Suppliers

1	- Identification of data processing goals	user
2	- System design	user (little detail)
3	- Data design	user (little detail)
4	- Software search	user
5	- Development of criteria for software packages	user
6	- Development of request for proposal for software suppliers	user
7	- Software selection	user
8	- Development of criteria for hardware (set forth by software suppliers)	user
9	- Development of request for proposal for hardware suppliers	user
10	- Hardware selection	user
11	- Computer system implementation	user
12	- Operation	user

3.2 Identification Of Data Processing Objectives

Prospective computer system buyers often tend to diminish the potential advantage offered by a computer system by initially focusing upon an overly narrow set of objectives and/or by projecting data processing requirements over too short a period a time. A short sighted approach may result in the purchase of a system which does not enhance the growth or performance of a business. The system may be well geared to perform applications originally considered, but totally inadequate to accommodate application of future importance. Buyers often find themselves limited by a system which cannot be upgraded to perform more sophistocated applications as their business is capable of supporting the investment. The establishment of data processing objectives forces the buyer to analyze data processing needs on a comprehensive basis so that the maximum advantage over the life of the computer system may be realized.

Data processing objectives should be projected over a period of at least five years. Computer hardware depreciates its' full initial purchase price within a period of three to five years. Computer systems which are fully depreciated however are usually still of value to the user, depending upon the applications which are being implemented on the system. Within the depreciation period, technology usually progresses sufficiently to suggest the purchase of newer systems which can perform applications more efficiently than the systems originally purchased. The user must then evaluate the relative benefits of investment in a new system, or continuing with and/or upgrading the old system.

Data processing priorities may be identified by consideration of the range of tasks performed within a firm, and the subsequent determination regarding the suitability of each task for computerization. A work profile for a typical landscape architectural firm is represented in Appendix A. Within the profile, the types of tasks commonly undertaken by a firm are identified. Since the purpose here is to determine the general areas best suited to computer implementation, the tasks need not be described in great detail. Those tasks selected for computerization will be defined more thoroughly within the system and data design phases of the computer system selection process.

The work profile also represents a description of office procedures and permanent files which are kept on record. Essentially, the work profile serves as a tool by which to summarize all of the operations involved within a practice.

Once having developed a work profile, the suitability of each task for computer implementation may be ascertained. The primary determinants of suitability include the following:

1 - the initial cost required to computerize the activity,
2 - the on-going cost required to computerize the activity,
3 - the benfits realized from computerization of the task, and
4 - the relative value of the task within a firm's operations or pratice

An accurate estimation of cost and benefit must take into account the following factors:

1 - time required to perform the task manually,

2 - time required to perform the task by computer,

3 - value of the time of the professional who performs the task,

4 - percentage of time expended on the task as compared to all tasks performed within the firm,

5 - value of the task within the business, and

6 - cost of the computer system

At this point within the selection process, the factors noted may be estimated based upon the general criteria set forth below.

1 - Initial Cost Required To Computerize The Task

Initial hardware cost will be greatest for applications which require relatively expensive equipment such as plotters, or letter-quality printers. Applications which require the processing and storage of large quantities of data are relatively costly as well. Design and drafting applications tend to generate greater hardware and software expense than applications such as engineering calculations, word processing, or accounting for small landscape architectural firms.

In addition, the programming costs associated with sophisticated applications for which there exists no application software packages are usually high. The cost of software development is especially high in the event of the following circumstances:

- there are no self-customizing packages available which would lessen the programming effort required,
- the programs to be developed must be capable of interaction with other programs
- the problem and/or data is difficult or impossible to define and represent in logical terms
- the problem is complex, involving many decisions and logic branches, or involves software development which will require a high level of programming expertise such as that required by CADD applications which typically require an extensive knowledge of programming data bases.

2 - On-going Cost Of Computerization

Applications which require extensive data entry often incur a great deal of on-going cost due to operator expense. CADD applications commonly require a large amount of data input. In most cases the time expended upon the input of graphic data can be minimized by use of a graphic input device such as a digitizer or an optical scanner. Integrated software which automatically passes data from one program to another, diminishes the time required for data entry operations.

Applications which require a high degree of flexibility are usually most costly to implement, especially in the event that data and/or programs must be altered frequently. Software flexibility is especially critical to landscape architectural practice as many of the tasks involved are less standardized than those of related professions.

3 - Benefits Offered By Computerization

Advantages rendered by computerization of a task include the time/cost savings affected as well as the more intangible benefits which are more difficult to measure. Tasks which yield the highest ratio between time required to perform the tasks manually versus by computer, are most likely to affect a high time/cost savings. Marketing efforts may be enhanced by the use of a computer system to generate and maintain up-to-date mailing lists, and client histories. Computer usage may also award high-level management more time to expend upon profit making ventures.

The design and construction processes may be enhanced by computer usage in a variety of ways. Some applications may be performed with greater accuracy by computer, which may be advantageous for some engineering and accounting applications. Designers may be freed of mundane and time consuming tasks, enabling more time and energy for creative and intuitive input into the design process. Computers may allow more efficient access to data stored either in-house or accessed via telecommunications links, providing the user a basis for more informed decision making. A computer system may enable landscape architects to generate a greater number of potential alternative solutions to a given problem, and therefore select from a wider range of options enabling designers to quickly and thoroughly observe the positive and negative aspects of alternative solutions.

4 - Relative Value Of The Task

The value of a particular task to a firm is dependent upon the percentage of time expended on the task, and the value of the time expended by the staff member who performs that task. The economic return generated in performance of the task within a business also effect the relative importance of the task, as well as present and future business goals.

The prioritization of potential tasks [illegible] implemetation involves consideration of a tremendous number of factors. The practicality of implementing an application on a computer system must be weighed against the usefulness of doing so. The evaluation matrix represented within Appendix A presents a format in which all factors may be more easily taken into account at once. Rows designated along the vertical axis are used to designate tasks performed in a typical landscape architectural office. Columns along the horizontal axis are used to record factors on a priority basis to include the following:

relative initial cost

relative on-going cost

relative benefit

relative value of the activity

Each prioritizing factor is assigned a weight which reflects the relative importance of that task. Greater weights reflect higher value.

The suitability of permanent files for computer storage may be ascertained according to the following criteria:

- files frequently accessed are most suitable
- files most vital to the operation of a firm are most suitable
- files which must be updated most frequently can benefit from computerization
- files containing information which would become more valuable with improved access are most suitable
- files which can most easily be converted to computer storage are most suitable

Once having developed a prioritized list of tasks to computerize, a schedule may be designed which sets forth a time frame for the implementation of each task. As a rule of thumb, approximately three months should be allowed for the implementation of each task, allowing time to purchase the necessary equipment and software, train the operators, and convert to the new system. This time frame should, of course, be adjusted to accommodate the complexity of each task. Applications need not necessarily be scheduled in the order of their priority ratings as some applications may benefit from the implementation of another and applications which require similiar system components may be implemented most cost effectively out of the initial priority sequence.

Identification Of Data Processing Objectives

A Case Study

The hypothetical landscape architectural firm used to demonstrate the selection methodology proposed within this study shall be referred to as Environmental Design Associates. The hypothetical firm is a sole proprietorship consisting of seven staff members. The work profile presented within Appendix A reflects the procedures practiced within Environmental Design Associates.

Development of a prioritized list of tasks performed within Environmental Design Associates was based upon the evaluation matrix presented in Appendix B. These priorities are presented within Table 3.1. The highest priorities include financial management, construction calculations, construction scheduling, cost estimation, and various aspects of the design process. The projected priorities reflect an increase in the importance of computer-aided design and graphics within the future. The projection also indicates a desire to perform more construction services, and less in the area of planting design.

Development of an implementation schedule requires consideration of factors other than the priority ratings. As indicated in Table 3.2, the schedule set forth for EDA groups tasks according to the type of hardware and software required for their implementation. The schedule has been sequenced so that Environmental Design Associates may venture a relatively small investment initially, and gradually increase the financial

Prioritized List of Tasks

for Computer Implementation

1 Financial management

2 Marketing

3 Site engineering calculations

4 High-level design development

5 Conceptual site engineering design

6 Construction scheduling

7 Cost estimation

8 Schematic design

9 Construction specifications

10 Schematic grahics

11 Site analysis graphics

12 Presentation graphics

13 Schematic evaluation

14 Hard materials palette

15 Plant materials palette

16 Planting specifications

17 Construction maintenance guide

18 Inspection reports

19 Contract documents

Table 3.1

Prioritized Tasks For Computer Implementation

Environmental Design Associates

COMPUTER IMPLEMENTATION SCHEDULE

FIRST YEAR

JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
ACCOUN-TING	WORD PROCESSING		CONSTRUCTION SPECIFICATIONS		CONSTRUCTION SCHEDULING		CONSTRUCTION COST ESTIMATION		CONSTRUCTION CALCULATIONS		

SECOND YEAR

JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
CONSTRUCTION CALCULATIONS						SCHEMATIC GRAPHICS					

THIRD YEAR

JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
SITE ANALYSIS GRAPHICS											

FOURTH YEAR

JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
WORKING DRAWINGS											

Table 3.2

Schedule For Computer Implementation

Environmental Design Associates

commitment as the computer system begins to pay for itself.

High priority applications which can make use of word processing, file management, and accounting software are the first applications scheduled for implementation. Packaged software will be utilized for these applications as much as possible as there exists an abundance of relatively inexpensive general purpose packages. Software to perform construction calculations, however, will be programmed in-house to allow the required level of flexibility. The development of software designed to perform construction calculations requires a relatively limited knowledge of computer programming and will serve as a tool for the staff to develop programming skills.

Although CADD applications are high priority tasks, they are scheduled for implementation at the end of the scheduled period. This will allow the staff an opportunity to develop programming expertise required to write, or at least modify much of the CADD software. The in-house development of software to perform design and graphics applications is considered essential to ensure the degree of flexibility required throughout the design process. User-written software designed to perform construction calculations may later be used as a basis to generate construction drawings. Although this approach will alleviate the necessity to purchase a system capable of performing CADD applications initially, the selection of a system which can be upgraded to perform those applications will be critical.

3.3 Task Definition

The work performed by a computer system must reflect the purposes of the user, whether or not the user be an individual or an organization. The ultimate success of a computer system is dependent upon how well the user objectives have been defined and the role the of computer in the attainment of those objectives. Once data processing objectives have been identified individual applications may be further defined within a task definition.

A **task definition** essentially provides an explanation of how a computer system will be used to perform a particular application. The task definition eventually serves as a basis for the development of computer system specifications, indirectly in the case of pre-packaged software, and directly in the case of software developed in-house or by custom programming consultants. The level of detail provided within a task definition is dependent upon the degree of user involvement in the software design. The task definition need only provide a level of detail adequate for the development of computer system specifications.

Task definitions for applications to be implemented using packaged software need only be defined in general terms. The time expended to develop a highly specific task definition for packaged programs would probably be largely wasted as packages which perform precisely according to user requirements are usually a rare find. Task definitions for packaged programs do not serve as a basis for the development of computer system specifications directly, but instead as a guide for the location and selection of software packages. Hardware specifications for packaged programs are provided by the software supplier.

Task definitions for applications to be implemented using software written in-house or customized software will be most useful if developed in a thorough manner with great attention to detail. Task definitions for software yet unwritten will provide the sole basis for development of computer system specifications. In these cases, the task definition may later serve as a basis for software development as well.

Task Definition For Environmental Design Associates

A Case Study

Applications to be implemented by Environmental Design Associates were identified within Section 3.2 (The Identification Of Data Processing Objectives). The majority of applications to be performed within the first six months will be implemented using packaged programs. The majority of the initial applications will make use of self-customizing data base management and word processing software. Those programs scheduled to be written in-house will be written in an integrated fashion such that each individual program will be developed independently in the initial stages, but will be modified to operate in a progressively integrated manner throughout the implementation period. "Integration is essentially the technique of making multiple use of input data, and of using the output of one sub-system as the input of another." (Campbell, 1984:45). This approach was selected to accommodate the highly interactive nature of the design processes.

The software source of each application to be implemented by Environmental Design Associates is indicated within the following summary.

Pre-written packages	Software written in-house
financial management	construction calculations
cost estimation	site analysis graphics
marketing	schematic design graphics
construction specifications	presentation graphics
construction scheduling	

Some of the applications which are to be implemented using packaged software in the initial stages, may later be re-written so as to become a component of a more integrated comprehensive software system. The assumption will be made, for the purposes of this study, that Environmental Design Associates has conducted a software search and selected the packages to be implemented on the proposed system.

Programs developed to perform each aspect of construction calculation will be developed and implemented on an individual basis initially. Each will be modified to operate interactively throughout the implementation period.

Task definitions for projected graphics applications to be implemented will be developed in-house once the Environmental Design Associates staff has acquired an adequate level of programming expertise and experience. Since Environmental Design Associates intends to upgrade the initial system for graphics applications, software portability will be a critical software design factor.

Anatomy Of A Task Definition

A task definition is essentially comprised of two parts; the process flow, and the data description. The process flow is a step by step procedure by which to solve a problem. The process flow is developed in phases according to a top down approach which devotes progressively greater detail to each successive phase. The components which comprise the process flow include the following:

- problem statement
- structure diagram
- hierarchy of input/process/output
- flow chart
- code

The data description provides an explanation of each data element which will be input, processed, and output throughout the system. It should be noted that simple problems need not necessarily be approached in such a thorough manner. The development of a task definition for complex problems can render a tremendous time savings and result in a software system which more accurately addresses user requirements.

The task definition developed to serve as an example within this study has been designed to accommodate the road alignment application proposed by Environmental Design Associates.

3.3.1 Process Flow

Problem Statement

A problem statement is a written description of the functions to be performed by the computer system. The statement should generally explain the purpose of each program and how outputs will be derived from inputs. This usually begins with a listing of all data to be input by the user, processed by the computer, and output to the user. Ideally, the statement should be defined with as accuracy and detail as possible. "Programmers frequently find that the shorter the problem definition, the longer it takes to develop the solution to the problem." (Campbell, 1984:39). Campbell further noted that "The acid test of a problem definition is whether it is so clear and so complete that anyone designing the program from it will develop basically the same results." (Campbell, 1984:40). The following problem statement sets forth basic objectives which apply to all of the construction programs to be developed for Environmental Design Associates as well as the objectives particular to the road alignment application.

General Problem Statement

For Construction Calculation Applications

The general purpose of all programs developed to perform construction calculations will be to perform computation necessary to produce working drawings and specifications for each aspect of construction on an individual basis in the initial stages. The collection of construction programs will be upgraded to operate more interactively as the software system is developed. The construction programs to be implemented include the following:

- road alignment design
- earthwork estimation
- storm drainage design
- construction detail design
- sanitary sewer design
- water distribution design
- irrigation design

Individual programs will generate pertinent data to be accessed by related programs allowing a more comprehensive approach to the solution of design problems. Programs will be designed with flexibility adequate to facilitate interaction with other software to be written in-house, such as programs designed to perform cost estimation, project management, the development of construction specifications, site layout, and graphics. Individual programs will be designed to generate project histories which may be stored on auxiliary storage media. The project histories will contain files to be edited and stored for future reference as needed. Graphics will be performed manually in the initial stages, however, programs eventually will be upgraded to generate working drawings.

Problem Statement

To Perform Road Alignment Calculations

The basic objective of the road alignment program will be to perform calculations necessary to close a traverse and to design horizontal and vertical curve layout. Traverse computations will be performed first, followed by the calculation of horizontal curve and then vertical curve data.

The traverse program will accept the following as input from the user:

- traverse line distances and bearings approximated by the user from a manually drawn site plan, unless given
- required precision factor
- designation of fixed traverse bearings or distances

The program will calculate the following variables for each traverse line:

- traverse line ID
- precise bearing
- precise distance
- sine
- cosine
- latitude
- departure
- north coordinate
- east coordinate

The program shall then determine the following:

- sum of latitudes
- sum of departures
- diff. in the sum of north lats and the sum of south lats
- diff. in the sum of east deps and the sum of west deps
- total traverse length
- error of closure
- precision factor

The program will then recalculate all program variables to the preferred correction method until the required precision factor has been achieved. Three permanent files will be generated to provide project histories which may be accessed both by other programs and by the user as needed. Those files will include a general project data file, a traverse line computation file, and a traverse totals file. The contents of those files is outlines below.

General Traverse Data File

project name
street/road name
closed traverse ID
required precision factor
traverse line correction method

Traverse Line File

for each traverse line:

traverse line ID
bearing
distance
sine
cosine
latitude
departure
north coordinate
east coordinate

Traverse Totals File

sum of north latitudes
sum of south latitues
sum of east departures
sum of west departures
diff. in sum of north and south latitudes
diff. in sum of east and west departures
total traverse line lengths
error of closure
precision factor

The portion of the program designed to perform horizontal curve computation will accept the users specification of the following:

street/road name
desired regular station interval
design speed
for each proposed curve
    traverse point reference at point of intersection (PI)
    either:
        preferred curve radius
        or
        preferred point of curvature (PC) and curve length

The program shall read from the appropriate traverse computation files the appropriate traverse point IDs, traverse line lengths and traverse line bearings. The program will also generate a station ID for each regular road station.

For each horizontal curve the prgram will generate values for the following variables:

delta angle
arc length
distance between the PI and the PC or PT (tangent)
chord length
PC station (point of curvature)
PT station (point of tangency)
PI station (point of intersection)
degree of curvature
external ordinate
mid-ordinate
incoming traverse reference
outgoing traverse reference

The program will also calculate the total road length. The program will generate two files to be accessed by other programs or users as needed. The contents of those files are listed below.

General Project Data File

project name
street/road name
design speed
regular road station interval
total road length

Horizontal Curve File

for each horizontal curve:
- curve ID
- delta angle
- curve length
- distance between PI and PC or PT (tangent)
- chord length
- PC station
- PT station
- PI station
- degree of curvature
- external ordinate
- mid-ordinate
- incoming traverse ID
- outgoing traverse ID

The portion of the program designed to perform vertical curve computation will accept the following data from the user as input for each proposed vertical curve:

point of vertical intersection (PVI) reference
PVI station
PVI elevation
regular road station interval

The program will generate values for the following variables for each vertical curve:

PVC station
PVC elevation
PVT station
PVT elevation
incoming traverse gradient
outgoing traverse gradient
algebraic difference between incoming & outgoing gradients
minimum curve length

The program will display the minimum length of each curve to to the user, and then accept the preferred length of each curve from the user. The program will then calculate values for the following variables for each vertical curve:

PVC station
PVC elevation
PVT station
PVT elevation
mid-ordinate
end-ordinate
hi-point or low-point station and elevation

The program will generate three permanent files to be accessed by other programs or the user as needed as summarized below:

General Project Data

project name
road name

Vertical Curve Data

for each vertical curve:
- curve ID
- PVC ID
- PVI ID
- PVT ID
- PVC station
- PVI station
- PVT station
- PVC elevation
- PVI elevation
- PVT elevation
- incoming traverse gradient
- outgoing traverse gradient
- algebraic difference between incoming and outgoing gradients
- minimum allowable curve legnth
- curve length
- mid-ordinate
- end-ordinate
- hi- or low-point station

Station File

for each regular station throughout the entire vertical curve:

reference
elevation

Development Of A Structure Diagram

A problem statement may be represented by a structure or tree diagram, a graphic illustration of a problem and it's components. A structure diagram is represented as a hierarchy of modules which represent aspects of a design solution. The modules are stacked into levels of detail which become progressively more defined from top to bottom. Each module represents a unique function and is branched into constituent sub-functions at the next lowest level. Each module exerts control over it's branches.

The main function module represents the basic problem to be solved. The main function is usually broken into three sub-functions; input, process, and output. These sub-functions are in this order on the diagram from left to right. Diagram 3.1 illustrates the basic format of a structure diagram. Diagram 3.2 illustrates the use of that format to structure the solution to the road alignment problem for Environmental Design Associates. The structure diagram serves primarily as a means to clarify and communicate ideas and maintain perspective of the basic problem to be solved.

Development Of Flowcharts

Solutions to problems defined within problem statements are most efficiently developed into computer programs in a modular fashion in which the major task to be performed is broken into progressively smaller related subcomponents usually called

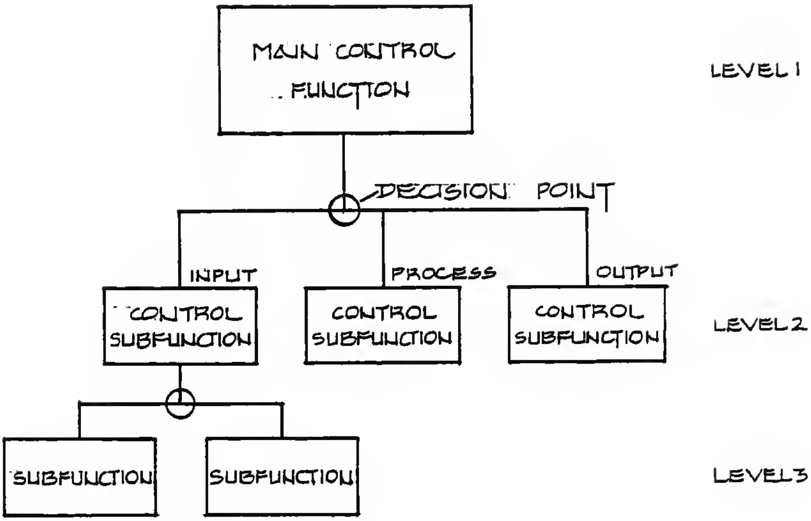


Diagram 3.1

Format Of A Structure Diagram

Adapted From Campbell (1984:52)

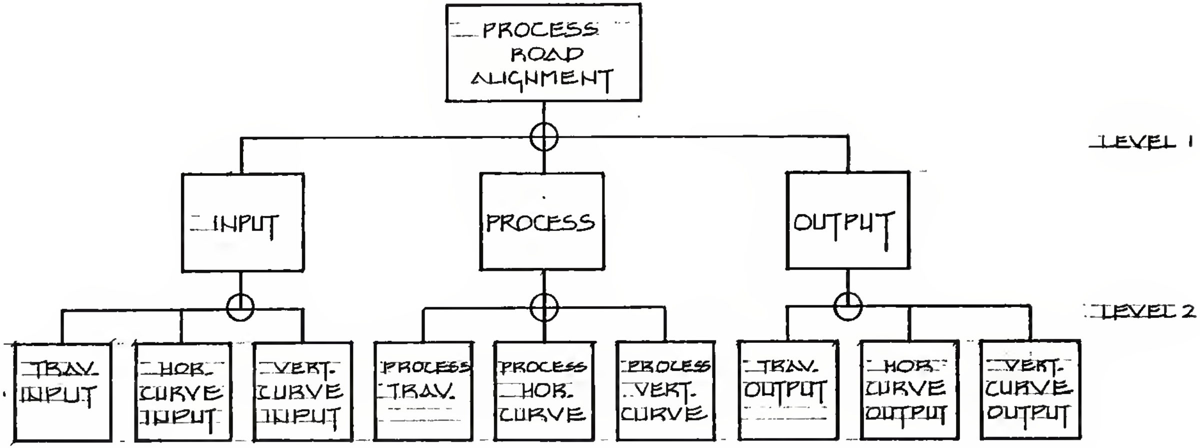


Diagram 3.2

Structure Diagram

Solution To A Road Alignment Problem

Environmental Design Associates

modules. Modular programming gained popularity in the 1970's due to the reduced complexity and maintainability enabled by structured programs. Modular programming is a tool which allows the software designer to break a problem into manageable components while maintaining perspective of the whole solution.

Components to a problem solution may be represented within a flowchart, a diagram which graphically illustrates the sequence of steps required to solve a defined problem. Flowcharts allow program designers to check problem solving logic prior to coding the problem solution into a specific programming language, often saving a great deal of time when operator errors are detected.

System flowcharts represent high-level problem solutions in which individual modules represent loosely defined functions. Program flowcharts represent low-level solutions in which functions are defined in more specific terms and often need only be translated into a computer language. Typical flowchart symbols developed by the American National Standards Institute and the International Standards Organization are illustrated in Diagram 3.3.

According to the top-down design approach a problem is initially abstracted to a level which is manageable. Once the problem has been solved at this level, the solution may be defined at a lower, more detailed level. The problem is initially set forth as a sequence of loosely defined functions. Such a general solution may be represented graphically within a system flowchart. A high-level solution to the road alignment problem is represented within a system flowchart in Diagram 3.4

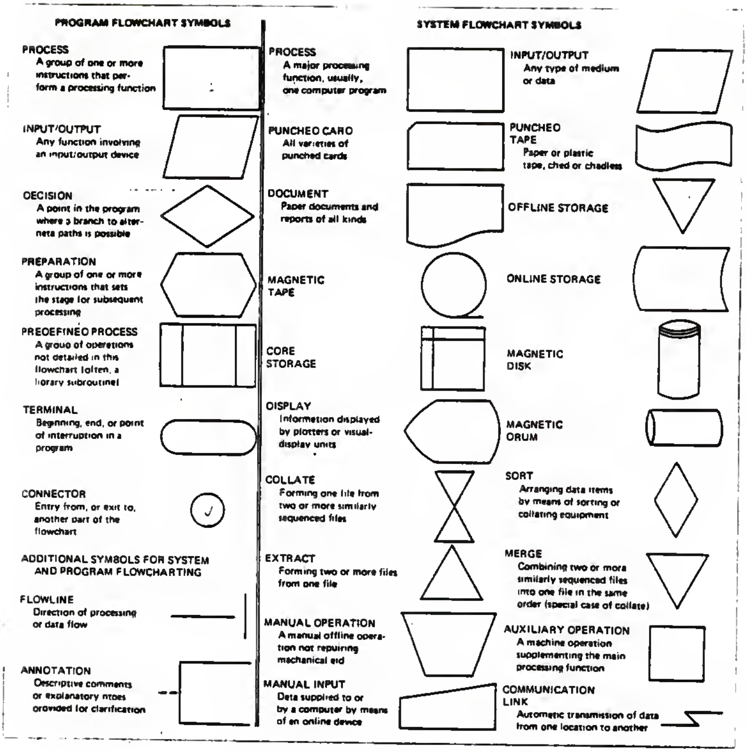


Diagram 3.3

Standard Flowchart Symbols

Adapted From Campbell (1984:212)

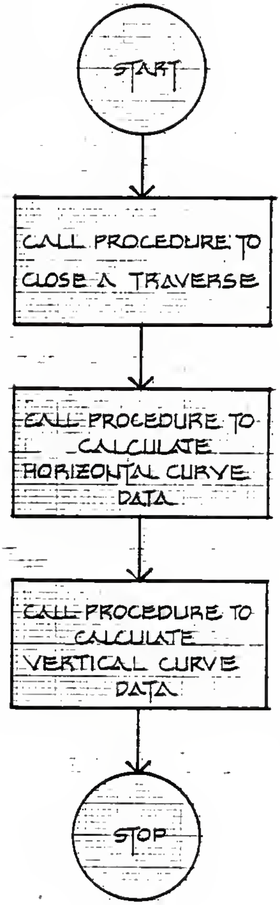


Diagram 3.4

System Flowchart

High Level Solution

Road Alignment Problem

Environmental Design Associates

Once having developed the high-level solution, the software developer should refer to the general problem statement to ensure that the solution accurately addresses the problem. If so, then the solution may be developed at a lower level, in which each module is more explicitly defined. In the case of complex problems each module may generate another system flowchart. Each succesive level of program development must be checked to ensure that the defined problem is being solved. Flowcharts illustrated in Diagram 3.5 through Diagram 3.10 represent the solution to one aspect of the road alignment problem through each phase of development. Procedures to be performed by the user, as opposed to the computer, are outlined with a double line.

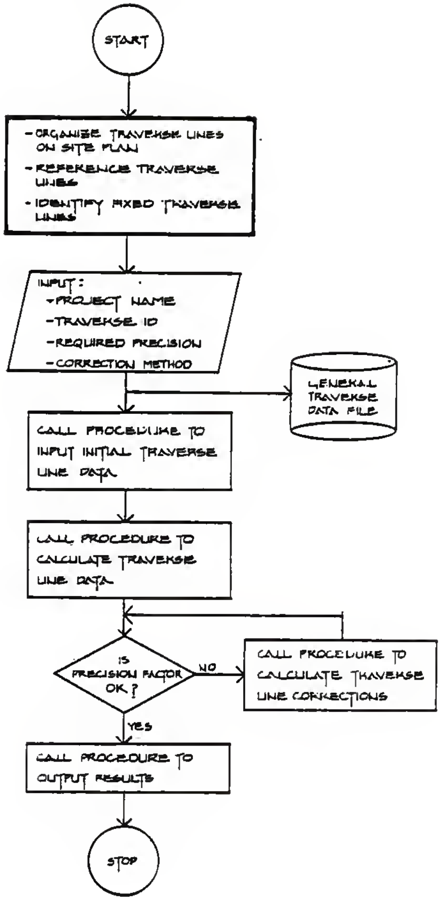


Diagram 3.5

Procedure To Close A Traverse

Program Flowchart

Road Alignment Problem

Environmental Design Associates

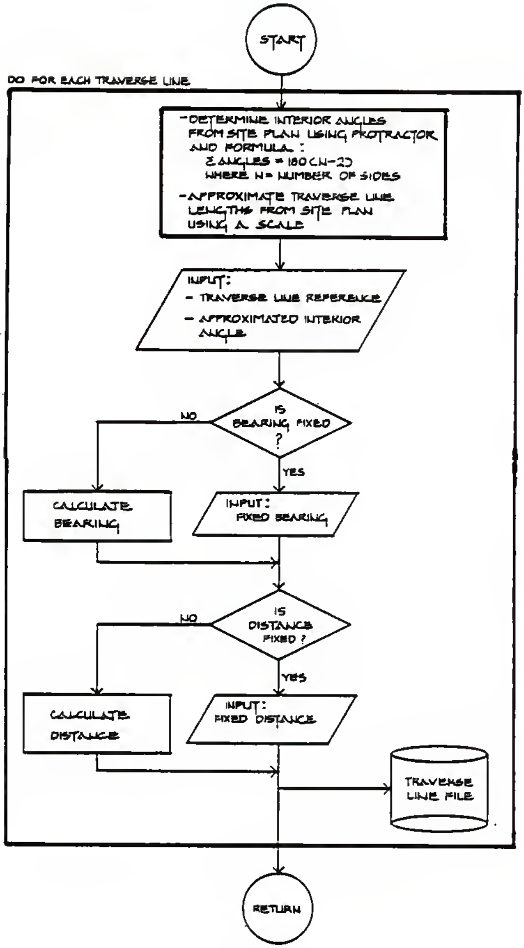


Diagram 3.6

Procedure To Input Initial Traverse Data

Program Flowchart

Road Alignment Problem

Environmental Design Associates

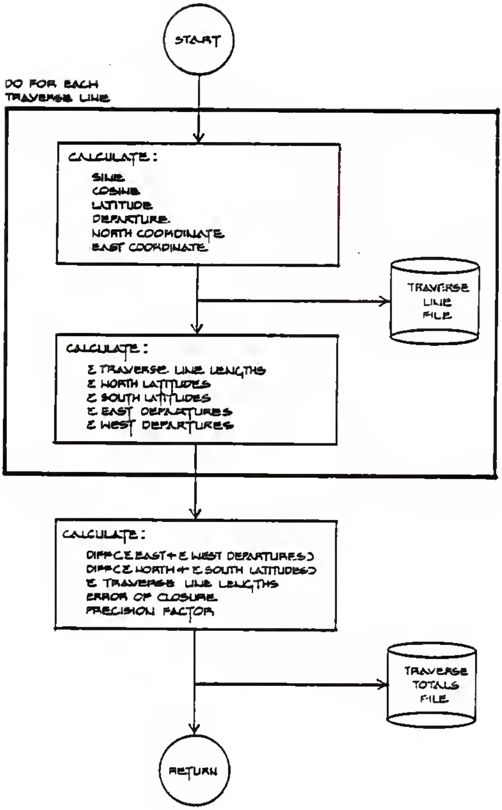


Diagram 3.7

Procedure To Calculate Traverse Data

Program Flowchart

Road Alignment Problem

Environmental Design Associates

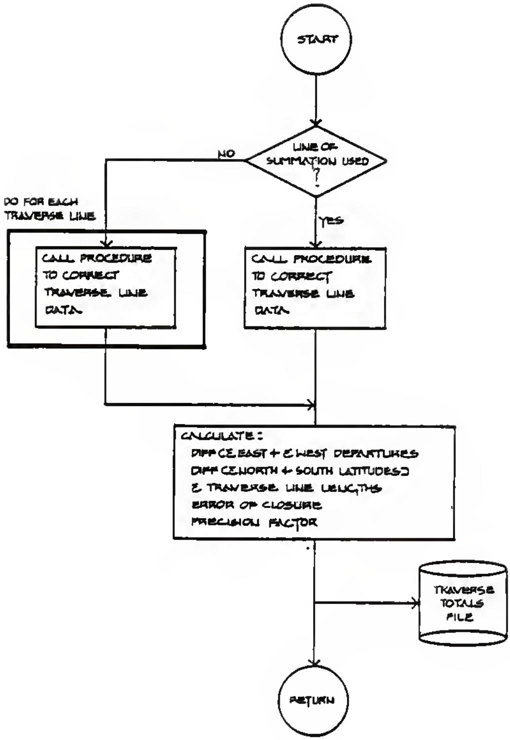


Diagram 3.8

Procedure To Correct Traverse Line Data

Program Flowchart

Road Alignment Problem

Environmental Design Associates

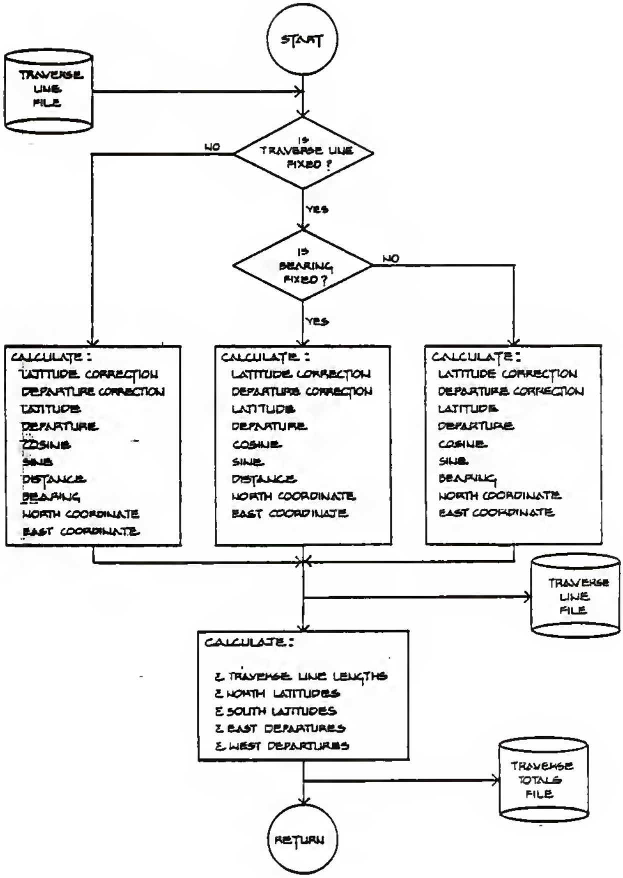


Diagram 3.9

Procedure To Calculate Traverse Line Corrections

Program Flowchart

Road Alignment Problem

Environmental Design Associates

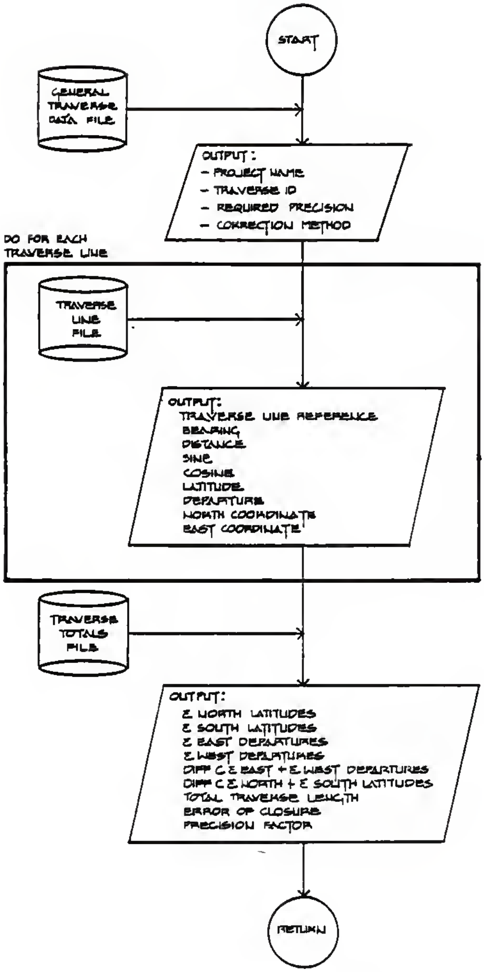


Diagram 3.10

Procedure To Output Traverse Data

Program Flowchart

Road Alignment Problem

Environmental Design Associates

3.3.2 Data Description

A data description serves to identify the attributes of data to be used within a program. The description should be developed concurrently with all phases of the process flow as individual data elements are identified.

Data is any information which is controlled by the computer system, whether the information be entered, processed, or generated as output. A data item is an individual unit of information which is not a constituent of a set of data. A data element is a unit of information which is a subset of a larger set of data. A variable is a uniquely named data item or data element representing a value which can fluctuate during program execution. A constant is a uniquely named data item or data element representing a value which does not change throughout program execution.

Data is commonly arranged within files, which are collections of information organized by data elements (fields) within records. Each record within a file contains the same set of fields. Fields are arranged identically within each record. Data files may be stored within the computer system either temporarily or permanently. Temporary files are used only within an individual program. Permanent files are stored on auxiliary storage media.

Arrays are temporary storage areas within programs, which exist only in main memory. Data elements of an array are arranged within a table with rows and columns which provides convenient indexing for the programmer. Individual data elements within the array can be accessed by specification of the array name and index reference of the data element location. Arrays do not make efficient use of the computer, but they ease the task of programming for some applications.

As the process flow is developed, the system designer should keep account of the data items to be used as well as the attributes of those items.

Data Attributes

Data attributes which affect program design and computer system selection include the following:

data type
format
minimum and maximum data values
required storage capacity
number of occurences
option to access

Data elements may be of several types, depending upon which language is used. The most common data types used within most programs include type integer, real, and character. Data items of type integer represent the values of whole numbers. Data of type real represent numbers with fractional parts. Data of type character represent textual data, usually letters and numbers.

The minimum and maximum values of data required for an application should be determined to ensure that those values can be represented by the system selected. The number of bytes required for the storage of each data item should be determined to enable the estimation of memory requirements, both main memory and auxiliary storage. Most 8-bit machines require 1 byte to store each character plus one byte to store the length of each character string, 2 or 4 bytes to store each integer, and 6 or 8 bytes to store each real number. Most 16-bit machines require 4 bytes to store each integer and 8 bytes to store each real number. Some systems will allow any data type to be stored within a text file as character type data, in which case the required memory capacity for numbers should be calculated the same as character type data.

The number of occurrences for each data item must be calculated to determine total required memory capacity which is equivalent to the memory required to store each data item multiplied times the number of occurrences of that item. The memory required of both temporary and permanent files should be determined independently. The estimated storage capacity for each file should be multiplied by a factor of 1.25 to account for memory required by the operating system which will manage the files. The option to access certain information will affect file and program design.

Certain program design factors may affect the design of files and the estimation of memory requirements. Data entered into a system should be stored within a file as quickly as possible within the location from which it is to be accessed. This practice will avoid the possibility of duplication which can needlessly double memory requirements. Data elements stored within an array must all be of the same data type unless using the computer language SNOBOL. If programming in Pascal, all records within a file must contain fields of the same types. However, fields within a record may be of varying types. Basic, as well as some dialects of FORTRAN will not allow both integer and real type data elements to be stored within the same record. In the event that all files are stored permanently on auxiliary storage media and one or more fields need to be accessed, the record in which that field is stored will be fetched into RAM. The consideration will affect the estimated amount of RAM required at any one time during program execution.

Appendix B presents a data description and summary of estimated memory requirements for the road alignment program for Environmental Design Associates. Estimation of memory requirements was based upon the use of Pascal which was selected as the programming language to be used for software developed in-house by Environmental Design Associates.

Conclusions

Systems analysts are computer professionals typically employed to develop task definitions for complex user applications. Systems analysts are usually knowledgeable in the area of programming as well as available hardware and software systems. They must become equally knowledgeable of the application areas to which a computer system is to be utilized in order to develop a successful computer system design. Landscape architects are usually much better equipped to define the tasks performed within a landscape architectural practice. This is particularly significant due to the tremendous degree of flexibility required from one project to the next in a typical office.

A high level of user involvement throughout the development of a task definition will yield a basis for software design and computer system selection which best meets the requirements of the user.

3.4 Development Of Computer System Specifications

The set of characteristics which describe a particular computer system are collectively referred to as computer system specifications. Once having defined the tasks to be computerized (as illustrated in Section 3.3) the potential buyer may identify the computer system specifications that describe a system which will best perform those tasks. Systems under consideration will include available systems which represent state of the art technology. The development of specifications involves consideration both of the tasks to be performed and the hardware and software selection considerations discussed throughout Section 2, Introduction to Computer Systems.

The computer system selection process can be performed more efficiently if specifications are distinguished according to their relative importance to the intended applications. The most useful distinction occurs between specifications which are critical and those which are only preferable, for both the initial and the projected applications.

The following section describes the development of computer system specifications for the case study, Environmental Design Associates. Appendix C provides a summary of selection considerations discussed throughout this study, and indicates the relative importance of each consideration for the applications to be implemented by Environmental Design Associates. Numbers within the Page Reference column indicate the page within this study which provide a more detailed description of each selection consideration. Appendix C also serves as a basis for the design of an evaluation matrix used for the comparison of potential computer systems.

The Development Of Computer System Specifications

For Environmental Design Associates

A Case Study

Software to be used for the majority of initial applications proposed for Environmrntal Design Associates will be implemented using pre-written software packages. Software designed to perform site engineering calculations, as well as projected design and graphics applications will be written in-house. The task definition described in Section 3.3 provides the basis for development of specifications for initial site engineering applications. Computer system specifications required for the implementation of packaged software is provided by the software supplier of each package. The specifications will be developed to accommodate projected design and graphics applications as well. Although the projected CADD applications are not accurately defined at this point, the most essential computer characteristics required may be identified.

The computer system selected for Environmental Design Associates must meet the requirements of all packages to be implemented, as well as the requirements for applications to be programmed in-house. If one application requires greater capability than another, the highest capability will be specified.

Configuration

The development of computer system specifications begins with the design of general configuration (i.e. the identification of individual system components required). Each of the seven member Environmental Design Associates staff will eventually be equipped with a work station suited to individual staff requirements. One staff member, the computer system proctor, will be responsible to familiarize himself with the new system, and manage the integration of the system into the landscape architecture practice. One work station will be acquired initially, to be used by the proctor at first. Once having gained adequate familiarity, work station one will be introduced to the office manager, who will implement the first scheduled applications. The remaining six work stations will be acquired as each staff member is prepared for computer implementation, and as demanded by the work load.

The first work station (to be used by the office manager) will be used primarily to perform applications based upon word processing, accounting, and database management software packages, and therefore will not require extensive graphics capability. Due to the small size of the staff, the remaining staff members each perform a wide variety of tasks encompassing writing and engineering as well as design and drafting. Work stations to be used by the landscape architects must therefore be capable of accommodating a wide range of job types. Those tasks which require the smallest degree of capability will be implemented initially, according to the implementation schedule set forth in Table 3.2 so that the amount of investment may be increased as the computer system is capable of supporting the investment. Each work station will originally be comprised of a monitor, a keyboard, and dual floppy disk drives.

The first station will require only a monochromatic CRT to accommodate business applications. The remaining work stations must be upgradeable to perform graphics, as CADD applications are implemented. All work stations will be networked to share one letter-quality printer, and two high speed dot matrix printers The letter-quality printer will be purchased for work station one to accommodate the production of correspondance quality documents. Output generated to leave the office will be produced using the letter-quality printer. The high speed printers will be operated to generate output for in-house use, (e.g. the results of calculations and first draft documents). As CADD applications are implemented, work stations two through seven will be networked to share a plotter, and a digitizer to enable graphic input and output. All stations will eventually be networked to share a hard disk system for the storage of commonly used data and programs.

Main Memory

Main memory capacity imposes a limitation upon software which may be run on a particular system, and is therefore a critical factor in system selection. RAM is usually required to store application programs and their associated data. Some systems, however, provide slots for ROM cartridges or modules which contain application programs. The cartridges are easy to use, and can enable the use of software which will not fit into RAM.

Programming and developmental software required to compile or interpret application software, and the operating system, are stored either in ROM or on disk. Software stored on disk is pulled into RAM when needed. Since the amount of RAM required to store language and system software varies from one system to the next, computer system specifications should indicate the required amount of user available RAM. User RAM is the RAM capacity required to store application programs and their associated data.

Most systems require that a program be stored within main memory in its entirety to enable program execution. Data may usually be stored on auxilliary storage media during execution and accessed as needed. The programmer must control the movement of information throughout the memory hierarchy using program instructions. The programmer must also keep track of the quantity of information required in RAM and on auxilliary storage media at each point during program execution. Some languages require that a program as well as its associated data both be stored within RAM prior to execution, which requires a greater amount of RAM. This is most commonly the case with particular dialects of BASIC.

Computer systems which have virtual memory capability allow a programmer to write programs without regard to the quantity of data or instructions stored throughout the memory hierarchy as long as the memory capacity required for both the data and program does not exceed mass storage capacity. The computer system keeps track of each program and data element, and controls the movement of information between main memory and mass store to accommodate the needs of the program. This process is transparent to the programmer and tremendously simplifies the task of programming. The estimation of RAM capacity required for virtual memory systems is not so critical because mass store can be treated as main memory. Few microcomputer systems have virtual memory capability at this time.

Main Memory - Estimation Of RAM Capacity Required For Programs

Main memory capacity required for packaged programs is specified by the software supplier. The estimation of memory required to store programs yet unwritten is extremely difficult for one without substantial programming experience. One can only venture a 'best guess' based upon the nature of the program as described within the task definition.

Programs which perform extensive data manipulation to generate a relatively small amount of data often require more memory than does the data. On the other hand, programs which perform relatively few calculations to generate a large quantity of data often require less memory than does the resultant data. Based upon these considerations, the program designed to accommodate the task defined in Section 3.3 will most likely require less memory than the resultant data. However, the assumption will be made that memory required for the program will be equal to that required by the data in order to provide a contingency. This estimation will be considerably high. The RAM capacity required for the program described in section 3.3 is therefore estimated to be 92K.

Main Memory - Estimation Of Ram Capacity Required For Data

RAM capacity required to store data for a program may be estimated fairly accurately according to the method described in section 3.3. The associated data is not usually required within RAM in its entirity at one time. Most systems allow a programmer to assign the data of a program to individual files which may be stored on auxilliary storage devices. Individual records of a file may be called into RAM as required by a program. Arrays provide the programmer a conveniant means in which to store related data. However, almost all systems require that arrays associated with a program must be present in RAM throughout program execution. Each array must be present in its entirity before any of it may be accessed by the CPU. Arrays which exchange data must be present within RAM simultaneously in order for the exchange to occur.

Based upon these considerations, the memory capacity required for the application defined in Section 3.3 is estimated as follows:

Total memory capacity required for data-92K bytes
(mass storage for data)

Maximum RAM capacity required at one time for data-126 bytes
(largest record)

Main Memory - Total RAM Required For Interpreted Program

Interpreted programs (i.e. those written in an interpreted language such as BASIC) require that the interpreter be present within main memory both when the program is entered, and during execution. Language interpreters may require anywhere between less than 100K to 450K bytes of memory, depending upon the sophistocation of the interpreter. The maximum amount of RAM required for the interpretation and execution of an interpreted program, on a system without virtual memory capability, may be estimated by the sum of the following:

User RAM

Maximum RAM capacity required by data at one time

RAM capacity required by the program

RAM capacity required by the language interpreter

RAM capcity required by operating system

Main Memory - Total RAM Capacity Required By Compiled Program

Programs written in compiled languages require RAM space both during program compilation and execution. The maximum amount of RAM required by a compiled program on a system without virtual memory capability may be estimated by the sum of either of the following:

RAM capacity required during program compilation:

RAM required for the compiler

RAM required for the compilation process

RAM required for the operating system

Or:

RAM required during program execution:

User RAM

RAM required for the object code

Maximum RAM capacity required for the data

RAM required for the operating system

Main Memory - Estimation Of RAM Required For Program Defined Within The EDA Task Definition

The amount of user available RAM required for the application described within Section 3.3 may be estimated by the sum of the following:

Maximum amount of RAM required for data 126 bytes

RAM capacity required for program 92K bytes

Total user available RAM required @ 92K bytes

The maximum total RAM capacity required by the largest packaged program to be implemented is 256K. Since this exceeds the capacity required for defined applications to be programmed in-house, 256K will be the specified RAM requirement. A system with virtual memory capability may not require this much RAM.

Environmental Design Associates intends to develop software in-house in an increasingly more integrated fashion, which incorporates a greater amount of data into each project. The ability to add more internal memory is critical to the projected design and graphics applications. For this reason, the system should be upgradeable to provide as much internal memory as possible for projected applications.

The ROM capacity required is dependant upon the system software and language translators to be stored within ROM. This will vary from one system to the next, and therefore is not a critical selection consideration. The flexibility enabled by use of user-programmable ROMs is not required for any of the intended applications.

CPU Word Length

Most 8-bit computers have a maximum internal memory capacity of 64K. The largest proposed application software packages requires a main memory capacity of 256K, which will require at least a 16-bit computer. The maximum internal storage capacity of most 16-bit microcomputers is 1 megabyte. The projected design and graphics applications will require rapid manipulation of large quantities of data. A 32-bit processor can operate with much greater speed and efficiency than can a 16-bit CPU, and would be much preferable for CADD applications where processor speed will be a significant factor.

Data Bus Word Length

A true 16-bit computer has a 16-bit data bus as well as a 16-bit CPU word length. Some of the acclaimed '16-bit' processors currently available have a 16-bit word length and only an 8-bit data bus. A wider data path is preferable, particularly for the projected CADD applications, as a 16- or 32-bit data path enables much faster operation.

Address Bus Word Length

Width of the address bus affects the number of addressable internal memory locations. The address bus width is important to the potential buyer only in that it poses a limitaton upon total internal memory capacity. Since internal memory capacity has already been taken into consideration, address bus width is not an important selection consideration.

Necessity And Availability Of An Expansion Chassis

Due to Environmental Design Associates intention to expand the internal memory capacity of the computers, the necessity and availability of expansion chassis should be investigated. If required, the availability of the chassis is a critical consideration for the projected applications.

Speed

Due to the projected CADD applications, processor cycle time may become a significant factor. In general, processors which operate in excess of 8 hz are relatively fast. Those which operate at less than 1 hz are painfully slow. Computational speed, however, is effected by factors other than cycle time, such as operating system speed.

The use of a benchmark test such as the test listed in Table 3.5 can be much more indicative of computational speed. The benchmark program can be entered and run on each system under consideration, so that run time may be compared. The program should be expressed in relatively few lines so that the test may be entered quickly. The benchmark test should preferably utilize commands which will be used with greatest frequency for intended applications. Since speed is best measured using a benchmark test, the required speed will not be specified to the manufacturer.

CPU Instruction Set

The value of a hardwire multiply, divide, or float is the increase in computational speed. However, speed is best measured by use of a bench mark test as described above.

Monitors - Type

A refresh monochromatic CRT will be most suitable for the first work station, to accommodate primarily word processing, accounting, and database management applications. Monitors selected for work stations two through seven must be upgradeable to display color graphics as they will be used to perform a wider range of tasks involving both textual and graphic display.

```
PROGRAM benchmark (input, output);

CONST
      outer_loop_size = 10000;
      inner_loop_size = 5;

TYPE
      array_range = 1...inner_loop_size;
      array_type = ARRAY [ array_range, array_range ] of real;

VAR
      array1   : array_type;
      x,y,z,a  : real;
      k,l      : integer;
      i        : 1...outer_loop_size;
      j        : 1...inner_loop_size;

PROCEDURE do_nothing;
      BEGIN END;

BEGIN  { main program }
      writeln( `program start')
      FOR i := 1 to outer_loop_size
      DO BEGIN
            x:=7.895; y:=4.7; z:=1.2; k:=5;
            if y > z then; (same result true or false, no action)
            a:=(x + y - (z * x)/x) + k;
            FOR j:=1 to inner_loop_size
            DO array1(j,j):=a + sin(a)/cos(y+x);
            do_nothing;
            l:=k + i
      END; { for }
      writeln ( `program end' )
END. { main program }
```

* The benchmark test is written in Pascal. *

Table 3.5

Benchmark Test For Computer Speed

Monitors - Display Quality

A high persistence phosphor (preferably type p7) will create a higher quality display, which will become of greater significance as graphics applications are implemented. A high persistence phosphor will also reduce eye strain during long periods of usage. The refresh rate is almost always fixed at a minimum of 30 hz for an interlaced display, and 60 hz for a noninterlaced display and therefore requires no specification. The refresh rate of a vector refresh CRT should be fixed instead of adjustable to eliminate the occurance of flicker as monitors are used to display more complex images. These factors are highly preferable in that they will enhance display quality and reduce user fatigue, but are not critical to the intended applications. Brightness is not a critical factor as the level of ambient light can be adjusted within the user environment and can best be evaluated in the user environment.

Monitors - Color

Color capability is not an important requirement for initial applications. Although the projected CADD applications are not yet accurately defined, some display charateristics are better suited to graphics applications than others. In general, a larger palette of simultaneously displayable colors will enable a greater number of discrete sets of information to be simultaneously displayed and distinguished by color. This capability can serve as a design tool when several design factors are under consideration; the screen can provide a means for visual conceptualization. The use of user defineable colors are preferable in that greater flexibility is enabled.

The color dot grain must be relatively small to enable a high resolution color display. However, a high screen resolution for color displays is indicative of a small color dot grain. Color dot grain, therefore is not in itself an important selection consideration. A user adjustable convergence will be moderately preferable in that the cost of maintenence may be reduced.

Monitors - Number Of Character Blocks per screen

Monitors used for all work stations must be capable of at least an 80 column display to enable users to view the appearance of a typical 8 1/2 by 11 inch page as text is entered. The number of displayable lines should be at least 24 so that users may view as much of the text as possible while typing. The number of pixels defined within the character block matrix is dependent upon the screen resolution and the number of characters displayed per line. For example, for a given screen resolution, the character block matrix for characters displayed in an 80 column line will have more pixels than characters displayed in a 132 character line. Specification of an adequately high screen resolution will ensure an acceptable character display.

Monitors - Screen Size

The screen should measure at least 9 inches diagonally to ease the effect of long term usage.

Monitors - Screen Resolution

Screen resolution of the monochromatic display used for intial applications should be at least 256 x 256 (or an equivalent number of pixels) to provide a clear and distinct picture adequate for extensive word processing applications. Monitors to eventually perform CADD applications should be upgradeable to display the equivalent of 512 x 512 pixels to provide a relatively clear dispaly of complex images. Screen resolution decreases when color capability is added to some systems. One should ensure that the required screen resolution can accommodate color graphics.

Monitors - High-Low Resolution Graphics Switch

The capability to display both textual and high resolution graphic data would offer little advantage for initial applications, but would be useful for design and graphic applications. The presence of a high/low resolution graphics switch (usually a software switch) would be moderately preferable for work stations two through seven.

Monitors - Electrostatic Vs. Electromagnetic Deflection

The additional control enabled by an electrostatic deflection system would be moderately preferable for design and graphics applications, but is not sufficient to consider an electrostatic system essential.

Monitors - Associated Software Routines

Although not a part of the display unit itself, software routines which may be used to drive a monitor can impact the usefulness of the machine, and should be taken into account as a selection consideration. Some of the more useful routines for design and graphics applications may include the following:

- generation of vector drawn lines, circles, rectangles, and curves,
- image scaling,
- automatic dimensioning,
- image rotation

Digitizers

The reading surface size of the selected digitizer must be able to accommodate drawings which measure at least 24" x 36", as the majority of drawings which would be used to supply graphic input are at least this large. Digitizer reading speed is not considered an important consideration, as most operators enter data more slowly than can be read by the slowest digitizer. A reading sensor with magnified cross hairs would serve best to enter detailed images with accuracy e.g. graphic data from engineering drawings. A pencil type reading device would enable more rapid data entry, most appropriate for the entry of rough sketches and drawings where accuracy is not critical. A digitizer which supports both types of reading sensors would be preferable.

Associated software routines which would be most useful include linear and area calculation, and angle determination. Automatic reversal and output data formatting rountines could save a great deal of time as well.

Keyboards - Output Code

Use of a standard output code ensures a larger number of compatible computers with which a keyboard can communicate. This consideration is most important if a keyboard is to be selected independently of a computer. However, most microcomputer systems currently available market the computer with the keyboard. If marketed together, the manufacturer has ensured that the keyboard can communicate with the computer. Since Environmental Design Associates intends to buy the individual work stations as a set comprising both computer and keyboard from the same manufacturer, use of a standard output is not an important consideration.

Keyboards - Data Code

Both initial as well as projected applications require that the keyboard generate a character ASCII set which includes both lower and upper case letters. The specification of mathematical notation is not necessary because character sets for virtually all keyboards include mathematical symbols.

Keyboards - Layout

A standard QWERTY keyboard layout is considered essential as all Environmental Design Associates staff members are familiar with the typewriter keyboard, and could use a QWERTY keyboard immediately without relearning the keyboard layout.

Keyboards - Baud Rate

The keyboard baud rate is not an important selection consideration as keyboards transmit data much more rapidly than most operators can type.

Keyboards - Features

Due to the large amount of numeric data anticipated, a separate numeric cluster which includes a comma, a period, and a carriage return, would add a great deal of speed to data entry operations. Rollover enables the most rapid typing speeds, and is therefore considered an essential characteristic due to the large quantity of data entry anticipated. A touch switch keyboard would be unacceptable for extensive usage.

Due to the extent of intended graphics applications, the provision of a separate cursor control keypad would simplify the movement of the cursor on the screen. Many keyboards use the numeric keypad to double as a cursor control pad. Due to the combined use of numeric data entry and cursor control required by many grahpics applications, the double function of the numeric/cursor controls may slow down data entry operations.

Keyboards - Editing Controls

Character insert/delete, line insert/delete, split screen control, and wraparound are functions which add convenience, particularly to word processing applications. Keys which are marked in a manner which indicates the functions which they may generate (intuitive function keys), are considered an asset by some operators, in that the marked keys alleviate the need for operators to learn which keys generate certain functions. It should be noted, however, that the character or control function generated by any key is dependant upon the software used to drive the keyboard. Any key can be defined to generate any function using appropriate software. The use of intuitive function keys is a matter of personal preference.

Monitors - Display Controls

Display controls as well as keyboard editing controls must be supported by appropriate software to be of use. Display controls such as reverse video, double-intesity, and blinking capability add some conveience to operations as a means by which to draw the operators attention to certain areas of the display. These controls are not considered critical to any of the projected applications.

Printers - Type

The printer purchased for the first work station will be used primarily to generate correspondance quality documents such as letters, reports, specifications, and contract documents. The printer will also be used to generate legends, title blocks, and notes for use on presentation drawings. A high resolution correspondance-quality dot matrix printer would be most suitable to provide both the flexibility and the high quality output required. Low cost dot matrix printers would be most suitable for the remaining work stations, where speed is of greater importance and output quality is not critical to generate documents for in-house usage.

Printers - Legibility

Legibility is a critical factor for the initial correspondance-quality printer to be purchased. Legibility is moderately significant for the printers to be used to generate output for in-house usage. Dot-resolution for the correspondance quality printer should be at least on the order of 24 x 18 dots to ensure the appearance of fully formed characters. The use of overstrike and doublestrike capability would enable bold-faced headings which would be highly preferable for the ouput of legends, and reports to be sent out of the office. The correspondance-quality printer should be capable of proportionality spacing to provide a neat appearing type-written page.

Contrast, distinctness, uniformity, and pitch are best judged by visual inspection. One may request that the manufacturer supply an example of printed output produced by each correspondance-quality printer under consideration.

Printers - Speed

Due to the high quantity of high quality textual output which leaves the office, the correspondance quality printer should be capable of printing at a speed of at least 40 characters per second. Dot matrix printers which will be used to generate documents for in-house usage should be capable of a reasonable printing speed at least 120 characters per second as the lower cost machines will be used more extensively than the correspondance-quality printer. Since few microcomputers can be used during print operations, a slow printer can cost a great deal of computing time.

Printers - Output Character

Both printers must be capable of printing the full character set. Foreign and graphic characters are not required for any of the intended applications. Graphics characters typically provided on microcomputer printers are not very useful to the intended design and graphics applications. The capability to generate user defineable characters and the provision of a variety of type styles would be most convenient to produce title blocks and legends using the correspondance-quality printer. The capability to produce compressed and expanded text would be useful on all printers to print tables. All printers must be capable of printing a standard 80 column line, and preferably a 132 column line for charts and tables.

Output for the majority of design and graphics applications will be generated by a plotter. However, the ability to generate some graphic output by the correspondance-quality printer will enable limited graphics applications in the initial stages of computer implementation. For this reason color capability would be preferable but not essential.

The correspondance-quality printer must be capable of printing on single sheets to generate letters and forms, as well as continuous paper for long documents. The other dot matrix printers need only be capable of printing on continuous paper. The correspondance-quality printer should be capable of printing on transparencies, so that legends, title blocks, and notes may be adhered to printable drawings. The ability to print multi-copies is not important, as high quality copies may be obtained more efficiently using photocopy methods.

Printers - Reliability

The reliability of printers is critical due to the number of electro-mechanical parts. Visual inspection, as well as the manufacturers reputation should be checked to ascertain reliability.

Ease Of Operation

The two factors which may contribute most appreciably to ease of operation are a paper-out stop, and a paper-out alarm. These features will alert the user to the fact that paper needs to be added, and will stop the printing process when paper runs out. Although acoustics is not considered a critical factor, quiet printers would be preferable as printing operations will occur in an open office environment.

Plotters

A flatbed plotter will most likely be required to enable a drawing size 24" x 36"minimally. Accommodation of 36" x 42" drawings would be much preferable. The plotter must be able to handle at least four pen types in order to provide the number of line widths required to produce a presentation quality drawing. The plotter should preferably be capable of producing output on either vellum or mylar.

The resolution should be at least equivalent to that of the screen, which should be .001 inches minimally. The ability to both produce vector driven lines and to operate in an incremental mode would be most advantageous. The capability to plot off-line would enable a time savings. However this feature is not commonly available on plotters driven by microcomputers. The capability to accept data directly from the keyboard, a graphic input device such as a digitizer, and an auxilliary storage device, would reduce the sophistication required of the software which drives the plotter, and enable more conveniant plotter operation. Rapidiograph ink is the preferred pen type to enable the highest quality of reproduceable output. Velocity optimization and the ability to rotate the working surface from 0 to 90 degrees are preferable but not essential characteristics.

Software routines which may be used to drive the plotter can ease the programming burden required for the projected design and graphics applications. It should be noted that the software routines are not actually a part of the plotter. Some of the most useful routines to accommodate the projected CADD applications include the following:

plot initialization

pen movement control

generation of lines, axes, circles and circular arcs, ellipses and elliptical circles, alphanumeric characters, user defineable symbols and labels, tic marks, dashed lines which connect datum points, linear grids, arrowheads, centerlines, and shades,

automatic scaling and off-setting,

automatic pen change,

assertation of pen location

Floppy Disk Systems

Each work station will be equipped with two floppy disk drives. The use of two drives will enable a rapid method of data back-up. The floppy disk drives are preferable to magnetic tape for applications which require rapid random access.

Floppy Disk Systems - Storage Media

Disk size and data density are not critical factors. However, double-sided double-density (quad density) microfloppy disks tend to provide the greatest reliability and lowest cost per byte.

Floppy Disk Systems - Disk Drives

Specifications concerning the disk drive are not of critical importance to the intended applications. Individual specifications concerning speed, and motor type may be compared once a range of workable systems have been located.

A disk-in-place switch, a write protect, and software security features would add conveniance, but are not critical factures. A daisy-chaining feature is not necessary as increased auxilliary storage will be provided by a hard disk drive system when needed.

The error rate and occurence of read/write head failure is so low that these factors do not warrant consideration in the selection process. Read/write head life is highly dependant upon care and maintenance procedures practiced by the user. The error rate of disk media is brand dependent.

Hard Disk Systems

Certain charateristics of the proposed hard disk system may be specified more precisely once the initial system has been in operation for a period of time and projected applications may be more accurately defined. At that time the total storage capacity, data transfer rate, and the required number of disks may be specified. At this point, the most important objective is to locate a computer system which may network seven computers to share a common hard disk system.

A hard disk system which includes a removable disk for back-up purposes would be most conveniant.

Programming And Developmental Software
Structured Programming Facilities

Due to the modular nature of applications to be programmed in-house, use of a highly structured programming language is essential.

Programming And Developmental Software - Readability

Programs will be written in-house by more than one programmer. Readability of the programming language is critical to enable the communication of program logic from one programmer to another.

Programming And Developmental Software
File Handling Capability

Programs written to handle large files using random instead of sequential access, will operate faster and more effeiciently. The maximum file size required by the application described in Section 3.3 is 126 bytes The greater the number of files which may be open simultaneously, the less difficult the task of transferring data from one to another. Efficiency of data transfer will become of greater significance as projected applications are programmed to operate more interactively. The applications which are to be programmed in-house use at least three data types extensively -- textual data, integers, and real numbers. Files which can store more than one of these data types simultaneously are less difficult for the programmer to deal with. Although maximum allowable array size is not a critical consideration, the ability to use arrays simplifies the task of the programmer.

File creation, file deletion, transfer of data to and from a file, change within a file, and transfer of data to a storage device are capabilities essential for the programmer, and must be provided within the language selected.

Programming And Developmental Software
Portability

The capability of the selected programming language to operate on the system initially purchased, as well as the upgraded system is critical. As hardware becomes obsolete, a high degree of language portability will reduce the requirement of extensive reprogramming effort to accommodate new hardware.

Programming And Developmental Software
Speed At Run-time

Most of the programs written in-house will be used repeatedly to process large amounts of data. As design and graphic programs are developed, speed will become increasingly more critical. Compiled as opposed to interpreted languages are more likely to provide faster run-time speed.

Programming And Developmental Software
Arithmetic Precision

The greatest arithmetic precision required by the proposed applications is accuracy to 10 significant digits. This level of accuracy is required for traverse computations.

Programming And Developmental Software
Built-in Functions

Functions built into the language should include those most commonly used for intended applications. Functions commonly used for applications proposed by Environmental Design Associates include sine, arcsine, cosine, arccosine, tangent, arctangent, natural logarithms, exponentiation, and decimal/degree conversion. The ability of the programmer to create a library of user-defineable functions would be highly useful.

The length and maximum number of variables definable within a program, the maximum number of paramaters which may be defined per procedure, and the maximum number of procedures which may be nested are factors which also affect the level of sophistication which may be achieved by programs written in a particular language.

Pascal, and FORTRAN, are the two languages most commonly available for microcomputers, which meet most of the above requirements for structured programming facilities, readability, file handling capability, and run-time speed. The remaining critical requirements (as arithmetic precision, and certain built-in functions) are specific to individual versions of such languages.

System Software

The operating system selected must be capable of supporting a single-user/single-program operating environment during initial applications, and a single-user/multi programming environment as projected applications are implemented. The capability to support the selected application software packages, and the specified hardware is critical as well. One must ensure that the proposed network configuration can be supported, that is the network which interfaces all work stations to share a plotter, a hard disk drive, and the printers.

The ability to access data randomly will enable faster operation. Portability becomes critical as the system is upgraded to accommodate new hardware and software. Speed was taken into account in the benchmark test. Sort, merge, edit, and copy routines and the ability to create a library of user-definable routines is essential if this capability is not provided within the programming language. A trace facility which enables a programmer to track the instructions of a program as they are executed can save a great deal of programming time.

3.5 System Selection

3.5.1 Selection Of A Manufacturer

Once having developed computer system specifications the potential buyer must locate computer systems which meet those specifications, compare those systems on the basis of cost and suitability, and select a system. With more than 150 computer systems from which to choose within the United States alone, the buyer may wish to first narrow down the range of acceptable manufacturers based upon some preliminary considerations.

The potential manufacturers may first be limited to those which support the application software packages to be implemented. The software supplier will indicate the systems on which the packaged programs will operate. Potential manufacturers may be further limited to those which meet the most critical specifications, and to those which fall within an acceptable price range. The reputation, financial stability, and long range goals of manufacturers are also considerations which may affect the long range effectiveness of the system selected. Some manufacturers, for example, focus their efforts towards a broad market in the design of general purpose systems which can be useful in a wide variety of situations. Others sacrifice wide range applicability to address more industry specific markets, such as those interested in engineering or architectural applications. Buyers representative of small markets, with highly individualized needs, can benefit from research and developmental efforts directed towards their specific field of interest.

Preliminary information concerning individual manufacturers may be obtained from a number of sources, such as, consumer and business reports, and professional and trade magazines, such as, Creative Computing, Infoworld, Byte Magazine, and Mini-Micro Small Systems Journal. Trade shows, such as, Western Electric's show and convention, and the National Mini-Micro Computer Conference also provide an efficient means by which to acquire an overview of systems available.

Once having narrowed the number of potential manufacturers according to these initial considerations, each contender may be investigated to identify those which offer the most suitable system. The most important objective throughout this investigation is to obtain pertinent and thorough information concerning each system, which may provide a basis for consistent and objective comparison.

One effective method by which to obtain consistent and thorough information concerning computer systems is by use of a form or system survey which provides a summary of computer system requirements and preferences developed by the user. The form may be used to record information concerning systems under consideration. The first information to be acquired is the required configuration of system components, both hardware and software, which will comprise a complete and working system. Computer vendors such as manufacturer sales representitives, sales engineers are usually best qualified to provide this type of information because they are most knowledgeable of the range of products offered by a particular manufacturer and are trained to match those products to user needs.

An accurate representation of buyer needs and preferences provided within the form will maximize the efforts of the vendor. The system survey form will enable the sales representative to quickly zero in on buyer needs, and develop an accurate system proposal. Provision of the form may also indicate to the vendor a well informed buyer and may result in a more energetic response. The system survey also provides the user a basis for point by point comparison of systems under consideration. The system survey form developed for Environmental Design Associates is represented in Appendix D.

This initial research should result in a system proposal from each contending manufacturer which sets forth the system configuration which best meets the required and preferred system specifications. In some cases the vendor will be able to provide the more specific information concerning each system component requested in the system survey. In most cases however the most technical information must be acquired directly from the manufacturer. Whereas the sales representatives are best equipped to provide general information concerning computer systems and their applications, various divisions of the manufacturer are best qualified to provide more specific information. The technical assistance department of some manufacturers may be accessed using a toll-free number.

In some cases, information concerning individual systems may be acquired most efficiently in two phases. The 'first pass' of the investigation may be used to secure information concerning only the most critical requirements. That data may be used to 'weed out' systems which do not meet the critical specifications. Systems that meet the critical specifications may be further investigated on the basis of less significant selection criteria. This approach may eliminate a great deal of unnecessary research.

Preliminary Selection Of Manufacturer

A Case Study

The range of potential manufacturers selected to supply the computer system for Environmental Design Associates was identified on the basis of packaged application software support, financial stability and reputation, basic business directives, and the ability to provide a system which generally approaches the capability required. Manufacturers which have focused upon professional architectural and engineering applications, and indicate intentions to continue were given prime consideration. Manufacturers which offer a high level of upgradeability and those which demonstrate a strong chance of continued survival were also considered as prime contenders.

Based upon the configuration required, an initial overview of the computer market indicated that a system priced within the range of $5,000 to $7,000 will be required for the initial work station. A system ranging between $10,000 to $15,000 will be required for subsequent work stations. Manufacturers selected for further investigation by EDA include the following:

Digital Equipment Corporation

Hewlett-Packard

Tandy Corporation

Internation Business Systems

Texas Instruments

The following letter provides an example request for information for distribution to manufacturers by Environmental

Design Associates. Information concerning systems proposed by each manufacturer are provided in Appendix D.

August 24, 1984

Digital Equipment Corporation

Dear Mr. ______________:

Environmental Design Associates is a small landscape architectural firm preparing to invest in a microcomputer system. The system must be capable of accommodating a wide range of applications ranging from word processing (in the initial stages of implementation) to computer aided design and graphics applications (within a period of the next 3 to 5 years). Work stations will be provided for each of our seven member staff over the implementation period. The proposed hardware configuration includes the following components:

WORK STATION ONE	WORK STATIONS TWO THROUGH FIVE
computer	computer
keyboard	keyboard
monochromatic CRT	color CRT
2 floppy disk drives	2 floppy disk drives
	1 draft-quality dot matrix printer

WORK STATIONS SIX AND SEVEN

computer

keyboard

color CRT

2 floppy disk drives

1 draft-quality dot matrix printer

PERIPHERALS TO BE SHARED BY ALL WORK STATIONS

one correspondence quality dot matrix printer

one hard disk drive system

one flatbed plotter

one digitizer

We are prepared to invest between $2,500 and $3,500 for the first work station, and up to $6,000 for each additional station. The enclosed description summarizes our system requirements. If you have a system which meets these requirements we would appreciate a description of all components required to comprise a complete and working system. This description should include necessary auxiliary equipment (such as interfaces and cables) as well as associated costs. Please complete the enclosed request for information and return to us if interested. We would appreciate the opportunity to consider your system.

Respectfully,

Jan Keathley

System Comparison

The comparison of computer systems in an objective and consistent manner will indicate the most suitable system for the potential buyer. Use of an evaluation matrix can simplify system comparison. The request for information distributed to manufacturers under consideraton provides an ideal basis for design of the matrix, as illustrated in Appendix E. Each system characteristic has been weighted to indicate relative importance for proposed applications. Information concerning each system characteristic will provide a basis by which to rate each system. Ratings may be tallied to enable a capability versus cost comparison.

Ratings listed within the evaluation matrix presented within Appendix E are based upon data acquired from each manufacturer. Weighting factors reflect the relative importance of each selection consideration for the proposed applications. As indicated within Appendix E this study indicates that the system proposed by Tandy Corporation is most suitable for Environmental Design Associates. Systems available through Digital Equipment Corporation and Hewlett-Packard offer much greater capability. However, system proposals were not yet provided by these manufacturers at the time of this writing.

3.5.2 Selection Of A Supplier

Once a computer system has been selected, a supplier must be located who will provide the required level of support and maintenance for the most reasonable cost. In some cases the manufacturer may be the best supplier. However, most computer systems may be acquired only indirectly through computer dealerships. The manufacturer can often provide the buyer a recommendation for suitable suppliers. The effort required to consider a large number of bidders is relatively small compared to the potential advantage which may be gained.

Potential suppliers may be singled out on the basis of financial strength, application expertise and reputation within the buyer's particular business or profession and geographic locale. The ability of an individual supplier to provide all system components, particularly those required for future expansion, may prevent a great deal of inconveniance and expense.

Submission of a request for proposal to individual suppliers will encourage the most serious response. A notation to the effect that the written response of the selected supplier will be incorporated into the final sales contract, will further ensure the accuracy of solicited bids and reduce the chance of over-representation.

In general, the request for proposal should contain a specification for all equipment and service to be provided by the supplier and a request for a description of each item and associated costs. The following categories should be addressed within the request for proposal:

background of buyers firm,

system requirements

    hardware

    software

request for description of equipment and services to be provided:

    system components

    system support

    associated cost

    contractual obligations

request for references

4. Conclusions

4.1 Case Study Results

Data processing objectives will vary to some extent between landscape architectural firms to accommodate the distinct characteristics unique to each practice. The hypothetical firm presented within this study was designed to represent a typical small to medium sized landscape architectural firm. As a representative of this market it was assumed that the case study firm was not prepared to invest in an advanced CADD system in the initial stages. More common applications, such as those which can make use of well tested, reliable packaged software were scheduled for immediate implementation. This plan was intended to provide the computer system an opportunity to render a return on the initial investment prior to the implementation of more advanced and innovative applications. The most common computer applications currently implemented within landscape architectural practice include the following:

- accounting
- payroll
- general file management
- word processing
- statistical analysis
- telecommunications
- econometric modeling
- cost estimation
- construction estimation
- plant pallette
- marketing
- construction scheduling
- site engineering calculations

Most of these applications can make use of word processing and data management packaged software.

The most significant criteria for selection of a microcomputer system to accommodate the data processing objectives proposed by the case study firm as indicated within this study are summarized below by order of importance:

(1) A reputable, financially stable manufacturer that provides strong support and upgrade potential to allow system expansion as needed is essential to insure long term usefulness of the system.

(2) The system must provide the required configuration as specified to comprise a complete and working system. This necessitates compatibility among all components, both hardware and software. In some cases, however individual components may be provided by more than one manufacturer. In case of a malfunction, each manufacturer may tend to cast blame upon the other. This situation may be remedied to some extent by a service contract which establishes the responsibility of each supplier.

(3) The standard and maximum RAM capacities of the computer are critical to any application. Initially, the RAM capacity must be able to accommodate the packaged software to be used. Maximum RAM capacity will become of increasing importance as graphics applications are implemented.

(4) High system speed, which is partially dependent upon CPU and data bus word length, is essential to accommodate design and graphics applications, particularly where large amounts of information must be processed.

(5) An adequately high screen resolution of the color monitors is essential to provide the highly resolved display required for

projected graphics applications.

(6) The plot size of the plotter, and the reading area of the digitizer must be adequately large to accommodate projected graphic input and output operations.

(7) A large total auxiliary storage capacity, particularly that of the hard disk drive system will be required to accommodate the storage needs of the projected design and graphics applications.

(8) High dot resolution for the correspondance-quality printer will be necessary to insure high quality output for documents to be sent out of the office.

(9) Arithmetic precision must allow accuracy adequate for the proposed applicaitons to be developed in-house, particularly the site engineering applications. Arithmetic precision is dependent upon both the computer and the programming language to be implemented on the machine.

The following summary presents the comparitive suitability of each of the systems proposed by the contending manufacturers to accommodate the data processing objectives set forth for the case study firm.

The IBM Alternative

A system based upon the IBM PC was not considered adequate to accommodate the data processing objectives set forth for the case study firm due to the relatively low system speed. While adequate for the initial applications proposed, the 8/16 bit CPU (the Intel 8088) would not perform at optimum speeds required for projected CADD applications. The more recently introduced IBM AT, however is equipped with a more powerful 16/16 bit processor (the 80286). The wider data path can allow faster input/output operations which can be significant for graphics applications. The AT has a relatively high maximum RAM capacity of 3 megabytes and a high auxiliary storage capacity (1.2M for each floppy disk drive and 20M for each of the two internal hard disk drives providing a maximum hard disk capacity of 40M per work station). The screen resolution (640 x 200) is adequate for the proposed graphic applications but not acceptional.

The Hewlett-Packard lazerjet printer, which is compatible with the IBM PC, represents state-of-the-art speed, quality, and buffer capacity for microcomputer printers at this time. The lazerjet prints a dot resolution of 300 x 300 dots per inch (or a 30 x 30 character block matrix) at a pace of eight pages per minute. The buffer capacity for the Lazerjet is 50K, which is adequate to store 6 pages of text.Houston Instrument provides digitizers and plotters which meet the required specifications and can be interfaced with several computers available, the IBM AT included.

The system proposed by IBM which is based upon the IBM AT offers a great deal of capability for a reasonable cost. A major advantage of IBM as a choice is of course the vast number of compatible software packages and hardware peripherals available. IBM is also reliable to provide strong system support. However, at the time of this writing, the IBM AT was recently pulled from the market due to a technical problem with the operating system and hard disk. Additionally, the software required to support the proposed networking will not be available until the first quarter of 1985. The problem with the IBM AT will undoubtedly be corrected, but the timeframe required for the correction is unknown rendering a system based upon this machine a risky investment at this time.

The Texas Instruments Alternative

The system proposed by Texas Instruments was based upon the TI Professional Computer, which uses an Intel 8088 CPU. The computer can be equipped with a numeric coprocessor (the Intel 8087) which will provide greater processing speeds to accommodate the projected CADD applications. Systems based upon the 8088 microprocessor operating in tandem with an 8087 coprocessor can operate faster than systems using only an 8088 (such as the IBM PC), but not as fast as those based upon a 32-bit processor such as the Motorola 68000 or 16/16 bit processors such as the 80186 and the 80286.

The major limitation posed by the TI system is the maximum RAM capacity of 256K. The standard RAM capacity provided is 64K which may be upgraded in 64K increments. Texas Instruments claims that the maximum RAM capacity will be increased to 1M. The screen resolution provided is 720 x 300, which is extremely good for a microcomputer system. Additionally, this resolution is provided both for monochrome and color displays. Most systems sacrifice resolution to produce color.

The floppy disk capacity (320K) and hard disk storage (10M) is acceptable. Texas instruments proposed a dual-mode correspondance-quality dot matrix printer which prints a character block matrix of 35 x 18 dots at 35 characters per second and has a 4K buffer. This print capability meets the required specifications, but does not measure up to the performance of the HP Lazerjet printer, which is compatible with the TI Professional Computer. The Lazerjet would be acquired at the sacrifice of obtaining the printer and the computer from a single manufacturer, which can lead to difficulty with respect to system maintenance. Texas Instruments did however recommend the use of a Houston Instrument plotter and digitizer.

Texas Instruments is not reputed to provide acceptionally strong system support. However, a TI system may be purchased from a dealer who is contracted to provide the required level of support. In general, the only outstanding attribute offered by the TI solution is the high screen resolution.

The Tandy Alternative

Tandy Corporation proposed a system based upon the Tandy 2000 microcomputer, a fairly powerful machine which uses a 16/16 bit processor (the 80186). The standard memory capacity provided is 256K, and the maximum Ram capacity is 768K. Each floppy disk provides 720K of storage and the hard disk capacity is 10M. Each work station within the network can be equipped with a hard disk if needed, enabling a total hard disk capacity of 70M.

The system proposed by Tandy does not require a dedicated microcomputer to manage the resources of the network as do most network systems based upon microcomputers. This allows a substantial cost savings. The screen resolution provided is 640 x 400 for both monochrome and color display, which is excellent. The Tandy correspondance-quality dot matrix printer can print 360 dots per inch at a rate of 160 characters per second. However, no buffer is provided with the printer. Tandy Corporation also recommended the use of a Houston Instrument plotter . and digitizer.

Although not as capable as the IBM AT system (given it were operational), the Tandy solution represents a great deal of capability for the cost. Tandy Corporation has also established a solid reputation to provide strong system support.

Other Alternatives

Although Digital Equipment Corporation and Hewlett Packard have not yet submitted a system proposal, they most likely provide the systems most capable to perform as required. Both DEC and HP can propose a system which provide most of the required system components, including the plotter and digitizer. Both manufacturers have provided systems which are used for advanced CADD applications and also provide a great potential for system expansion. DEC, in particular, has taken care to a hierarchy of capability into their systems so that software designed for one of their systems can eventually be used on their larger systems without extensive reprogramming effort. Some of DEC's microcomputers can eventually serve as terminals to their minicomputers, allowing optimal upgrade potential.

Sales engineers of both HP and DEC, who are trained to sell more advanced systems than those marketed by dealerships take great care to study the needs of potential users and to design a proposal which best accommodates the required specifications. This careful attention requires considerable effort on the part of the sales engineers and for this reason has not yet resulted in a system proposal for use within this study. Sales representatives which operate through microcomputer dealerships are not usually adequately knowledgeable of HP equipment to develop a workable system proposal for more advanced applications. They are more commonly trained to sell only a specific machine.

The systems offered by DEC and HP would most likely be far more suitable for the intended applications than other systems considered within this study, particularly in terms of potential expansion. The initial cost of these systems will be relatively high in comparison with similiar equipment provided by other manufacturers. Hewlett-Packard products, in particular, are typically high priced for the capability offered. This high initial cost, however, may be offset by long term cost savings enabled by upward compatibility and the potential for system expansion offered by HP and DEC.

4.2 Implications Of The Study

The number of variables to consider in computer system selection is overwhelming to most potential buyers of microcomputer systems. The buying process is further complicated by the rapid pace of technological advance within the computing industry and the marketing efforts put forth by computer manufacturers. There is often excessive emphasis focused upon computer system characteristics which are of no importance for proposed applications. Preoccupied by insignificant computer system attributes and misguided by computer sales campaigns, buyers often invest in computer system capability which is never realized, and in the worst case useless.

Selection of a useful and profitable computer system can be accomplished through the use of a computer system selection methodology which places emphasis upon the identification of user needs and enables a point-by-point comparison of computer system capability to accommodate those needs. The time expended upon a systematic selection approach may in the long run be well worth the added suitability of the computer system selected, particularly if advanced CADD applications are to be implemented.

Although the case study represented a typical landscape architectural firm, the methodology set forth within this study is applicable to a wide variety of potential data processing environments. Application of the methodology will vary with respect to the following:

(1) data processing objectives
(2) available computer system components

(3) sources of hardware and software
(4) degree of user involvement in the selection process

The methodology developed within this study places greatest emphasis upon the analysis of user needs and the identification of data processing objectives. Consideration of only those applications which have already been computerized within landscape architectural practice supports the assumption that present applications are completely satisfactory and that no further innovation is necessary. This approach diminishes the potential benefit of computers to the landscape architectural profession. The identification of data processing objectives for the case study firm allowed for the consideration of a broad range of potential tasks in order to ascertain the optimum benefit of a computer system.

Since data processing objectives will vary considerably for each potential data processing environment, the collection of selection criteria addressed within this study is intended to be adequately complete to accommodate a wide range of microcomputer applications. The inventory of computer system selection criteria presented within this study is intended to serve as a somewhat exhaustive base from which to identify pertinent factors for a given set of data processing objectives. In actual practice, the formal inclusion of this entire base may not be time efficient for the potential buyer. An awareness of possible criteria, however is essential to intelligently select those criteria of greatest significance and to eliminate those of lesser importance. Section 3.4 (The Development of Computer System Specifications) provides the reader a basis by which to identify the most pertinent selection criteria for a given set of objectives.

Computer system selection criteria will evolve as technological advances occur within the computing industry. The selection procedure set forth within this methodology will remain viable as this advance occurs.

4.3 Recommendations For Further Research

Further research efforts which may be of greatest value to the landscape architectural profession should expand the range of potential computer applications to the profession. This enhancement may evolve from research which focuses upon the definition of tasks within landscape architectural practice which may advantageously be performed by computer. A complete and accurate task definition for a landscape architectural application currently not implemented could be utilized by one with adequate programming expertise as a basis for software design to accommodate the application.

The research presented within this study encompasses a number of less comprehensive problems which may be addressed individually. The selection methodology was utilized within this study to select a computer system which could accommodate a wide range of data processing objectives within a typical landscape architectural firm. The use of this methodology to select systems suitable for a more limited set of objectives would serve both to test the methodology and to indicate the feasibility of more innovative or unfamiliar applications.

Given a set of data processing objectives, the methodology presented within this study may be compared with other selection methodologies in terms of usefulness (both long and short term) and efficiency.

APPENDIX A

EVALUATION MATRIX

POTENTIAL TASKS FOR COMPUTERIZATION

ENVIRONMENTAL DESIGN ASSOCIATES

Appendix A sets forth an evaluation matrix in which tasks performed within a hypothetical landscape architectural firm (Environmental Design Associates), are analyzed to determine the suitability of each task for computer implementation. Suitability is estimated with regard to the following criteria:

(1) the relative initial cost incurred,

(2) the relative on-going cost incurred,

(3) the relative benefit to be gained, and

(4) the relative value of the task within the operation of a firm

Each criteria is weighted to reflect the relative importance of that factor. This evaluation was used to establish the priority of each task for computerization, as represented within Table 3.1.

PRIORITIZING FACTORS

POTENTIAL TASKS FOR COMPUTER IMPLEMENTATION	RELATIVE INITIAL COST	RELATIVE ON-GOING COST	RELATIVE BENEFITS	RELATIVE VALUE OF THE TASK CURRENT	TOTAL PRIORITY RATING CURRENT	RELATIVE VALUE OF THE TASK PROJECTED	TOTAL PRIORITY RATING PROJECTED
weighting factors ------>	1	3	3	5		5	
1 Contract & negotiations							
1-1 Determine in-house authority for negotiations	N/A	N/A	N/A	5	0	5	0
1-2 Outline basic program of development	N/A	N/A	N/A	50	0	50	0
1-3 Determine services to be provided by the firm	N/A	N/A	N/A	10	0	10	0
1-4 Determine information to be provided by the client	N/A	N/A	N/A	5	0	5	0
1-5 Determine applicable govn. codes and specifications	N/A	N/A	N/A	15	0	15	0
1-6 Determine in-house staff requirements	N/A	N/A	N/A	10	0	10	0
1-7 Determine number & type of consultants required	N/A	N/A	N/A	10	0	10	0
1-8 Establish basis for fees	N/A	N/A	N/A	5	0	5	0
1-9 Draft contract	5	12	3	10	27	10	27
1-10 Secure contract with client	N/A	N/A	N/A	10	0	10	0
1-11 Secure sub-contracts with consultants	N/A	N/A	N/A	15	0	15	0
2 Project execution							
2-1 Site analysis							
2-1-1 Research factors which may impact development				20		20	
2-1-2 Record site analysis data graphically on map or plan of site	1	3	15	25	44	25	44
2-1-3 Determine impact of each site characteristic upon development	N/A	N/A	N/A	25	0	25	0
2-1-4 Record results of analysis graphically	1	3	15	25	44	25	0
2-2 Schematic design							
2-2-1 Develop design criteria	N/A	N/A	N/A	30	0	30	0
2-2-2 Determine constituent site components to be included in plan	N/A	N/A	N/A	5	0	5	0

PRIORITIZING FACTORS

POTENTIAL TASKS FOR COMPUTER IMPLEMENTATION	RELATIVE INITIAL COST	RELATIVE ON-GOING COST	RELATIVE BENEFITS	RELATIVE VALUE OF THE TASK CURRENT	TOTAL PRIORITY RATING CURRENT	RELATIVE VALUE OF THE TASK PROJECTED	TOTAL PRIORITY RATING PROJECTED
weighting factors ---->	1	3	3	5		5	
2-2-3 Identify optimum relationships between; - site components to each other - site components to the site	N/A	N/A	N/A	25	0	25	0
2-2-4 document optimum relationships graphically	1	3	3	10	17	10	17
2-2-5 document supporting rationale verbally	5	15	3	5	28	5	28
2-2-6 Generate alternative schematic designs	1	3	15	35	54	35	54
2-2-7 Represent each alternative graphically	1	3	9	10	23	10	23
2-2-8 Evaluate alternatives according to design criteria and program	1	3	15	30	49	10	26
2-2-9 Preliminary cost est.	5	6	3	10	26	10	26
2-2-10 Present alternatives to client	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-3 Design development							
2-3-1 Develop best alternatives	1	3	15	40	59	50	69
2-3-2 Prepare sketches and drawings necessary for presentation	1	3	12	35	51	35	51
2-3-3 Document supporting rational verbally	5	15	3	5	28	5	28
2-3-4 Select palette of hard materials	3	15	6	15	39	10	34
2-3-5 Prepare cost est.	5	15	15	25	20	30	60
2-3-6 Present design to client	N/A	N/A	N/A	10	0	10	0
2-4 Planting Design							
2-4-1 Identify planting areas on site	N/A	N/A	N/A	5	0	5	0
2-4-2 Determine plant growth requirements for each planting area	4	15	9	10	38	5	33
2-4-3 Represent planting areas and growth requirements on plan	1	3	6	10	20	5	15

POTENTIAL TASKS FOR COMPUTER IMPLEMENTATION	RELATIVE INITIAL COST	RELATIVE ON-GOING COST	RELATIVE BENEFITS	RELATIVE VALUE OF THE TASK CURRENT	TOTAL PRIORITY RATING CURRENT	RELATIVE VALUE OF THE TASK PROJECTED	TOTAL PRIORITY RATING PROJECTED
weighting factors ------>	1	3	3	5		5	
2-4-4 Determine functional objectives for each planting area such as; visual screening, climate control etc.	N/A	N/A	N/A	10	0	5	0
2-4-5 Represent functional requirements graphically	1	3	6	10	20	5	15
2-4-6 Determine aesthetic objectives for each planting area such as; enframement, color contrast, etc.	N/A 1	N/A 3	N/A 9	10 10	0 23	5 10	0 23
2-4-7 Represent aesthetic requirements graphically	1	3	6	10	20	5	15
2-4-8 Select palette of plant materials to meet objectives	4	15	9	10	38	5	33
2-4-9 Design arrangement of plant materials for each planting area	1	3	6	15	25	5	15
2-4-10 Represent final planting plan graphically	1	3	6	15	25	5	15
2-4-11 Compile plant materials list	4	9	3	10	26	5	21
2-4-12 Develop planting details	1	6	9	15	31	5	21
2-4-13 Develop planting specifications	4	15	9	10	38	5	33
2-5 Produce construction documents for each phase of construction as as necessary to include: road alignment grading earthwork estimation storm sewage sanitary sewage water distribution irrigation lighting layout & dimensioning construction details							
2-5-1 Define the problem	N/A	N/A	N/A	25	0	30	0
2-5-2 Define the objectives	N/A	N/A	N/A	20	0	25	0

POTENTIAL TASKS FOR COMPUTER IMPLEMENTATION	RELATIVE INITIAL COST	RELATIVE ON-GOING COST	RELATIVE BENEFITS	RELATIVE VALUE OF THE TASK CURRENT	TOTAL PRIORITY RATING CURRENT	RELATIVE VALUE OF THE TASK PROJECTED	TOTAL PRIORITY RATING PROJECTED
weighting factors ------>	1	3	3	5			
2-5-3 Generate alternative solutions	1	6	15	40	62	45	67
2-5-4 Perform calculations	4	3	18	35	60	35	60
2-5-5 Estimate cost	4	3	18	35	60	35	60
2-5-6 Present alternative solutions graphically	1	6	9	10	26	10	26
2-5-7 Analyze impact of alternatives	1	3	15	20	39	30	49
2-5-8 Compare alternatives & select option solution for further development	1	3	15	20	39	30	49
2-5-9 Finalize solution	1	3	15	35	54	45	54
2-5-10 Represent solution graphically	1	6	12	15	34	20	39
2-5-11 Select hard materials	2	6	9	10	27	10	27
2-5-12 Estimate cost (final)	4	3	18	35	60	35	60
2-5-13 Develop construction specifications	4	10	12	25	51	25	51
3 Pre-bid period							
3-1 Set forth construction schedule	4	12	12	35	63	35	63
3-2 Review project documents with coding authorities	N/A	N/A	N/A	10	0	10	0
3-3 Secure final approval with client	N/A	N/A	N/A	10	0	10	0
3-4 Select contractors for bidding	N/A	N/A	N/A	10	0	10	0
3-5 Issue the bidding documents	5	15	3	5	29	5	28
4 Bidding period							
4-1 Receive the bids	N/A	N/A	N/A	5	0	5	0
4-2 Analize submitted bids	N/A	N/A	N/A	10	0	10	0
4-3 Award contract	N/A	N/A	N/A	5	0	5	0
5 Secure contract							
5-1 Approve bonds & insurance	N/A	N/A	N/A	5	0	5	0
5-2 Approve sub-contractors	N/A	N/A	N/A	5	0	5	0

PRIORITIZING FACTORS

POTENTIAL TASKS FOR COMPUTER IMPLEMENTATION	RELATIVE INITIAL COST	RELATIVE ON-GOING COST	RELATIVE BENEFITS	RELATIVE VALUE OF THE TASK CURRENT	TOTAL PRIORITY RATING CURRENT	RELATIVE VALUE OF THE TASK PROJECTED	TOTAL PRIORITY RATING PROJECTED
weighting factors ------>							
5-3 Assist in contract prep.	1	3	3	5	12	5	12
5-4 Execute contract	N/A	N/A	N/A	5	0	5	0
5-5 Issue proceed orders	5	15	3	5	28	5	28
6 Construction supervision							
6-1 Observe construction	N/A	N/A	N/A	20	0	20	0
6-2 Prepare inspection reports	5	12	3	10	30	10	30
6-3 Prepare monthly certificates	5	12	3	5	25	5	25
6-4 Review construction reports	N/A	N/A	N/A	5	0	5	0
6-5 Make monthly contract payments	3	6	3	5	17	5	17
6-6 Prepare & approve change orders	5	6	3	15	29	15	29
6-7 Obtain contract guarantees	N/A	N/A	N/A	5	0	5	0
6-8 Make final inspection	N/A	N/A	N/A	5	0	5	0
6-9 Recieve waiver of liens	N/A	N/A	N/A	5	0	5	0
6-10 Prepare maintenance guide	4	12	6	10	32	10	32
6-11 Accept project	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-12 Make final payment	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-13 Receive 100% of fees	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Non-production activities	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marketing	5	9	15	25	54	50	79
Financial management	5	15	12	35	67	50	82

APPENDIX B

DATA DESCRIPTION

FOR THE ROAD ALIGNMENT PROBLEM

PROPOSED BY ENVIRNOMENTAL DESIGN ASSOCIATES

Appendix B sets forth a data description for the proposed road alignment problem presented within Section 3.3. The data description serves primarily serves primarily as a basis for estimation of memory requirements, both RAM and auxiliary storage. Memory capacity required to store data associated with a program varies according to the programming language to be used. Pascal was selected to implemented the road alignment applications proposed by Environmental Design Associates.

Programs written in Pascal may be designed to read only one record of a file as opposed to an entire file into RAM. Therefore, the memory capacity required to hold individual records which must occur within RAM simultaneously is the amount of RAM required at any one time to store data (excluding temporary data elements). The auxiliary storage capacity required for permanent data is the total storgage capacity required by the files.

Memory requriements for data generated by programs written in Pascal may be estimated as follows:

Character type:

1 byte per character + 1 byte to designate character string length

(exception: 1 character data elements require only 1 byte of storage

Integer type:

1 byte to store values within the ranges of 0 to 255 or -128 to 127

2 bytes to store values within the ranges of 0 to 65,515 or -32,758 to 32,757

Real type:

8 bytes if no greater than 16 digits of accuracy is required

Based upon this data description, the maximum amount of RAM required by the data is 126 bytes (required to store the vertical curve file). Approximately 91K bytes of auxiliary storage will be required to store the data files. A certain amount of storage will be required for file management overhead as well.

DATA DESCRIPTION

FOR PROCEDURE TO CLOSE A TRAVERSE

GENERAL TRAVERSE DATA FILE (1 Record)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Project Name	Character	30	N/A	31	1	31
Road Name	Character	30	N/A	31	1	31
Closed Traverse ID	Character	20	N/A	21	1	21
Required Precision Factor	Real	10	8	8	1	8
Correction Method	Character	1	N/A	1	1	1

Total Storage Required Per Record -- 92

Total Storage Required For File -- 92

TRAVERSE LINE FILE (Maximum 20 Records)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Traverse Line ID	Character	1	N/A	1	20	20
Bearing	Real	14	8	8	20	160
Distance	Real	14	8	8	20	160
Sine	Real	14	8	8	20	160
Cosine	Real	14	8	8	20	160
Latitude	Real	14	8	8	20	160
Departure	Real	14	8	8	20	160
N Coordinate	Real	14	8	8	20	160
E Coordinate	Real	14	8	8	20	160

Total Storage Per Record -------- 65 Bytes

Total Storage Required For File - 1300 Bytes

TRAVERSE TOTALS FILE (1 Record)

DATA FIELDA	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Sue Of N. Latitudee	Real	14	12	8	1	8
Sum Of S. Latitudee	Real	14	12	8	1	8
Sue Of E. Departures	Real	14	12	8	1	8
Sum Of W. Deqartures	Real	14	12	8	1	8
Diff. in Sum of Late.	Real	14	12	8	1	8
Diff. in Sum of Depe.	Real	14	12	8	1	8
Sue Traverse Line Lgthe.	Real	14	12	8	1	8
Error of Closure	Real	14	12	8	1	8
Precision Factor	Real	14	12	8	1	8

Total Storage Required Per Record - 72 Bytes

Total Storage Required For File — 72 Bytes

DATA DESCRIPTION

FOR PROCEDURE TO PERFORM HORIZONTAL CURVE COMPUTATION

GENERAL HORIZONTAL CURVE FILE (1 Record)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Project Name	Character	30	N/A	31	1	31
Road Name	Character	30	N/A	31	1	31
Design Speed	Integer	3	3	1	1	1
Regular Road Sta. Int.	Integer	4	4	2	1	2
Total Road Length	Real	14	12	8	1	8

Total Storage Required Per Record — 73 Bytes

Total Storage Required For File — 73 Bytes

HORIZONTAL CURVE FILE (Maximum 50 Curves)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Curve ID	Character	2	N/A	3	50	150
Delta Angle	Real	14	12	8	50	400
Curve Length	Real	14	12	8	50	400
Tangent Length	Real	14	12	8	50	400
Chord Length	Real	14	12	8	50	400
PC Station	Real	14	12	8	50	400
PT Station	Real	14	12	8	50	400
PI Station	Real	14	12	8	50	400
Degree Of Curvature	Real	14	12	8	50	400
External Ordinate	Real	14	12	8	50	400
Mid-Ordinate	Real	14	12	8	50	400
Incoming Traverse ID	Character	2	N/A	3	50	150
Outgoing Traverse ID	Character	2	N/A	3	50	150

Total Storage Required Per Record 89 Bytes

Total Storage Required For File - 4,450 Bytes

VERTICAL CURVE FILE (Maximum 50 records)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Curve ID	Character	2	N/A	3	50	150
PVC ID	Character	2	N/A	3	50	150
PVI ID	Character	2	N/A	3	50	150
PVT ID	Character	2	N/A	3	50	150
PVC Station	Real	10	9	8	50	400
PVI Station	Real	10	9	8	50	400
PVI Station	Real	10	9	8	50	400
PVC Elevation	Real	10	9	8	50	400
PVI Elevation	Real	10	9	8	50	400
PVI Elevation	Real	10	9	8	50	400
Incoming Gradient	Real	7	6	8	50	400
Outgoing Gradient	Real	7	6	8	50	400
Algebraic Difference	Real	7	6	8	50	400
Min. Curve Length	Integer	3	3	2	50	100
Curve Length	Real	8	7	8	50	400
Mid-ordinate	Real	10	9	8	50	400
End-ordinate	Real	10	9	8	50	400
Hi/Lo Pt. Station	Real	10	9	8	50	400
Hi/Lo Pt. Elevation	Real	10	9	8	50	400

Total Storage Required Per Record - 126 Bytes

Total Storage Required For File --- 6300 Bytes

DATA DESCRIPTION

FOR PROCEDURE TO PERFORM VERTICAL CURVE COMPUTATION

GENERAL VERTICAL CURVE FILE (1 Record)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Project Name	Character	30	N/A	31	1	31
Road Name	Character	30	N/A	31	1	31

Total Storage Required Per Record 62 Bytes

Total Storage Required For File 62 Bytes

STATION FILE (Maximum 5,000 Records)

DATA FIELDS	DATA TYPE	FIELD WIDTH	REQUIRED PRECISION	REQUIRED STORAGE # OF BYTES	MAXIMUM NUMBER OF CASES	TOTAL STORAGE REQUIRED-BYTES
Station ID	Real	10	9	8	5000	40000
Station Elevation	Real	10	9	8	5000	40000

Total Storage Required Per Record - 16 Bytes

Total Storage Required For File - 80000 Bytes

APPENDIX C

SUMMARY OF COMPUTER SYSTEM SELECTION CONSIDERATIONS

The summary of computer system selection considerations set forth within Appendix C includes all factors discussed throughout Section 2 which describes computer system hardware and software components. Asterisks are situated within the tables to indicate the relative importance of each factor to the selection of a computer system to accommodate the applications proposed by Environmental Design Associates. Page numbers listed to the left of each selection consideration indicate the location within this text which provides a description of that computer system characteristic. This summary provides a basis for the development of computer system specifications.

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Computers	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
	Memory Capacity								
126	RAM	*				*			
126	ROM			*				*	
127	PROM				*				*
127	EPROM				*				*
127	EEPROM				*				*
35	CPU Word Length	*				*			
34	Data Bus Word Length		*			*			
34	Address Bus Word Length				*				*
36	Expansion Chassis				*	*			
36	System Speed			*			*		
32	CPU instruction set				*				*
	DMA or Buffer Transfer			*			*		

Page Reference	Selection Considerations Relative Importance — Computer System Hardware: Monitors	Immediate Applications: Critical	Immediate Applications: High Significant	Immediate Applications: Moderate Significant	Immediate Applications: Unimportant	Projected Applications: Critical	Projected Applications: High Significant	Projected Applications: Moderate Significant	Projected Applications: Unimportant
53	Type	*				*			
	Display Quality								
43	Phosphor		*				*		
44	Brightness			*				*	
43	Refresh Rate				*				*
	Adjustable/Fixed				*		*		
54	Color								
	Number Of Displayable Colors				*		*		
	Number Of Simultaneously Displayable Colors				*		*		
54	User Defineable Colors				*			*	
55	Color Dot Grain				*				*
55	Convergence Adjustment				*			*	
46	Number Of Displayable Lines		*				*		

PAGE REFERENCE	Selection Considerations Relative Importance — Computer System Hardware Monitors	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
46	Number Of Displayable Characters Per Line	*				*			
46	Number Of Dots Per Block		*				*		
44	Screen Size	*				*			
44	Screen Resolution		*			*			
44	Bit Map (Bits Per Pixel)				*		*		
48	Hi/Low Resolution Graphics Switch				*			*	
41	Deflector Type (Electrostatic vs. Electromagnetic)				*			*	
	Associated Software Rountines			*			*		
	Display Controls								
70	Split Screen			*				*	
70	Wraparound			*				*	
70	Reverse Video			*				*	
70	Double-intensity			*				*	
71	Blinking			*				*	

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Keyboards	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
66	Output Code				*				*
66	Character Set	*				*			
66	Upper/Lower Case	*				*			
66	Graphic Symbols				*				*
69	Keyboard Layout	*				*			
67	Baud Rate				*				*
	Features								
68	Numeric Cluster	*				*			
68	Separte Cursor Control	*				*			
69	Rollover	*				*			
68	Tactile/Audio Response	*				*			
	Detachable Keyboard			*				*	
	Keyboard Editing Controls								
69	Function Keys			*				*	
69	Tab Sets			*				*	
70	Line Insert/Delete			*				*	
70	Scroll			*				*	

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Digitizers	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
75	Reading Surface Size				*	*			
74	Reading Sensor Type				*		*		
	Speed				*				*
75	Associated Software Rountines								
	Linear & Area Calcualation				*		*		
	Automatic Scaling				*		*		
	Angle Determination				*		*		
	Automatic Reversal				*			*	
	Data Output Formatting				*			*	

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Printers	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
81	Type	*				*			
98	Legibility								
99	Dot Resolution	*						*	
99	Overstrike		*					*	
99	Doublestrike		*					*	
100	Contrast	*						*	
100	Distictness	*						*	
101	Horizontal Pitch/ Proportionality Spacing	*							*
101	Vertical Pitch	*							*
	Uniformity	*							*
102	Speed			*				*	
102	Output Character								
102	Character Set	*						*	
103	Foreign Characters				*				*
103	Graphics Characters				*				*
103	Bit-mapped Graphics				*		*		
101	Upper/lower Case		*				*		
101	True Descenders		*				*		

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Printers	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
103	Print Styles		*						*
103	User Defineable Or Constructable Characters		*						*
103	Print Sizes								
103	Expanded		*					*	
103	Compressed		*					*	
103	Number Of Characters Per Line	*				*			
96	Colors		*						*
108	Buffer		*				*		
108	DMA or Buffer Transfer		*				*		
	Type Of Print Media	*					*		
105	Single Or Multiple Copies				*				*
106	Reliability	*				*			
106	Ease Of Operation								
107	Paper-Out Alarm	*				*			
107	Paper-Out Stop	*				*			
106	Self-Test Function			*				*	

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Plotters	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
114	Type				*	*			
117	Incremental vs. Vector				*		*		
114	On Line/Off Line				*			*	
116	Type Of Media				*		*		
118	Size Of Working Surface				*	*			
118	Sheet Size				*	*			
118	Pen Type				*		*		
	Number Of Pens				*	*			
118	Resolution				*		*		
118	Accuracy				*		*		
118	Repeatability				*		*		
118	Speed				*			*	
	Features								
117	Velocity Optimization				*			*	
	Work Surface Orientation				*			*	
	Buffer				*		*		
	DMA or Buff. Transfer				*		*		

PAGE REFERENCE	Selection Considerations Relative Importance **Computer System Hardware Plotters**	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
	Associated Software Rountines								
	Plot Initialization				*		*		
	Generation Of User Defineable Symbols				*		*		
	Generation Of Lines				*		*		
	Generation Of Axes				*		*		
	Generation Of Alphnumeric Characters				*		*		
	Generation Of User-Defineable Lables				*		*		
	Generation Of Pen Movements				*		*		
	Automatic Scaling				*		*		
	Automatic Pen Change				*		*		
	Determination Of Pen Location				*		*		
	Generation Of Dashed Lines				*		*		

PAGE	REFERENCE	Selection Considerations Relative Importance Computer System Hardware Plotters	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
		Generation Of Tic Marks				*		*		
		Generation Of Circles And Arcs Through Three Points				*		*		
		Generation Of A Linear Grid				*		*		
		Generation Of An Ellipsis or An Elliptical Arc				*		*		
		Generation Of Arrowheads				*		*		
		Generation Of Centerlines				*		*		

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Floppy Disk Systems	Immediate Applications CRITICAL	HIGHLY SIGNIFICANT	MODERATELY SIGNIFICANT	UNIMPORTANT	Projected Applications CRITICAL	HIGHLY SIGNIFICANT	MODERATELY SIGNIFICANT	UNIMPORTANT
	Storage Media								
133	Size			*				*	
134	Single/Dual Sided			*				*	
133	Track Density				*				*
133	Recording Density				*				*
	Data Transfer Rate			*				*	
	Total Storage Capacity		*				*		
	Disk Drive								
	Dimensions				*				*
	Weight				*				*
134	Average Access Time		*				*		
	Error Rate		*				*		
	Read/Write Head Life		*				*		
136	Motor Type			*				*	
	Features								
138	Write Protect		*				*		
138	Daisy-Chaining				*				*

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Floppy Disk Systems	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
138	Software Security			*				*	
139	Disk-In-Place Switch			*				*	
	Buffer			*				*	

REFERENCE	Selection Considerations Relative Importance Computer System Hardware Hard Disk Systems	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
140	Removeable/Nonremoveable Media				*		*		
140	Pack/Cartridge				*			*	
141	Fixed/Movable Heads				*				*
140	Number Of Disks				*			*	
	Media								
140	Size				*				*
140	Recording Density				*				*
	Data Transfer Rate				*		*		
140	Total Storage Capacity				*		*		
	Drive								
	Dimensions				*				*
	Weight				*				*
141	Average Access Time				*		*		
141	Disk Speed (RPM)				*				*
141	Latency				*				*
141	Head Loading Time				*				*

Page	Reference	Selection Considerations Relative Importance Computer System Hardware Hard Disk Systems	Immediate Applications: Critical	Immediate Applications: Highly Significant	Immediate Applications: Moderately Significant	Immediate Applications: Unimportant	Projected Applications: Critical	Projected Applications: Highly Significant	Projected Applications: Moderately Significant	Projected Applications: Unimportant
		Error Rate				*		*		
		Read/Write Head Life				*		*		
		Motor Type				*			*	
		Buffer			*				*	

PAGE REFERENCE	Selection Considerations Relative Importance Computer System Hardware Magnetic Tape Systems	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
146	Type				*				*
	Total Storage Capacity				*				*
	Packing Density				*				*
145	Inter-record Gap				*				*
	Operating Speed				*				*
146	Read/Write Speed				*				*
146	Maximum Start/Stop Rate				*				*
146	Total Speed Variation				*				*
146	Average Access Time				*				*
147	Data Transfer Rate				*				*
147	Type Read/Write Head				*				*
146	Features								
	Fast/Forward				*				*
	Rewind				*				*
	Gap Search				*				*
	Buffer				*				*

		Immediate Applications				Projected Applications			
PAGE REFERENCE	Selection Considerations Relative Importance Computer Software Programming And Developmental Software	CRITICAL	HIGHLY SIGNIFICANT	NOT SIGNIFICANT	UNIMPORTANT	CRITICAL	HIGHLY SIGNIFICANT	NOT SIGNIFICANT	UNIMPORTANT
160	Structured Programming Facilities	*				*			
161	Readability	*				*			
161	File Handling Capability								
162	Random/Sequential File Access	*				*			
	Maximum File Size	*				*			
	Number Of Files Which May Be Open At Once		*			*			
	Acceptable Data Types		*				*		
	Maximum Array Size			*			*		
162	File Creation		*				*		
162	File Deletion		*				*		
162	Transfer Of Data To And From A File		*				*		
162	Change Within A File		*				*		
162	Transfer of A File To A Storage Device		*				*		

PAGE REFERENCE	Selection Considerations Relative Importance Computer Software Programming And Developmental Software	Immediate Applications: CRITICAL	HIGHLY SIGNIFICANT	MODERATELY SIGNIFICANT	UNIMPORTANT	Projected Applications: CRITICAL	HIGHLY SIGNIFICANT	MODERATELY SIGNIFICANT	UNIMPORTANT
161	Portability			*		*			
162	Speed At Run Time			*			*		
162	Arithmetic Precision	*				*			
163	Built-In Functions		*				*		
158	Interpretted/Compiled		*			*			

PAGE REFERENCE	Selection Considerations Relative Importance Computer Software System Software	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MOST SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MOST SIGNIFICANT	Projected Applications: UNIMPORTANT
175	Required Application Software Support	*				*			
175	Required Hardware Support	*				*			
175	Preferred Programming Language support		*				*		
	Required Telecommunications Support			*				*	
	Support For Required Networking	*				*			
171	Single-User/ Single-Program	*				*			
172	Single-User/ Multi-Program				*				
172	Multi-User/ Multi-Processing				*				*
173	Multi-User/ Multi-Program				*				*

PAGE REFERENCE	Selection Considerations Relative Importance Computer Software System Software	Immediate Applications				Projected Applications			
		CRITICAL	HIGHLY SIGNIFICANT	MODERATELY SIGNIFICANT	UNIMPORTANT	CRITICAL	HIGHLY SIGNIFICANT	MODERATELY SIGNIFICANT	UNIMPORTANT
174	ROM vs. Disk Storage			*				*	
176	Method Of Data Access Random vs. sequential	*				*			
176	Portability	*				*			
176	Speed			*			*		
179	Essential Utilities								
	Sort		*				*		
	Merge		*				*		
	Library		*				*		
	Trace		*				*		
	Edit	*				*			
	Copy	*				*			

PAGE REFERENCE	Selection Considerations Relative Importance Computer Software Application Software	Immediate Applications: CRITICAL	Immediate Applications: HIGHLY SIGNIFICANT	Immediate Applications: MODERATELY SIGNIFICANT	Immediate Applications: UNIMPORTANT	Projected Applications: CRITICAL	Projected Applications: HIGHLY SIGNIFICANT	Projected Applications: MODERATELY SIGNIFICANT	Projected Applications: UNIMPORTANT
199	Documentation								
200	Integration								
201	Ease Of Modification								
201	Error Processing								
201	Exception								

APPENDIX D

COMPUTER SYSTEM SPECIFICATIONS

The summary of computer system specifications set forth within Appendix D provides a list of both critical and preferred system characrteristics required to accommdate both the initial and projected applications proposed by Environmental Design Associates. The development of these specifications is discussed throughout Section 3.4 (The Development Of Computer System Specifications). The specifications provide an efficient means by which the user may communicate computer system requirements to computer sales representatives. Computer vendors may use the specifications to determine the computer system configuration best suited to user needs.

Sales representatives of six computer manufacturers were presented with this table of specifications enclosed with a request for a computer system proposal. Responses to those requests as well as information concerning each proposed system is recorded within the forms presented in Appendix D.

SYSTEM PROPOSAL

BY IBM

IBM has not provided a proposal which recommends a complete and working system and for this reason system costs are not included within this system description. IBM proposed a system based upon the IBM AT. Networking capability for the AT is not yet available on the market. In addition, the AT was recently pulled from the market due to some difficulty with the hard disk and the operating system. The system described within this summary is based upon the assumption that IBM will correct those problems and that networking capbility will become available. Until networking is available, it is not possible to determine all required system components or associated cost. For this reason the following proposal is not complete.

WORK STATION #1

IBM AT Computer 512K with dual 1.2M floppy drives
    Monochromatic CRT
    Monochrome graphics card
MS DOS

WORK STATION #2 THROUGH #7

IBM AT Computer 512K with dual 1.2M floppy drives
    Color CRT
    Hi-resolution color graphics card
    80287
MS DOS
UCSD Pascal compiler
Okidata 82A dot matrix printer

NETWORK SERVER (required to manage resources of proposed network)

IBM AT Computer 512K, 2 20M hard disk drives
MS DOS

Due to the high cost of the digitizer, it was recommended that the digitizer be shared, and that additional digitizers be incorporated into the system as justified by the work load.

SHARED PERIPHERALS

Hewlett-Packard Lazerjet Printer	$3495.00
Houston Instrument 7048G Digitizer	$5400.00
Houston Instrument 52 MP Plotter	$5995.00
Total Cost For Shared Peripherals	$14,890.00

Cable costs are not included due to their relative insignificance.

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY IBM	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
COMPUTERS						
RAM capacity	256K		maximum possible		512K	3M
CPU word length	16-bit			32-bit	16-bit	
Data bus word length	8-bit	16-bit		32-bit	16-bit	
System speed	maximum possible		maximum possible		ran benchmark in 4 min. 27 sec.	
DMA or buffer transfer		*		*	no	no
MONOCHROMATIC MONITORS						
phosphor type		p7				
# of displayable lines		24			25	
# of columns per line	80				80	
character block matrix	48 min.				9 x 12	
screen size	9" min.				11 1/2"	
screen resolution	256x256	512x512			640 x 200	
Display control						
Split screen control		*		*	no	
Wraparound		*		*	yes	
Reverse video		*		*	yes	
Double intensity		*		*	yes	
Blinking capability		*		*		
COLOR MONITORS						
Phosphor type	p7					
# of displayable colors			maximum possible		16	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS CRITICAL	INITIAL APPLICATIONS PREFERRED	UPGRADE POTENTIAL CRITICAL	UPGRADE POTENTIAL PREFERRED	SYSTEM PROPOSED BY IBM STANDARD SYSTEM	SYSTEM PROPOSED BY IBM UPGRADE POTENTIAL
# of simultaneously displayable colors			maximum possible		16	
User defineable colors			maximum possible		no	
Convergence adjustment				user adj.		
# of displayable lines		24			25	
# of columns per line	80	80 & 132			80	
Character block matrix	48 min.				8 x 8	
Hi/low resolution graphics switch				*	N/A	
Display control						
Split screen control		*		*	no	
Wraparound		*		*	yes	
Reverse video		*		*	yes	
Double intensity		*		*	yes	
Blinking capability		*		*		
Associated functional software rountines						
Line generation				*		
Circle generation				*		
Curve generation				*		
Rectangle generation				*		
Image scaling				*		
Automatic dimensioning				*		
Image rotation				*		

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS: CRITICAL	INITIAL APPLICATIONS: PREFERRED	UPGRADE POTENTIAL: CRITICAL	UPGRADE POTENTIAL: PREFERRED	SYSTEM PROPOSED BY IBM: STANDARD SYSTEM	SYSTEM PROPOSED BY IBM: UPGRADE POTENTIAL
DIGITIZERS						
Reading surface size	24 x 36				38" x 50"	
Reading sensor type					magnified cross hairs	
Associated functional software rountines						
Linear & area calc.		*			yes	
Automatic scaling		*			yes	
Angle determination		*			yes	
Automatic reversal		*				
Data output formating		*			yes	
KEYBOARDS						
Character set	full ASCII or EBCDIC required				yes	
Upper/lower case	*				yes	
Keyboard layout	QWERTY				yes	
Numeric cluster	*				yes	
Separate cursor controls	*				no	
Rollover	*					
Detatchable keyboard		*			yes	
Keyboard editing controls						
Function keys		*			10	
Tab sets		*			yes	
Scroll		*			yes	
Line insert/delete		*			no	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS: CRITICAL	INITIAL APPLICATIONS: PREFERRED	UPGRADE POTENTIAL: CRITICAL	UPGRADE POTENTIAL: PREFERRED	SYSTEM PROPOSED BY IBM: STANDARD SYSTEM	SYSTEM PROPOSED BY IBM: UPGRADE POTENTIAL
CORRESPONDANCE-QUALITY DOT MATRIX PRINTERS						
Dot resolution	150 dpi	300 dpi			300 dpi	
Overstrike capability		*			N/A	
Double-strike capability		*			yes	
Proportionality spacing	*				yes	
Speed	60 cps				8 pages/min (300cps)	
Character set	full ASCII or EBCDIC required				yes	
Print styles		> 1			2 (+ optional cartridges)	
User defineable chars.		*			yes	
Expanded print capability		*			yes	
Compressed print capability		*			yes	
Characters per line	80	80 & 132			80 to 176	
Bit-mapped graphics				*	yes	
Upper/lower case	*		*		yes	
True descenders		*		*	yes	
Buffer		8K		8K	50K	
DMA or Buffer transfer		*		*	no	
Print media	single & continuous sheets transparencies				single sheets	
Paper-out alarm	*				yes	
Paper-out automatic stop	*					

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY IBM	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
LOW COST MATRIX PRINTERS						
Dot resolution		7 X 7			9 x 9	
Overstrike capability				*		
Double-strike capability				*	yes	
Speed	60 cps				120 cps/60cps	
Character set	full ASCII or EBCDIC required				yes	
Expanded print capability		*			yes	
Compressed print capability		*			yes	
# characters per line	80	80 & 132			80/132	
Print media	contin.				single and continuous	
Paper-out alarm	*				yes	
Paper-out automatic stop	*				yes	
Buffer		8K			no	
DMA or Buffer transfer		*			no	
PLOTTERS						
Vector & incremental mode		*			either	
Plot media		vellum mylar			mylar vellum	
Plotting area	21"x35"				21" x 33"	
Sheet size	24"x36"				24" x 36"	
Pen type		rapidio-graph ink			rapidiograph ink	
Number of pens	> 2	4			14	

	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY IBM	
SYSTEM CHARACTERISTICS	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
Resolution		.001"			.005"	
Accuracy		.01"			.01"	
Repeatability		.001"			.002"	
Speed		maximum			16 ips (axial)/22 ips diagonal)	
Velocity optimization		*			N/A	
Buffer		*				
DMA or Buffer transfer		*			no	
Associated functional software rountines						
Plot initialization		*			yes	
Generation of user-defineable symbols		*			yes	
Generation of lines		*			yes	
Generation of axes		*			yes	
Generation of alphanumeric characters		*			yes	
Generation of pen movements		*			yes	
Automatic scaling		*			yes	
Automatic pen change		*			yes	
Determination of pen location		*				
Generation of dashed lines connecting datum points		*			yes	
Generation of tic marks		*			yes	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS CRITICAL	INITIAL APPLICATIONS PREFERRED	UPGRADE POTENTIAL CRITICAL	UPGRADE POTENTIAL PREFERRED	SYSTEM PROPOSED BY IBM STANDARD SYSTEM	SYSTEM PROPOSED BY IBM UPGRADE POTENTIAL
Generation of circles and arcs through three points		*			yes	
Generation of an ellipsis or an elliptical arc		*			yes	
Generation of a linear grid		*			no	
Generation of arrowheads		*			no	
Generation of centerlines		*			no	
FLOPPY DISK SYSTEMS						
Size					5 1/4"	
Single/dual sided					dual	
Total storage capacity					1.2M	
Average access time						
Buffer						
Features						
Write protect		*				
Software security		*				
Disk-in-place switch		*				
HARD DISK SYSTEM						
Fixed/removeable media		*			fixed	
Total storage capacity					20M	
Number of disks					2	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS: CRITICAL	INITIAL APPLICATIONS: PREFERRED	UPGRADE POTENTIAL: CRITICAL	UPGRADE POTENTIAL: PREFERRED	SYSTEM PROPOSED BY IBM: STANDARD SYSTEM	SYSTEM PROPOSED BY IBM: UPGRADE POTENTIAL
Data transfer rate		*				
Method of data back-up	(removable hard disk or tape streamer pref.)				floppy disk	
Average access time						
Buffer						
PROGRAMMING LANGUAGE	Pascal or FORTRAN	Pascal			Pascal	
Random/sequential file access	random				either	
Maximum file size	maximum possible				512K or disk capacity	
Maximum # of files which may be open at once	maximum possible preferred				as many as will fit into RAM	
Data types which may be stored simultaneously within a file	maximum possible number of types preferred - especially real, integer & chars				typed & untyped files	
Maximum array size	maximum possible				4080 elements	
Arithmetic precision		12			real #s in either 32 or 64 bits	
Built-in functions						
File creation		*			yes	
File deletion		*			yes	
Transfer of data to & from a file		*			yes	
Transfer of a file to a storage device		*			yes	
User-defineable libraries		*				

	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY IBM	
SYSTEM CHARACTERISTICS	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
SYSTEM SOFTWARE						
Required application software support	*				yes	
Required programming language support	*				yes	
Required hardware support	*				yes	
Support of proposed networking	*				not yet	
ROM or disk stored						
Method of data access random or sequential	random or both					
Utilities						
Sort		*				
Merge		*				
User defineable library		*				
Trace		*				
Edit	*				yes	
Copy	*				yes	

SYSTEM PROPOSAL

BY TEXAS INSTRUMENTS

WORK STATION #1

TI Professional Computer 128K with 2 floppy disk drives	$2895.00
Monochromatic CRT	included
+128K RAM	$ 170.00
MS DOS	$ 75.00
Etherlink Accessories Card	$ 795.00
Total Cost For Station #1	$3935.00

WORK STATION #2 THROUGH #7

TI Professional Computer 128K w/two floppy disk drives	$2895.00
Color CRT	included
3 plane graphics enhancement board	$ 325.00
8087 Coprocessor	$ 325.00
128K RAM	$ 170.00
MS DOS	$ 75.00
Etherlink Accessories Card	$ 795.00
UCSD Pascal compiler	$ 450.00
Omni 800 Model 850XL dot matrix printer	$ 659.00
4K printer buffer	$ 90.00
Total Cost For Stations #2 through #7	$5794.00
Total Cost For 6 Stations	$34,764.00

NETWORK SERVER (required to manage resources of proposed network)

TI Professional Computer 128K with 10M hard disk & 1 320K floppy disk drive	$3265.00
Monochromatic monitor	included
128K RAM	$ 170.00
MS DOS	$ 75.00
Ethershare server software	$ 500.00
Etherprint server software	$ 500.00
Total Cost of Network Server	$4510.00

Due to the high cost of the digitizer, it was recommended that the digitizer be shared, and that additional digitizers be incorporated into the system as justified by the work load.

SHARED PERIPHERALS

Hewlett-Packard Lazerjet Printer	$3495.00
Houston Instrument 7048G Digitizer	$5400.00
Houston Instrument 52 MP Plotter	$5995.00
Total Cost For Shared Peripherals	$14,890.00
Total Cost Of System	$58,099.00

Cable costs are not included due to their relative insignificance.

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
COMPUTERS						
RAM capacity	256K		maximum possible		64K	256K
CPU word length	16-bit			32-bit	16-bit	
Data bus word length	8-bit	16-bit		32-bit	8-bit	
System speed	maximum possible		maximum possible		ran benchmark in 4 min. 25 sec.	
DMA or buffer transfer		*		*	no	no
MONOCHROMATIC MONITORS						
phosphor type		p7				
# of displayable lines		24			25	
# of columns per line	80				80	
character block matrix	48 min.				9 x 12	
screen size	9" min.				12"	
screen resolution	256x256	512x512			720 x 300	
Display control						
Split screen control		*		*		
Wraparound		*		*	yes	
Reverse video		*		*	yes	
Double intensity		*		*	yes	
Blinking capability		*		*	yes	
COLOR MONITORS						
Phosphor type	p7				p31	
# of displayable colors			maximum possible		8	

	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
SYSTEM CHARACTERISTICS	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
# of simultaneously displayable colors			maximum possible		8	
User defineable colors			maximum possible		no	
Convergence adjustment	.			user adj.		
# of displayable lines		24			25	
# of columns per line	80	80 & 132			80	
Character block matrix	48 min.				9 x 12	
Hi/low resolution graphics switch				*	N/A	
Display control						
Split screen control		*		*		
Wraparound		*		*	yes	
Reverse video		*		*	yes	
Double intensity		*		*	yes	
Blinking capability		*		*	yes	
Associated functional software rountines						
Line generation				*	yes	
Circle generation				*	yes	
Curve generation				*	yes	
Rectangle generation				*	yes	
Image scaling				*		
Automatic dimensioning				*		
Image rotation				*		

	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
SYSTEM CHARACTERISTICS	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
DIGITIZERS						
Reading surface size	24 x 36				38" x 50"	
Reading sensor type					magnified cross hairs	
Associated functional software rountines						
Linear & area calc.		*			yes	
Automatic scaling		*			yes	
Angle determination		*			yes	
Automatic reversal		*				
Data output formating		*			yes	
KEYBOARDS						
Character set	full ASCII or EBCDIC required				yes	
Upper/lower case	*				yes	
Keyboard layout	QWERTY				yes.	
Numeric cluster	*				yes	
Separate cursor controls	*				yes	
Rollover	*					
Detatchable keyboard		*			yes	
Keyboard editing controls						
Function keys		*			12	
Tab sets		*			yes	
Scroll		*			yes	
Line insert/delete		*			yes	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS: CRITICAL	INITIAL APPLICATIONS: PREFERRED	UPGRADE POTENTIAL: CRITICAL	UPGRADE POTENTIAL: PREFERRED	SYSTEM PROPOSED BY TEXAS INSTRUMENTS: STANDARD SYSTEM	SYSTEM PROPOSED BY TEXAS INSTRUMENTS: UPGRADE POTENTIAL
CORRESPONDANCE-QUALITY DOT MATRIX PRINTERS						
Dot resolution	150 dpi	300 dpi			300 dpi	
Overstrike capability		*			N/A	
Double-strike capability		*			yes	
Proportionality spacing	*				yes	
Speed	60 cps				8 pages/min (300cps)	
Character set	full ASCII or EBCDIC required				yes	
Print styles		> 1			2 (+ optional cartridges)	
User defineable chars.		*			yes	
Expanded print capability		*			yes	
Compressed print capability		*			yes	
Characters per line	80	80 & 132			80 to 176	
Bit-mapped graphics				*	yes	
Upper/lower case	*		*		yes	
True descenders		*		*	yes	
Buffer		8K		8K	50K	
DMA or Buffer transfer		*		*	no	
Print media	single & continuous sheets transparencies				single sheets	
Paper-out alarm	*				yes	
Paper-out automatic stop	*					

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
LOW COST MATRIX PRINTERS						
Dot resolution		7 X 7			9 x 9 & 15 x 18 (dual mode)	
Overstrike capability				*	yes	
Double-strike capability				*	yes	
Speed	60 cps				150 cps/35cps	
Character set	full ASCII or EBCDIC required				yes	
Expanded print capability		*			yes	
Compressed print capability		*			yes	
# characters per line	80	80 & 132			80/132	
Print media	contin.				single and continuous	
Paper-out alarm	*				yes	
Paper-out automatic stop	*				yes	
Buffer		8K			4k	
DMA or Buffer transfer		*			no	
PLOTTERS						
Vector & incremental mode		*			either	
Plot media		vellum mylar			mylar vellum	
Plotting area	21"x33"				21" x 33"	
Sheet size	24"x36"				24" x 36"	
Pen type		rapidio- graph ink			rapidiograph ink	
Number of pens	> 2	4			14	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
Resolution		.001"			.005"	
Accuracy		.01"			.01"	
Repeatability		.001"			.002"	
Speed		maximum			16 ips (axial)/22 ips diagonal)	
Velocity optimization		*			N/A	
Buffer		*				
DMA or Buffer transfer		*			no	
Associated functional software rountines						
Plot initialization		*			yes	
Generation of user-defineable symbols		*			yes	
Generation of lines		*			yes	
Generation of axes		*			yes	
Generation of alphanumeric characters		*			yes	
Generation of pen movements		*			yes	
Automatic scaling		*			yes	
Automatic pen change		*			yes	
Determination of pen location		*				
Generation of dashed lines connecting datum points		*			yes	
Generation of tic marks		*			yes	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
Generation of circles and arcs through three points		*			yes	
Generation of an ellipsis or an elliptical arc		*			yes	
Generation of a linear grid		*			no	
Generation of arrowheads		*			no	
Generation of centerlines		*			no	
FLOPPY DISK SYSTEMS						
Size					5 1/4"	
Single/dual sided					dual	
Total storage capacity					320K	
Average access time						
Buffer						
Features						
Write protect		*				
Software security		*				
Disk-in-place switch		*				
HARD DISK SYSTEM						
Fixed/removeable media		*			fixed	
Total storage capacity					10M	
Number of disks					1	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS CRITICAL	INITIAL APPLICATIONS PREFERRED	UPGRADE POTENTIAL CRITICAL	UPGRADE POTENTIAL PREFERRED	SYSTEM PROPOSED BY TEXAS INSTRUMENTS STANDARD SYSTEM	SYSTEM PROPOSED BY TEXAS INSTRUMENTS UPGRADE POTENTIAL
Data transfer rate		*				
Method of data back-up	(removable hard disk or tape streamer pref.)				floppy disk	
Average access time						
Buffer						
PROGRAMMING LANGUAGE	Pascal or FORTRAN	Pascal			Pascal	
Random/sequential file access	random					
Maximum file size	maximum possible					
Maximum # of files which may be open at once	maximum possible preferred					
Data types which may be stored simultaneously within a file	maximum possible number of types preferred - especially real, integer & chars					
Maximum array size	maximum possible					
Arithmetic precision		12				
Built-in functions						
File creation		*				
File deletion		*				
Transfer of data to & from a file		*				
Transfer of a file to a storage device		*				
User-defineable libraries		*				

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TEXAS INSTRUMENTS	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
SYSTEM SOFTWARE						
Required application software support	*				yes	
Required programming language support	*					
Required hardware support	*				yes	
Support of proposed networking	*				yes	
ROM or disk stored						
Method of data access random or sequential	random or both					
Utilities						
Sort		*				
Merge		*				
User defineable library		*				
Trace		*				
Edit	*				yes	
Copy	*				yes	

SYSTEM PROPOSAL

BY TANDY CORPORATION

WORK STATION #1

Tandy 2000 dual disk 256K computer	$2499.00
+ 128K RAM (on 256K expansion board) (additional RAM required to support network)	$ 399.95
MS DOS	included
Tandy 2000 Vianet board	$ 499.95
Total Cost For Station #1	$3398.90

WORK STATIONS #2 THROUGH #6

Tandy 2000 dual disk 256K computer	$2499.00
+128K RAM (on 256K expansion board) (additional RAM required to support network)	$ 399.95
MS DOS	included
HI-resolution color graphics chip kit	$ 149.95
Tandy 2000 Vianet board	$ 499.95
Microsoft Pascal compiler	$ 299.95
DMP - 105 dot matrix printer	$ 199.95
Total Cost For Each Station	$4048.75
Total Cost For Five Stations	$20,243.75

WORK STATION #7

Tandy 2000 single disk computer with 10M hard disk ---$3950.00

Work stations #2 through #6 may also be equipped with a shared hard disk drive it greater external storage capacity is required.

MS DOS	included
Hi-resolution color graphics chip kit	$ 149.95
Tandy 2000 Vianet board	$ 499.95
Microsoft Pascal compiler	$ 299.95
DMP - 105 dot matrix printer	$ 199.95
Total Cost For Work Station #7	$5099.80

Due to the high cost of the digitizer, it was recommended that the digitizer be shared, and that additional digitizers be incorporated into the system as justified by the work load.

SHARED PERIPHERALS

```
DMP-2100P correspondance-quality dot matrix printer --$1995.00
Bi-directional tractor feed --------------------------$ 169.95
Houston Instrument 7048G Digitizer -------------------$5400.00
Houston Instrument 52 MP Plotter ---------------------$5995.00
---------------------------------------------------------------
            Total Cost For Shared Peripherals    $13,559.95


                       Total Cost Of System    $42,302.20
```

Cable costs are not included due to their relative insignificance.

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANDY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
COMPUTERS						
RAM capacity	256K		maximum possible		256K	768K
CPU word length	16-bit			32-bit	16-bit	
Data bus word length	8-bit	16-bit		32-bit	16-bit	
System speed	maximum possible		maximum possible			
DMA or buffer transfer		*		*	no	no
MONOCHROMATIC MONITORS						
phosphor type		p7				
# of displayable lines		24			25	
# of columns per line	80				80	
character block matrix	48 min.				8 x 16	
screen size	9" min.				12"	
screen resolution	256x256	512x512			640 x 400	
Display control						
Split screen control		*		*		
Wraparound		*		*		
Reverse video		*		*		
Double intensity		*		*		
Blinking capability		*		*		
COLOR MONITORS						
Phosphor type	p7					
# of displayable colors			maximum possible		16	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANDY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
# of simultaneously displayable colors			maximum possible		8	
User defineable colors			maximum possible		0	
Convergence adjustment				user adj.		
# of displayable lines		24			25	
# of columns per line	80	80 & 132			80	
Character block matrix	48 min.				8 x 16	
Hi/low resolution graphics switch				*	N/A	
Display control						
Split screen control		*		*		
Wraparound		*		*		
Reverse video		*		*		
Double intensity		*		*		
Blinking capability		*		*		
Associated functional software rountines						
Line generation				*		
Circle generation				*		
Curve generation				*		
Rectangle generation				*		
Image scaling				*		
Automatic dimensioning				*		
Image rotation				*		

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS: CRITICAL	INITIAL APPLICATIONS: PREFERRED	UPGRADE POTENTIAL: CRITICAL	UPGRADE POTENTIAL: PREFERRED	SYSTEM PROPOSED BY TANDY CORPORATION: STANDARD SYSTEM	SYSTEM PROPOSED BY TANDY CORPORATION: UPGRADE POTENTIAL
DIGITIZERS						
Reading surface size	24 x 36				38" x 50"	
Reading sensor type					magnified cross hairs	
Associated functional software rountines						
Linear & area calc.		*			yes	
Automatic scaling		*			yes	
Angle determination		*			yes	
Automatic reversal		*				
Data output formating		*			yes	
KEYBOARDS						
Character set	full ASCII or EBCDIC required				yes	
Upper/lower case	*				yes	
Keyboard layout	QWERTY				yes	
Numeric cluster	*				yes	
Separate cursor controls	*				yes	
Rollover	*					
Detatchable keyboard		*			yes	
Keyboard editing controls						
Function keys		*			12	
Tab sets		*			yes	
Scroll		*				
Line insert/delete		*				

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANDY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
CORRESPONDANCE-QUALITY DOT MATRIX PRINTERS						
Dot resolution	150 dpi	300 dpi			180 dpi	
Overstrike capability		*				
Double-strike capability		*				
Proportionality spacing	*				yes	
Speed	60 cps				160 & 100 cps	
Character set	full ASCII or EBCDIC required				yes	
Print styles		> 1			several	
User defineable chars.		*			yes	
Expanded print capability		*			yes	
Compressed print capability		*			yes	
Characters per line	80	80 & 132			80/132	
Bit-mapped graphics				*	yes	
Upper/lower case	*		*		yes	
True descenders		*		*		
Buffer		8K		8K	no	
DMA or Buffer transfer		*		*	no	
Print media	single & continuous sheets transparencies				single and continuous sheets	
Paper-out alarm	*				yes	
Paper-out automatic stop	*					

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS CRITICAL	INITIAL APPLICATIONS PREFERRED	UPGRADE POTENTIAL CRITICAL	UPGRADE POTENTIAL PREFERRED	SYSTEM PROPOSED BY TANDY CORPORATION STANDARD SYSTEM	SYSTEM PROPOSED BY TANDY CORPORATION UPGRADE POTENTIAL
LOW COST MATRIX PRINTERS						
Dot resolution		7 X 7			8 x 9	
Overstrike capability				*	yes	
Double-strike capability				*	yes	
Speed	60 cps				80 cps	
Character set	full ASCII or EBCDIC required				yes	
Expanded print capability		*			yes	
Compressed print capability		*			yes	
# characters per line	80	80 & 132			80/132	
Print media	contin.				single and continuous	
Paper-out alarm	*					
Paper-out automatic stop	*					
Buffer		8K			no	
DMA or Buffer transfer		*			no	
PLOTTERS						
Vector & incremental mode		*			either	
Plot media		vellum mylar			mylar vellum	
Plotting area	21"x35"				21" x 33"	
Sheet size	24"x36"				24" x 36"	
Pen type		rapidio-graph ink			rapidiograph ink	
Number of pens	> 2	4			14	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANOY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
Resolution		.001"			.005"	
Accuracy		.01"			.01"	
Repeatability		.001"			.002"	
Speed		maximum			16 ips (axial)/22 ips diagonal)	
Velocity optimization		*			N/A	
Buffer		*				
DMA or Buffer transfer		*			no	
Associated functional software rountines						
Plot initialization		*			yes	
Generation of user-defineable symbols		*			yes	
Generation of lines		*			yes	
Generation of axes		*			yes	
Generation of alphanumeric characters		*			yes	
Generation of pen movements		*			yes	
Automatic scaling		*			yes	
Automatic pen change		*			yes	
Determination of pen location		*				
Generation of dashed lines connecting datum points		*			yes	
Generation of tic marks		*			yes	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANDY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
Generation of circles and arcs through three points		*			yes	
Generation of an ellipsis or an elliptical arc		*			yes	
Generation of a linear grid		*			no	
Generation of arrowheads		*			no	
Generation of centerlines		*			no	
FLOPPY DISK SYSTEMS						
Size					5 1/4"	
Single/dual sided					dual	
Total storage capacity					720K	
Average access time						
Buffer						
Features						
Write protect		*				
Software security		*				
Disk-in-place switch		*				
HARD DISK SYSTEM						
Fixed/removeable media		*			fixed	
Total storage capacity					10M	
Number of disks					1	

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANDY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
Data transfer rate		*				
Method of data back-up	(removable hard disk or tape streamer pref.)				floppy disk	
Average access time						
Buffer						
PROGRAMMING LANGUAGE	Pascal or FORTRAN	Pascal			Pascal	
Random/sequential file access	random					
Maximum file size	maximum possible					
Maximum # of files which may be open at once	maximum possible preferred					
Data types which may be stored simultaneously within a file	maximum possible number of types preferred - especially real, integer & chars					
Maximum array size	maximum possible					
Arithmetic precision		12				
Built-in functions						
File creation		*				
File deletion		*				
Transfer of data to & from a file		*				
Transfer of a file to a storage device		*				
User-defineable libraries		*				

SYSTEM CHARACTERISTICS	INITIAL APPLICATIONS		UPGRADE POTENTIAL		SYSTEM PROPOSED BY TANDY CORPORATION	
	CRITICAL	PREFERRED	CRITICAL	PREFERRED	STANDARD SYSTEM	UPGRADE POTENTIAL
SYSTEM SOFTWARE						
Required application software support	*				yes	
Required programming language support	*				yes	
Required hardware support	*				yes	
Support of proposed networking	*				yes	
ROM or disk stored					ROM	
Method of data access random or sequential	random or both					
Utilities						
Sort		*				
Merge		*				
User defineable library		*				
Trace		*				
Edit	*				yes	
Copy	*				yes	

APPENDIX E

COMPUTER SYSTEM EVALUATION MATRIX

The evaluation matrix presented within Appendix E provides a means for point-by-point comparison of systems proposed for Environmental Design Associates by six contending manufacturers. Systems are compared and rated according to the selection considerations set forth within Appendices C and D. Relative importance of each factor, as indicated within Appendix C, as well as the system requirements set forth within Appendix D were taken into consideration to determine the ratings assigned to proposed systems. Relative importance of each selection consideration is reflected in the weighting factor.

Computer system ratings are tallied on page ___ of Appendix E to determine the system most suitable for Environmental Design Associates.

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
20	COMPUTERS							
6	RAM Capacity	10:60.00	1: 6.00	7:42.00				
4	CPU Word length	5:20.00	5:20.00	5:20.00				
4	Data bus word length	6:24.00	2: 8.00	6:24.00				
4	System speed							
2	DMA or Buffer transfer	10:20.00	0: 0.00	0: 0.00				
	TOTAL RATING - COMPUTERS	124.00	34.00	88.00				

5	MONOCHROMATIC CRTS							
.50	# of displayable lines	5:25.00	5:25.00	5:25.00				
1.25	# of columns per line	5: 6.25	5: 6.25	5: 6.25				
.50	Character block matrix	6: 3.00	6: 3.00	8: 4.00				
.45	Screen size	6: 2.70	6: 2.70	6: 2.70				
2.00	Screen resolution	5:10.00	8:16.00	9:18.00				
	Display controls							
.05	Split screen control							

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
.05	Wraparound							
.05	Reverse video							
.05	Double intensity							
.05	Blinking capability							
	TOTAL RATING - MONOCHROMATIC MONITORS							

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
20	COLOR MONITORS							
.40	Phosphor type							
.40	# of Displayable Colors	7: 2.80	5: 2.00	7: 2.80				
1.00	# simultaneously displayable colors	7: 7.00	5: 5.00	5: 5.00				
.40	User definable colors	0: 0.00	0: 0.00	0: 0.00				
.20	Convergence adjustment							
2.00	# of displayable lines	5:10.00	5:10.00	5:10.00				
3.00	# of columns per line	5:15.00	5:15.00	5:15.00				
1.00	Character block matrix	3: 3.00	6: 6.00	8: 8.00				
2.00	Screen size	5:10.00	5:10.00	5:10.00				
6.00	Screen resolution	3:18.00	8:48.00	9:54.00				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
	Display control							
.20	Split screen control							
.20	Wraparound							
.20	Reverse video							
.20	Double intensity							
.20	Blinking capability							
.60	Hi/lo res graphics switch							
2.00	Associated software							
	TOTAL RATING - COLOR MONITORS	65.80	96.00	104.80				

6	**DIGITIZERS**							
4.20	Reading surface size	10:42.00	10:42.00	10:42.00				
.90	Reading sensor type	10: 9.00	10: 9.00	10: 9.00				
.90	Associated software	10: 9.00	10: 9.00	10: 9.00				
	TOTAL RATING - DIGITIZERS	60.00	60.00	60.00				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
5	**KEYBOARDS**							
1.0	Character set	10:10.00	10:10.00	10:10.00				
.75	Upper/lower case	10: 7.50	10: 7.50	10: 7.50				
1.00	Keyboard layout (QWERTY)	10:10.00	10:10.00	10:10.00				
.75	Numeric cluster	10: 7.50	10: 7.50	10: 7.50				
.75	Separate cursor controls	0: 0.00	10: 7.50	10: 7.50				
.25	Rollover							
.05	Detatchable keyboard	10: 0.50	10: 0.50	10: 0.50				
	Keyboard editing controls							
.10	Function keys	5: 0.50	7: 0.70	7: 0.70				
.15	Tab sets							
.10	Scroll							
.10	Line insert/delete							
	TOTAL RATING - KEYBOARDS	36.00	43.70	43.70				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
10	**CORRESPONDANCE-QUALITY DOT MATRIX PRINTER**							
2.5	Dot resolution	10:25.00	10:25.00	6:15.00				
.10	Overstrike capability							
.10	Double-strike capability	10: 1.00	10: 1.00	10: 1.00				
.10	Proportionality spacing	10: 1.00	10: 1.00	10: 1.00				
.50	Speed	10: 5.00	10: 5.00	6: 3.00				
.50	Character set	10: 5.00	10: 5.00	10: 5.00				
.20	Print styles	10: 2.00	10: 2.00	10: 2.00				
.10	User definable chars	10: 1.00	10: 1.00	10: 1.00				
.20	Expanded print	10: 2.00	10: 2.00	10: 2.00				
.20	Compressed print	10: 2.00	10: 2.00	10: 2.00				
1.00	# characters per line	10: 1.00	10: 1.00	10: 1.00				
1.00	Bit-mapped graphics	10:10.00	10:10.00	10:10.00				
1.50	Upper/lower case	10:15.00	10:15.00	10:15.00				
.30	True descenders	10: 3.00	10: 3.00	10: 3.00				
1.00	Buffer	10:10.00	10:10.00	10:10.00				
.40	DMA or Buffer transfer	0: 0.00	0: 0.00	0: 0.00				
.10	Print media	2: 0.20	2: 0.20	8: 0.80				
.10	Paper-out alarm	10: 1.00	10: 1.00	10: 1.00				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
.10	Paper-out stop							
	TOTAL RATING - CORRESPONDANCE-QUALITY DOT MATRIX PRINTER	84.20	84.20	62.80				

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
5	LOW COST DOT MATRIX PRINTERS							
1.0	Dot Resolution	7: 7.00	9: 9.00	6: 6.00				
.05	Overstrike capability							
.05	Double strike capability	10: 0.50	10: 0.50	10: 0.50				
1.25	Speed	6: 7.50	7: 8.75	3: 3.75				
.75	# of printable characters	10: 7.50	10: 7.50	10: 7.50				
.10	Expanded print	10: 1.00	10: 1.00	10: 1.00				
.10	Compressed print	10: 1.00	10: 1.00	10: 1.00				
.50	# of characters per line	10: 5.00	10: 5.00	10: 5.00				
.10	Print media	10: 1.00	10: 1.00	10: 1.00				
.75	Buffer	0: 0.00	0: 0.00	0: 0.00				
.25	DMA or buffer transfer	0 0.00	0 0.00	0 0.00				
.05	Paper-out alarm							
.05	Paper-out stop							
	TOTAL RATING - LOW COST DOT MATRIX PRINTERS	30.50	33.75	25.75				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
8	PLOTTERS							
.08	Vector/incremental mode	10: 0.80	10: 0.80	10: 0.80				
.40	Plot media	10: 4.00	10: 4.00	10: 4.00				
4.00	Plotting area	10:40.00	10:40.00	10:40.00				
.40	Sheet size	10:40.00	10:40.00	10:40.00				
.16	Pen type	10: 1.60	10: 1.60	10: 1.60				
.16	# of pens	10: 1.60	10: 1.60	10: 1.60				
.25	Resolution	10: 2.50	10: 2.50	10: 2.50				
.25	Accuracy	10: 2.50	10: 2.50	10: 2.50				
.25	Repeatability	10: 2.50	10: 2.50	10: 2.50				
.25	Speed	10: 2.50	10: 2.50	10: 2.50				
.30	Buffer							
.25	DMA or Buffer transfer	0: 0.00	0: 0.00	0: 0.00				
.40	Associated software	0: 3.60	9: 3.60	9: 3.60				
	TOTAL RATING - PLOTTERS	65.60	65.60	65.60				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
5	FLOPPY DISK SYSTEMS							
.10	Size	B: 0.80	B: 0.80	B: 0.80				
.10	Single/dual sided	10: 1.00	10: 1.00	10: 1.00				
3.00	Total storage capacity	10:30.00	4:12.00	7:21.00				
.75	Average access time							
	Features							
.10	Write protect							
.10	Software-security							
.10	Disk-in place switch							
.75	Buffer							
	TOTAL RATING - FLOPPY DISK SYSTEMS	39.00	21.00	30.00				

8	HARD DISK SYSTEMS							
.16	Fixed/removable head	5: 0.80	5: 0.80	5: 0.80				
3.60	Total storage capacity	10:36.00	5:18.00	5:18.00				
.08	Number of disks	10: 0.80	5: 0.40	5: 0.40				

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
.16	Data transfer rate							
1.60	Data back-up method	3: 4.80	3: 4.80	3: 4.80				
.80	Average access time							
1.60	Buffer							
	TOTAL RATING HARD DISK SYSTEMS	42.40	24.00	24.00				

WEIGHTING FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
5	PROGRAMMING LANGUAGES							
1.25	Random/seq. file access							
.25	Maximum file size							
.25	Maximum # of files which may be open at once							
.25	Data types which may be stored at once within a file							
.10	Maximum array size							
2.50	Arithmetic precision							
.25	Built-in functions							
.15	User definable library							
	TOTAL RATING - PROGRAMMING LANGUAGES							

COMPUTER SYSTEM EVALUATION MATRIX

WEIGHTING	FACTOR	COMPUTER SYSTEM CHARACTERISTICS	IBM	TEXAS INSTRUMENTS	TANDY CORPORATION	HEWLETT PACKARD	DIGITAL EQUIPMENT CORPORATION		
4		**SYSTEM SOFTWARE**							
.80		Required application software support	10: 8.00	10: 8.00	10: 8.00				
.80		Preferred programming language support							
.80		Required network support	0: 0.00	10: 8.00	10: 8.00				
.80		Required hardware support	10: 8.00	10: 8.00	10: 8.00				
.04		ROM or disk storage							
.60		Random/seq. data access							
.16		Utilities							
		TOTAL RATING SYSTEM SOFTWARE	16.00	24.00	24.00				

TOTAL RATING - COMPUTER SYSTEMS	597.95	516.70	562.10				

TOTAL COST PER COMPUTER SYSTEM		$58,099	$42,302				

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A METHODOLOGY FOR THE SELECTION OF MICROCOMPUTER SYSTEMS FOR LANDSCAPE ARCHITECTURAL PRACTICE

by

JANET RUTH KEATHLEY

B. S., University of Missouri, 1975

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF LANDSCAPE ARCHTECTURE

Department of Landscape Architecture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1985

A growing number of landscape architects are beginning to the see the computer as a necessity to remain viable and competitive within the landscape architecture profession. Within this study, a methodology by which landscape architects may analyze data processing objectives and select a microcomputer system best suited to aid the attainment of those objectives has been developed. Although this research effort has focused primarily upon landscape architectural applications, the selection methodology may be successfully applied to some other applications. While the methodology may be applied to the selection of larger computer systems, the major emphasis is directed toward the microcomputer and its constituent components. Computer system hardware and software components were researched to determine pertinent computer system selection criteria as well as the relative importance of each consideration within the selection process. Application software selection criteria were addressed less extensively within this study.

The methodology sets forth a process by which individual hardware and software criteria may be specified to describe a system most suitable to attain established data processing objectives. The methodology includes the establishment of those data processing objectives as well as the definition of individual tasks involved. Finally, the selection methodology was demonstrated in the selection of a microcomputer system for a hypothetical landscape architectural firm.

The final product of this research includes: (1) a definition of the problem which acted as a catalyst for this research, (2) a description of computer system components, (3) a methodology for computer system selection, and (4) the final conclusions of the study.