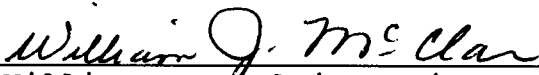
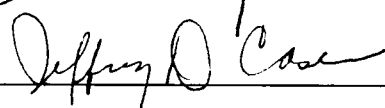


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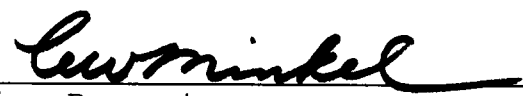
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Dr. William J. McClain, Major Professor

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A STUDY OF THE
RESPONSE TIME CONSIDERATIONS FOR
A PC-BASED CAD NETWORK

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Kathryn Cecilia Hotz Thompson

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ABSTRACT

Personal Computers (PCs) have entered the field of design in a relatively short period of time. PC-based Computer Aided Design (CAD) networks are a new development. More importantly, the technology behind the development did not come about with timing factors in mind. Originally, CAD system advancements came from the automobile and the aircraft industry. These corporations discovered the need to improve their design departments in order to keep up with their workload. In the 1980's the Personal Computer came to the attention of smaller corporations that could not afford the very expensive and large CAD systems. Software was written to perform CAD capabilities for the PCs. CAD system designers are now discovering ways to network the PCs to form a PC-based system allowing CAD functions to be performed with less cost than the original larger networks. In order to ensure that the PC-based networks will be useful, response times for the user must be minimized. Six timing aspects of a PC-based network are discussed to show

the points of interest for this type network. A particular network being developed by the Tennessee Valley Authority is presented to exemplify how some of these details were considered. Based on these studies, specific recommendations are presented for a general PC-based network.

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CHAPTER 1

What is a PC-based CAD System ?

1.1 Introduction

Computers play an important role in today's industrial environment. They are becoming more integrated into daily activities. They are no longer mysterious things that only highly-trained experts can operate. The Personal Computer (PC) was originally created to serve the needs of the novice as well as the expert computer user. As a result, the PCs are being adapted to serve many skills. The industrial design process is one of these skills.

The use of computers for design in architecture, engineering, construction, and industry is called computer-aided design, abbreviated CAD. CAD has been used for a variety of purposes, including the design of automobiles, aircraft, power plants, oil rigs, and sailboats, to name a few. The design process is a natural operation for computers. In the 1980s, PCs were adapted to this design process. By networking the

PCs, a PC-based CAD system can be created. These systems can supplement familiar skills, reduce errors where parts overlap, perform analyses, produce drawings, maintain data files, and stimulate the designer's imagination by increasing the design library.

1.2 History

Computer-aided design (CAD) has actually been in existence a long time. There is a slight dispute as to when it began and who started it. Some believe it links back as far as the 17th century with the beginnings of topology [1]. Others say it started in the 1950's with computer-aided graphics when Ivan Sutherland started the concept of interactive graphics with his work on the Sketch Pad drawing system [18]. Sutherland developed interaction techniques using the keyboard and light pen for selection, pointing, and drawing. These certainly contributed to CAD, but the real CAD systems began when the aerospace and automobile industries started using computers to aid in their design efforts.

It is important to note that, just like many advancements, the application of computing power to the design process came about by need and not by someone's recognition of its future demand. This is why the automobile and aerospace industries were the first to use CAD actively [31]. These industries found the practices of design of the 1960's to be unacceptable. General Motors Inc. (General Motors), Ford Motor Company (Ford), and Boeing Aircraft Corporation (Boeing) could not keep up with the additional work load of new product programs [10] [26] [52]. Before computers, full-size clay models were developed to show the appearance of all surfaces, shapes, and finishes [26]. Templates were cut to fill these clay models, and from these templates master surface layout drawings were created to show surface contours. Manual techniques were used by draftspeople to smooth and refine the drawings and to add hardware, inner panels and ornamentation. Metal templates were then constructed to develop a wood-die model, resulting in a master wood model which was used to

make plaster casts for cutting dies. This process took a lot of time.

In 1968 Ford introduced the electronic scanner into its operation. The scanner was used to collect data electronically from the clay model; this data was then transferred directly to an engineering design graphic station. This eliminated the time consumed in making the template previously described.

During this same time period ,General Motors, in a joint effort with International Business Machines Corporation (IBM), developed the Design Augmented by Computer (DAC-1) single-computer graphics system to help improve their production [52]. In the early 1970's their system was updated and replaced by two new systems called Computer-Aided Design and Numbered Control Effort (CADENCE) and Fisher Graphics. These two systems have been and are still being improved. Information from these systems is electronically transferred by a Network station into a vendor-supplied turnkey system where design can be completed.

Concurrently, in the mid-1960's Boeing was

developing the 737 model aircraft. Engineers used computer technology to design parts and to define mathematically the complex exterior surfaces of the aircraft [10]. This led to the development of sculptured surface technology which, in the early 1970's, Boeing used to generate engineering drawings. This laid the foundation for development of a CAD system. In the mid 1970's Boeing installed interactive computer graphics systems for the production of the 747 model aircraft. These systems allowed the operators to create part designs and associated drawings in a real-time graphics mode. Boeing has extended its CAD capabilities for its production of the 757, 767, and the 777 model aircrafts. The system produced more than 6000 drawings for the 767 model. By combining all of the information into a common data base, the entire aircraft can be assembled in the computer to check for clearances and fit.

CAD systems had a slow start, mostly because of the expense involved. It was very expensive to be on-line to a computer of any size in the early

1960's. In 1964, time-sharing of large computers resulted in the reduction in cost for on-line operation. With the advent of mini-computers and cheaper displays in the late 1960's and early 1970's, CAD systems were being developed for all types of industry. In the late 1960's the first computer-aided design systems were released on the market by American vendors [42]. In the early 1970's two-dimensional drafting systems, intended for plant design by large engineering firms, entered the architecture, engineering, and construction markets. Researchers at Cambridge in Great Britain started developing a system that was not only a drafting tool but also a design aid. Many organizations of CAD vendors, researchers and users were formed. For instance, the Society for Computer Applications in Engineering was formed in the United States. Many other countries also formed such societies.

By the mid-1970's, CAD had become very well-known in the computer industry, but it was still not used heavily. It became apparent that CAD systems would have to be developed beyond simple

drawing systems to be really useful [42]. Some vendors began developing systems for specific purposes, such as mapping, mechanical engineering, etc. These systems were still very expensive, and only large firms could consider investing the time and money required for their implementation.

Finally, at the end of the 1970's aggressive competition began among vendors to create improvements in CAD systems, which resulted in a steady reduction in the price [42]. What formerly cost several million dollars could now be obtained for a few hundred thousand dollars [31]. Also, designers' interests were greatly aroused. They found CAD systems to be an enjoyable new toy even though they were finding it difficult to justify the cost. By the early 1970's there were only about 200 CAD workstations in the world, and most of these were in-house systems in large aerospace and automobile companies [31]. In 1976 only about 35 percent of architectural and engineering firms were involved in computing [42]. In contrast, by 1981 sixty-five percent of architectural and engineering firms were involved with computers, and in

1982 there were more than 12,000 CAD workstations in place [31] [42]. Many feel that the advent of the minicomputer (with the resultant reduction in cost) was the major reason for the increased utilization of CAD systems. However, it should be noted that technological and software development also played a large part in the CAD systems' sudden growth.

In the 1980's another technological wonder came to the attention of the world. The Personal Computer, commonly called the PC, began showing up in many offices and homes. Engineers and designers found the PCs to be very useful and enjoyable. PCs progressed from home bookkeeping systems to powerful machines able to handle many of the tasks that in the past required mainframes computers. Along with these advancements, software was created to give graphic capabilities to PCs. Now, not only are the PCs being networked for communication purposes but they also have become an important and integral part of some CAD systems. CAD managers are directing their attention toward the relatively low-cost PC-based systems, and the PC-based workstation type CAD

systems are now being utilized by many firms. As PCs, PC-related equipment, and PC software improve, so will the usefulness of the PC as a CAD device. Many situations in which CAD networks would have been advantageous were cost restrictive; but the PC provided the computing power at a greatly reduced cost. The PC has brought CAD to the point where many can benefit from this technology.

1.3 Negative Aspects of CAD Systems

Many companies originally approached the subject of CAD with great apprehension. As with the introduction of any new technology, the initial reaction was rejection. Management saw it as just another system to manage. Employees would require retraining; people contact and interaction would be reduced. New equipment, new furniture, and new technology would be needed. Committees would have to be formed to study which CAD systems to purchase. There are literally dozens of systems to choose from, all having different prices and capabilities. With little research to depend on,

the committees would have to investigate all claims made by vendors.

It is obvious that these negative aspects, as well as the apparent high cost of CAD systems, are common negative aspects of all new technologies. Using a PC-based system may help reduce costs, but it stimulates other negative reactions. Many people think that PCs will not be capable of handling the tasks necessary for a CAD system. This fear can usually be resolved by considering existing PC-based systems. PCs and related equipment are now being developed which can handle not only small applications with minimal usage but also larger applications with frequent file sharing by several users. One real negative aspect of a PC-based CAD system is the increased difficulty in system management. This, however, is true for all distributed CAD systems and not just those that are PC-based.

1.4 Positive Aspects of CAD Systems

From the initial reaction of rejection, the CAD systems began adapting to both the vendors'

supply and the users' needs. This adaptation began in the late 1970's, and it led to the stage of utilization being experienced today. CAD technology is now considered one of the most powerful tools that can be given to the designer. Designers who are already conditioned to a changing environment adapt to CAD techniques easily.

Normal engineering and architectural practices also adapt readily to CAD systems. The traditional skills and organizational structures are hardly being affected by CAD systems due to networking. The systems can help the designer through all phases of the design process. Designers must gather, or have gathered for them, the necessary design data of an object plus the data about existing parts which may be used.

Networked computers are excellent for this. With a CAD system, the designer can have the data not only on paper but also on screen where it can be seen, manipulated, and changed at the push of a button.

The designer must create many drawings. The CAD system can produce many copies of a drawing without affecting the original. Overlay drawings for

comparisons to help prevent errors can be used. The CAD system can actually reduce the number of drawings necessary for a project by the many "what-if" drawings that now can be displayed on the screen but are never needed on paper.

Designers were formerly required to perform many time-consuming calculations, which the computer can easily perform. Much of the paper work that the designer or the clerical staff must perform can be reduced. The designers must use their imagination and creativity to produce effective results. The computer cannot do the human thinking for them; however, the designer's limited resources can be enhanced by an increased library of knowledge stored in the data banks of the computer. As long as the CAD system is considered a simulation of the normal human-design working process, the transfer to a CAD system is a natural improvement.

Many other benefits result from the use of a CAD system. One of the more obvious benefits is the increase in productivity. In most cases there is an initial drop in productivity for the first

few months of the use of a CAD system; however, increases of two-to-one by the end of the first year generally result [20]. Succeeding years usually show further increases.

Another benefit is the increased capabilities that are available to the designers. The designers can use the system to enhance their creativity. They can produce many "what-if" drawings with little effort and are able to view complex forms from many angles without having to construct physical models. With the rapid exchange of information between the designers and the computer system, the product-development cost can be reduced.

Another benefit which many users (or intended users) may overlook is the greatly increased amount of communication that can result from a CAD system. As any change takes place and is stored into the central files, all users, whether they are draftspeople, designers, clerical staff, accountants, or managers, can view and incorporate the change as it pertains to them.

If the non-PC-based CAD systems can do so

much, why bother with the PC-based systems? The reason is that a PC-based CAD system can also do these things. The PC offers another alternative for CAD system designs and may be the better alternative for some applications. It is certainly a very cost-effective alternative to the traditional workstation type systems. The PC-based systems have another advantage of their own: the networks are easily re-arranged. When a desk is moved across the room or into another office space, the PC and its attached equipment can be moved with minimal effort to re-configure the workstation.

1.5 Overview of Paper

Since CAD systems were developed in factories, they were designed to perform as many tasks as possible. Unlike developments created and tested in a laboratory type atmosphere, CAD systems were not developed to perform at optimum speeds. The PC-based CAD system is not unlike any other CAD system in development. It evolved within the industrial atmosphere where speeds were not always considered

to be as important as other factors. A system, no matter how many tasks it can perform, is not designed well if response time is slow enough to hinder productivity. Performance of all users is directly affected by the speed at which the system responds. Optimizing the timing of a system will improve productivity, thereby, potentially improving the quality of work and shortening project schedules. This may lead to a substantial financial savings for the organization utilizing the system.

PC-based CAD systems do not have as many advantages as the larger CPU-based systems when it comes to speed. This is why it is very important to study the networks of the PC-based systems in order to improve them as much as possible. Chapter 2 of this paper discusses studies of users productivity and cost savings as they relate to computer-response times. Chapters 3 and 4 cover the networks of PC-based CAD systems, emphasizing the areas that affect timing. These two chapters deal with the network as it relates to workstation display time, transmission time, CPU time, data access time, and peripheral access time.

A particular system being designed by the Tennessee Valley Authority is discussed in Chapter 5. The summary and conclusions are then covered in Chapter 6. There is no attempt in this paper to cover the many software packages that could certainly affect the timing of a PC-based CAD system.

CHAPTER 2

Productivity Studies

2.1 Introduction

Response time is the elapsed time from a command's entry to its returned action. When on-line systems first began, it was commonly thought that a two-second delay would be acceptable for the response time. This delay was considered thinking time. In the late 1970's and early 1980's researchers for IBM noted that this two-second delay was much too long and began studies attempting to determine the optimum response time.

2.2 Productivity Findings

The original belief that users need think time between each computer entry was proven to be incorrect. People seem to think in a sequence much like a group of computer program commands work together to form a solution. If this sequence is broken, the user must rethink the process [16]. Productivity increases if a user is able to work into

a mode of operation where the ideas and decisions can flow at the user's rate. The work of Arvind J. Thadhani of IBM's San Jose Laboratory shows a very substantial productivity increase as response time decreases to below one second, and even more as it decreases below a half second [5]. Figure 2.1 illustrates this.

Thadhani demonstrated that the number of transactions a programmer completes in an hour increases noticeably as system response time falls [16]. Figure 2.2 illustrates transaction completions as they relate to response time.

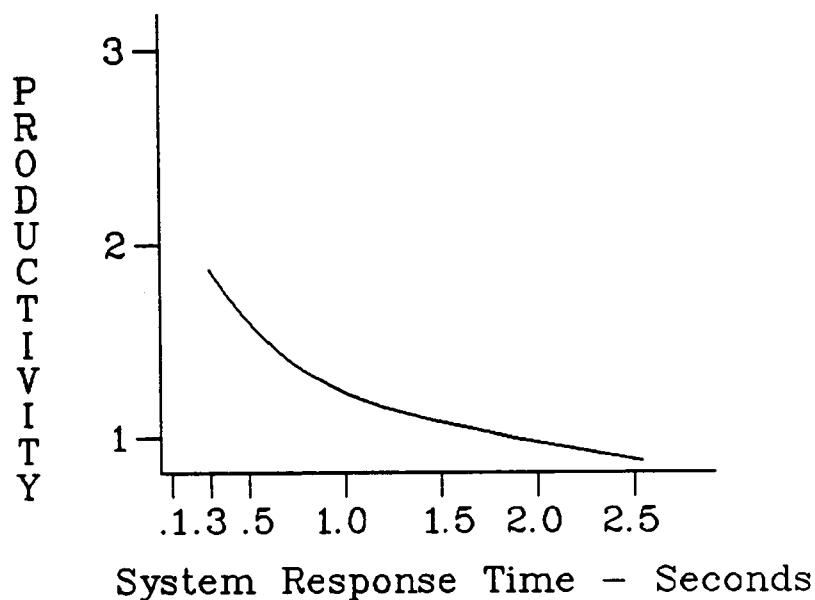


Figure 2.1. Productivity Increases as Response Time Decreases. [5]

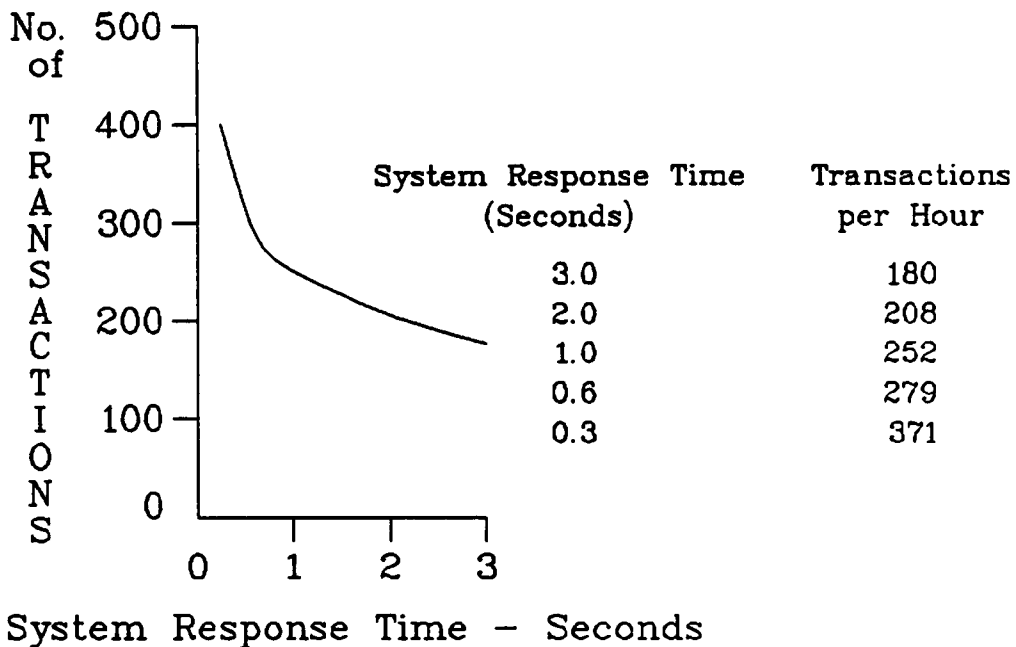


Figure 2.2. Transaction Completions Increase as Response Time Decreases. [16]

The studies show that at three-second response times, a programmer executes about 180 transactions per hour. In contrast, at 0.3 seconds the number of transactions leaps to 371, an increase of over 100 percent. In other words, a 2.7 second reduction in response time translates to a 10.3 times savings in user time. This is a sizable increase in productivity that could result in obvious financial savings over time [16]. Figure 2.3 demonstrates a potential monthly savings at a

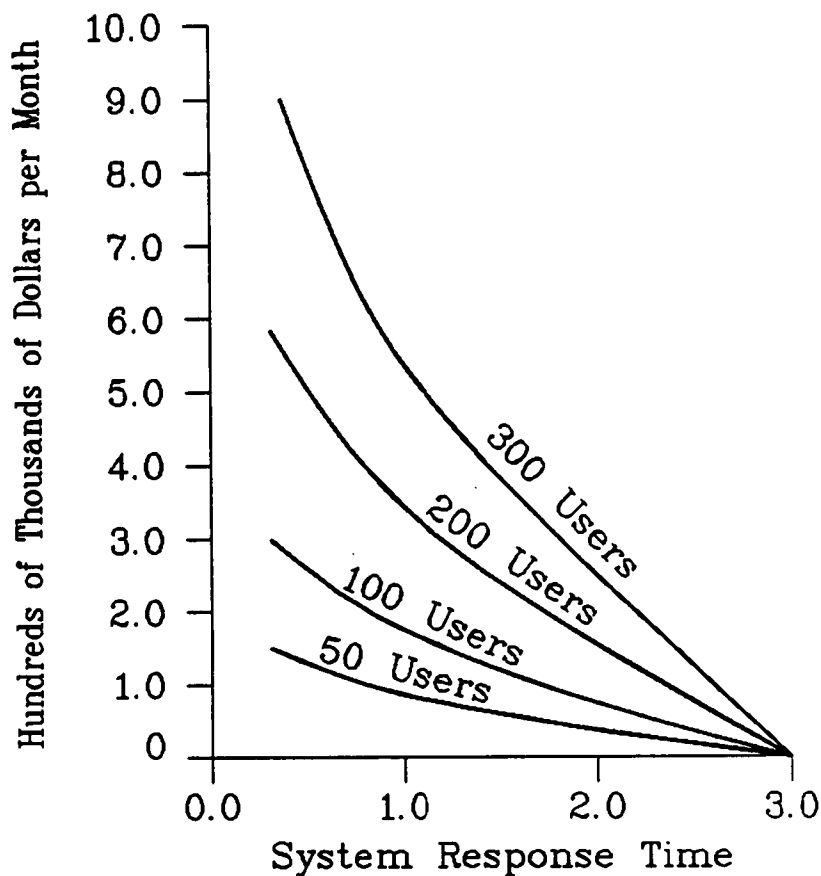


Figure 2.3. Potential Monthly Savings [16]

manpower labor rate of \$35 per hour. The performance of what previously was the average user has been increased to above that of the expert user.

After Thadhani's findings were published, IBM entered into more studies about response time. One of these studies involved a group of fifteen engineers at graphic display terminals. Their transaction rate not only confirmed Thadhani's

studies but also showed that the increase in response time helps all users whether they are novice or expert. Figure 2.4 shows these findings. IBM conducted an additional series of tests at various laboratories, and these also supported the findings.

In 1986, James T. Brady of IBM took these findings to produce a general theory in the cognitive process [5]. He called his theory the "roll theory". This theory states that (1) when an individual has all necessary data at hand, (2) his/her concentration is not disrupted by distractions, and (3) the individual can consistently organize data, then ideas and

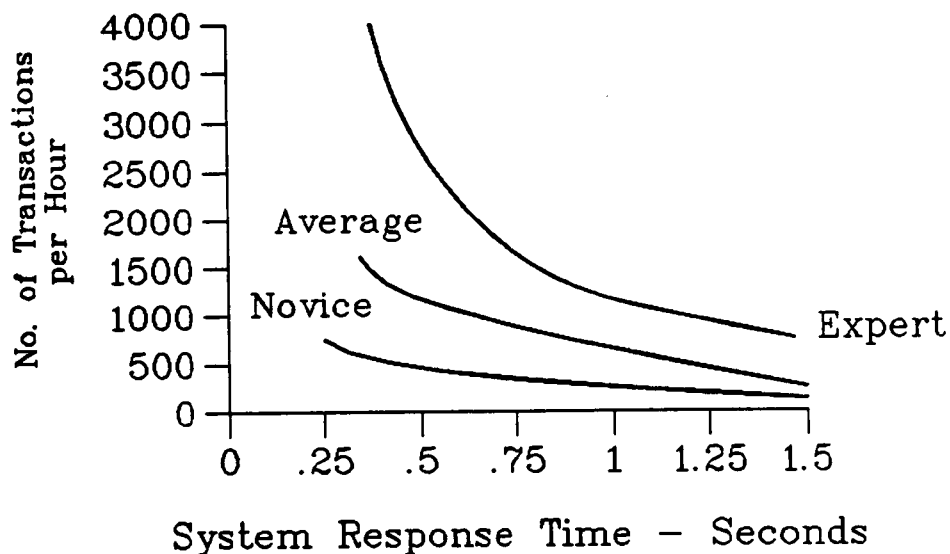


Figure 2.4. Increased Response Time Helps All Users. [16]

solutions will flow in a roll. The ideas and solutions will rapidly and orderly suggest further ideas and solutions to complement the creative process. Response times slower than the rate at which the individual can process ideas becomes a major distraction; therefore, reduction in the elapsed time between successive steps will greatly increase productivity of the individual.

Subsecond system response time resulted in substantial improvements in productivity. Super computers can speed up (or reduce) response time some, but this may not be enough or necessary. The system must be networked so that the response time is not greatly increased by the transmission time of the system. That is, the time that a command takes to get to the processor and then return with its action should be optimized.

Computer-aided design systems manipulate large files. These require special handling or the CAD system will have very slow response time. Studies by Digital Equipment Corporation have found that the network typically accounts for ten to thirty

percent of the response latency seen by the user [15]. These percentages did not include data access time or the processing time, which will increase response time even greater. This implies that the networking of a system must be considered when designing a CAD system so that the response time is adequate to enhance rather than detract from the creative process.

Since PC-based CAD systems were developed as cost-saving systems and not as speed producing systems, many factors can be studied which will affect the response times of the systems. It is apparent from the above studies that for interactive systems productivity is directly related to response times. CAD systems were developed to aid in design, thereby increasing the productivity of the design process. PC-based CAD systems were developed to bring these aids to applications at a lower cost than the traditional workstation systems. The timing aspects of the PC-based system are now being studied so as to improve their response times. The vendors of PC-based

systems and PC equipment recognize the needs for faster response times. This is obvious by their many claims of increased speeds in their advertisements. With the many improvements for PC-based systems and proper installation of the systems, response times can become optimized for greater productivity. As technology continues to improve PC products, the PC-based CAD systems will begin to perform much more closely to the subsecond response times needed for optimum productivity.

CHAPTER 3

Basic Network Information

3.1 Introduction

CAD systems have moved from the dedicated computer graphics stations into a configuration where many workstations are being connected to form a decentralized network allowing CAD capabilities to be spread to many disciplines. Personal Computers (PCs) have given CAD developers another alternative in the design of CAD systems. PCs are the major computers used in PC-based networks. The workstations are made up of a PC, equipped with graphics software, connected to peripherals such as printers, etc. The PC may be used as the communication, print, and file servers as well. Mini-computers and mainframe computers may be used within a PC-based system also. If the mini-computer or mainframe computer is used, it is generally used as a server.

The networking of the PC-based systems may be

either complicated or simple, depending on the size and variety of the hardware connected. Local Area Networks (LANS) must be designed to handle all the necessary demands of the equipment and of the users at speeds required to support the necessary production. It is important that they be connected in such a manner as to enhance their usefulness with ease and to ensure the speeds needed to maintain response times fast enough to complement the designer's creativity.

3.2 Network Basics

In order to identify the areas of a network which may affect the the overall speed of a PC-based system, an understanding of PC-based CAD networks is necessary. Local Area Networks (LANS) are used to connect PC-based CAD systems. When designing a system to work at optimum speeds, the other functions of a LAN should not be neglected.

3.2.1 LAN Considerations

The Local Area Network should be flexible in

order to handle the new demands of the ever-changing systems. This is very important in that many computer needs change rapidly. Making the network flexible will permit it to grow and to change as necessary. Since a CAD system is comprised of many different types of equipment (in order to make it flexible), the network should be able to service a variety of equipment from different vendors [47]. Any system that must grow with the development of only one vendor will be stifled and less cost effective. To maintain flexibility, the CAD network should also be able to support a variety of connecting media (e.g., twisted pair wires, coaxial cable, fiber optics, etc). This allows the network to stretch across organizational boundaries such as from accounting offices, to design rooms, to factory floors, and so on.

Because of the nature of design, a CAD system should support the evolvement of the design through all stages of the design process from the schematic to the final production drawings [28]. However, a system installed to accomplish only design

functions would not be the most efficient use of the investment. All aspects of a project (including the people involved) should be considered in its development. All functions from the manager's to the clerk's will be affected by the use of a CAD system. Since many people are involved with the CAD system, its network should allow shared information of the many disciplines. This requires the ability to share files by sharing disk drives at central file servers. The files require archiving, stamping, and logging of each version [47]. The files must be managed for updating so that only one authorized person is creating a new version at a time while others are still able to utilize the old version for information purposes. The central file server is installed to allow sharing of files, designing a system that will function as a whole. All CAD systems should also be able to function at each CAD subsystem, that is, at the workstation level in the case of a PC-based system.

Computer security is another supportive function of a network. With the move to distributed systems, providing the security needed to assure technical

protection of data, programs, processes, and computer users is difficult. Unauthorized access to the PC's disk drives, data bases, etc., should be prevented. The early computer security concerns centered around natural disasters and accidental losses from errors [37]. The evolution of PC-based networks put increasing demands on security as a result of the increase in the degree of the networks' complexity and the extent of its shared resources. The PC-based networks are designed to extend accessibility of data to many users at different localities making them excellent targets for security risks [30].

The network should also provide administrative logs of sign-ons and sign-offs to track access. And, finally, one more very important consideration is the ease of the of the system. Equipment should be placed in proper arrangement and location so that users find them more than acceptable. A system not used is of no value. Successful installation of a PC-based CAD system will be accomplished only by careful assessment of the needs, evaluation of the costs and benefits, and communication of changes

before and as they occur [7].

3.2.2 The PC-based Network

The basic PC-based CAD system is made up of a central file server, workstations (usually PCs), connecting media, networking software, and network interfaces [11]. The central file servers may be of any size, ranging from microcomputers to mainframe computers. They are connected to storage devices such as tapes or disk drives. The type and size of computer used for the file server depends on the needs of the system. For PC-based systems, the file server may be another PC. The storage will be either a part of the server or directly connected to it. Sometimes a separate computer is used either as a print server or a communications link. The central file server runs the networking software to manage the file access.

A workstation consists of a PC connected to various pieces of input and output equipment. A typical workstation will have a PC, a printer, a digitizer or mouse, and possibly a graphics

plotter. Also, generally included in the network is at least one graphics station containing specialized, more expensive equipment which will be shared by all the users.

The connecting medium is usually twisted pair wire. Coaxial cable and fiber optics cable are also used occasionally. Infrared light and VHF radio are used in some rare cases, and some special products allow use of the 110-volt AC power wiring as the connecting medium with some limitations [11].

The network interface unit attaches each workstation to the medium. It controls the access to the medium (e.g. token passing, Carrier Sense Multiple Access (CSMA), etc.) as well as being the physical connection. The most common network interface used for PCs is a circuit board inserted into the PC expansion bus. A simple system may have the configuration shown in Figure 3.1.

3.3 Response Timing Points

Speed is a determining factor in the ultimate useability of a system; that is, productivity is

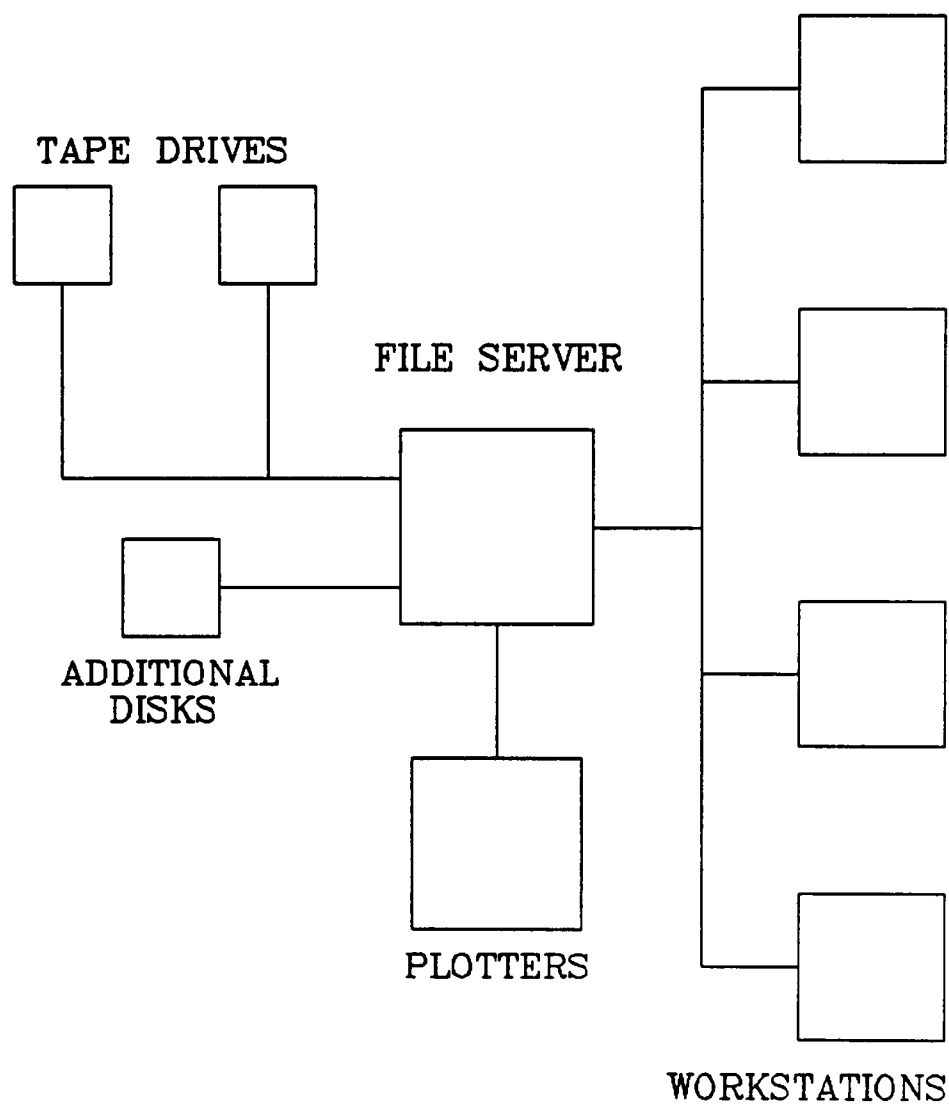


Figure 3.1. Typical PC-based System

directly related to response times. The network must be studied in terms of how speeds can be optimized. The following are the times that can be altered for improvements.

1) CPU Time : For PC-based systems the central processing unit (CPU) will be part of the PC. The amount of time required by the PC to process fully the command given by the user will be determined here. Additional processors, coprocessors, can be installed in the PC to improve timing. For example, a Math coprocessor is a necessity for most PCs that are expected to be used in a CAD network. Also, the type of network interface used may affect the CPU time.

2) Transmission Time : This is the time required to move the command and data from one device to another device. The transmission time includes the 1) the time required to access the medium, 2) the time required to put the command on the medium, 3) and the propagaion time for the message to be sent along the medium. This time will be determined by the transmitting medium, the configuration and the bandwidth of the communication system, and the protocols used by the system.

3) Data Access Time : This is the time required for the central file server to locate data after the file server has received the command requesting the data. In other words, this is the time that the file server uses to gather the information from the disk or tape drives. The central file server will be maintained by a management program.

4) Workstation Display Time : This is the time required by the user's equipment to display the data once it is returned. For example, this is the time it takes the PC to display the response once it begins receiving the output messages.

5) Peripheral Access Time : Once a user has output to be used elsewhere (such as to be printed or plotted), time may be required to access the peripheral equipment. Time is also required for the peripheral equipment to perform its functions, but most of these types of equipment have buffers to hold processing information allowing the user to continue working while the peripheral processing commands are being performed.

A typical sequence of events when using a

PC-based CAD system is as follows. First the user will enter a command on the PC. (For example: REDRAW). The CPU of the PC will analyze the command to determine if data is needed for processing, CPU Time (1). The CPU then transmits a command to the central file server to access the data needed, Transmission Time (2). The central file server must then access the data from the disk or tape drives, Data Access Time (3). A management program is utilized at the file server level to properly maintain the network resources and data files. The data is then transmitted back to the CPU of the PC, Transmission Time (2). The CPU can then process the data, CPU Time (1). Finally, the PC will display the result, Workstation Display Time (4). If the user wishes to output the result on another device, additional time is required to access the peripheral equipment and translate the result into commands the peripheral equipment can use. This is the Peripheral Access Time (5). Each of the individual times can be studied to plan the best possible system for a given installation.

CHAPTER 4

Timing Considerations for the PC

4.1 Introduction

Since all design departments are not the same in size, organization, volume, and type of action, it is impossible to suggest one system that will satisfy all conditions or work at optimum speeds for those conditions. In pursuit of the perfect system for an application, many factors must be weighed. A decision must be made about which of the many hardware and software products available must be used to produce the best system for a particular installation. This chapter attempts to utilize the five timing points, mentioned in chapter 3, for developing a PC-based CAD system.

4.2 Central Processing Unit Time

The Central Processing Unit (CPU) Time of a system will depend almost wholly on the PCs being utilized within the system and the software used by

those PCs. There will be no attempt here to cover the many software packages available for PC-based CAD systems. This section will instead cover the basic elements to consider when determining which PC to utilize and the requirements needed to produce an effective PC-based system with regard to timing aspects. Note that the software should not be ignored when developing a system. It is important that the system be able to perform the necessary tasks with ease and perform them with reasonable speeds. The software packages chosen may make the difference in a well-utilized system or a non-utilized system. In fact, selecting the software first and then finding the PCs that are able to accommodate the software may narrow the field of possible PCs to a reasonably small group. Adding processing power with a math coprocessor and using a network interface card which has processing power (discussed in the transmission time section) can improve CPU time also. These additional processors will take some of the workload

from the PC's CPU, thereby possibly greatly increasing the systems performance [11].

4.2.1 The Personal Computer

The use of PC-based CAD systems has become a serious consideration only in the past few years. Using PCs has brought the advancements of a CAD system to many areas where the larger workstation systems could not be afforded. Design packages based around PCs may not offer the speed and sophistication of the larger workstation systems, but they provide a very cost-effective alternative. There are, however, some limitations in using a PC, some examples being speed reduction, word length, and memory size. These limitations are rapidly narrowing with each new generation of PCs.

Since CAD programs make unusually heavy demands on the PCs being used, the machines must be equipped properly for optimal performance. A

high-performance CPU equipped with a faster-than-standard clock chip, two ports (the first for an input device such as a digitizer or mouse and the second for a printer/plotter), and a math coprocessor are desirable for the basic PC-based CAD system [24].

The IBM machines and their clones made by many vendors; Tandy Corp., Compaq Computer Corp., Wyse Technology, Dell Computer Corp., to name a few vendors, are the most commonly used PCs for CAD systems at the present time. Macintosh Computers, manufactured by the Apple Computer Inc., are becoming contenders in the CAD market also. The high-powered PCs utilizing Intel Corp.'s 80386 microprocessor are the fastest machines that have been on the market long enough to become good choices for the PC-based systems.

Table 4.1 lists the common features of the 80386 PCs. Clock speeds are measured in megahertz (MHz). Memory is measured in kilobytes (KB) and megabytes (MB).

Table 4.1. Common 80386 type PC Features

Feature	Specifications
Clock speeds	16, 20, 25 MHz
Standard Memory RAM on Motherboard	1, 2, 4, 8 MB
Extendable RAM	16 MB
Math Coprocessor	Intel 80387, WEITEK 3167
Cache	Cache Memory Controller Intel 80385 with Cache Memory of 32, 64, 128, 256 KB or Disk Caching Software Available
Ports	at least one serial and one parallel. Also may include mouse port, game port, and/or, additional serial and parallel ports
Hard Disk	range from 20 MB to 300 MB
Floppy Disk	1.2 , 1.44 MB
Processor	32 bit

Apple Computer Inc. has two Macintosh PCs using the 68000 series microprocessors; these may be competitive for the PC-based system market. The Macintosh II and the Macintosh SE both offer

advancements over the smaller Apple Company's PCs to provide the needed capabilities for a CAD system. Both machines can use 800 KB floppies and a 20 MB hard drive. The Macintosh SE is based on an 8 MHz 68000 microprocessor with additional memory. It has 1 MB of RAM and is expandable to 4 MB. The Macintosh II includes the 68881 numeric coprocessor to increase the speed of its operations [9].

The choice of which PC to use may be as much a matter of cost as of speed. PC-based systems are meant to provide graphic capabilities at low cost. If performance is of great concern and the cost is feasible, the 80386 machines will probably run faster than any other weathered PC at the present. It is important to note that the 80386 can only reduce response times if the disks and peripherals are able to keep up with it. There are many microprocessors for PCs with less cost and performance than the 80386 machines, such as the many PCs with the 80286 microprocessor from Intel. If the less expensive PC provides all the power the designer needs and performs all other tasks as well, then it may be the wiser choice for the

system, leaving more money for the important software products. The fast 80286 PCs with proven software support may be the best value for some applications. Table 4.2 lists the common features of 80286 machines.

Table 4.2. Common 80286 PC Features

Feature	Specifications
Clock speeds	6, 8, 12, 20 MHz
Standard Memory RAM on Motherboard	640 KB, 1 MB
Extendable RAM	varies from 4 MB to 16 MB
Math Coprocessor	Intel 80287
Cache	Some Disk Caching Software Available
Ports	at least one serial and one parallel. Also may include: game port, mouse port and/or additional serial and parallel ports.
Hard Disk	range from 20 to 300 MB
Floppy Disk	1.2, 1.44 MB
Processor	16 bit

In the upward cost direction, an upgraded version of the 80386, the 80486, is already in development. This chip is backward compatible with the 80386, therefore, the 80486 can replace the 80386 in some PCs. With the existence of CPUs that can be replaced easily to upgrade a system, the systems will be able to progress to faster speeds for less money than that required to replace entire PCs. The 80486 machines can run as fast as 2 to 3 times faster than the 80386 at the same clock speed. These machines, however, generally comes equipped with fast clock speeds of 25 MHz and 33 MHz that contribute to the processors performance. Another major improvement in the 80486 is the integrated cache memory and memory management on-chip. With the 8 Kbyte cache of very fast RAM, the need for larger amounts of cache memory with a cache controller may be eliminated.

Intel has yet another product, i860, based on a reduced-instruction-set computing (RISC) microprocessor design, which may further advance the PC-based systems [39].

The major factors to look for when deciding which PC to use for the workstation depend on the

needs of the system. The first concern of the designer should be to choose equipment that is compatible with the software. Some graphics packages require the capabilities of the higher priced PCs, such as those equipped with the Intel 80386 processor, to perform at reasonable speeds. A fast clock speed, as well as a math coprocessor, will greatly enhance speeds. At least two ports, one for an input device such as a mouse and one for a printer/plotter, are recommended. Sufficient memory is required to hold the software and the working files and have enough left to allow the CPU to process with reasonable speeds. Most PCs are capable of being extended to 16 MB of internal memory. One thing to consider with this option is the number of slots required to extend the memory. Some machines require a slot for each 2 MB of memory using up the slots quickly and making the extendable option less appealing.

Another feature of the extendable RAM requiring serious consideration deals with the 32-bit processors. Some of the 32-bit PCs actually use 16-bit processing for the extendable RAM, thereby causing two fetches instead of one to get

the 32 bits of information. This may also be due to a limited (16-bit) data bus between memory and CPU. This will increase the response times over machines which actually utilize 32-bit processing for the extended RAM. Cache memory is also desirable to improve performance, but sometimes it is more expensive than the designer can afford. If the cache memory is attainable, it should be purchased. It will definitely reduce the response times of the machine by reducing the number of fetches from RAM memory.

The size of disks and their seek times will also greatly affect the response times. The CPU should be able to use a variety of disks, either hard or floppy, so that each workstation can be properly equipped for its usage. The Hard disk should have enough capacity to hold the entire file being used so that additional transmissions from the file server can be eliminated. Generally, workstations should have a hard disk with at least a 40 MB capacity and at least one floppy disk drive. Seek times for the hard drives should be kept under 30ms; closer to 20ms would be better. Many PCs may serve the needs of a particular system. As long as

compatibility and all necessary requirements are provided, the system will work smoothly and with acceptable speeds.

4.3 Transmission Time

The transmission time, as mentioned earlier, is the time the command takes to leave one device and be received by another device. This time will be determined by the medium used, the configuration or topology of the system, the network interface, and the media access method or protocol which governs the transmission.

4.3.1 Media

A PC-based CAD network may use the familiar twisted pair of wires, coaxial cable, fiber optics, or more exotic infrared light or VHF radio transmissions. The most common medium used for PC-based CAD network is twisted pair cabling because of the cost. The cost of the medium and its installation is a major factor in the total cost of the LAN [11]. For multipoint applications, twisted pair cabling is less expensive than coaxial cable, but it is also lower-performance and supports fewer workstations.

A twisted pair consists to two insulated wires twisted in a spiral fashion [48]. The wires are made of copper or steel coated with copper. The copper provides conductivity; the steel provides strength. The pairs may be bundled, especially when used over long distances. One wire-pair acts as a single communication link. For local networks, twisted pair cable is typically used within one building or among a few close buildings. Twisted pair cable may be shielded or unshielded. Shielded twisted pair cable helps eliminate electrical interferences and cross talk. Transmission rates for unshielded twisted pair cables are typically 64 thousand bits per second and are typically limited to 512 thousand bits per second because of the susceptibility to interference and noise [27]. Shielded twisted pair cable has been shown to have transmission rates of up to 10 million bits per second [27].

Coaxial cable is considered the most versatile for local networks such as CAD systems [48]. It can transmit data faster over longer distances than do twisted-pair systems. It consists of two conductors such as twisted pair but is constructed differently to permit it to operate over a wide

range of frequencies. The cable is made of a single inner-wire conductor surrounded by an outer cylindrical conductor. The outer conductor is covered by either a jacket or shield. The most common coaxial cable used is the flexible, single-conductor type [27]. The 50-ohm cable is used exclusively for digital transmissions and can produce data rates of up to 10 million bits per second [48]. The 75-ohm cable may be used to achieve data rates above 20 million bits per second [48]. Higher grade cable is required for broad bandwidth applications such as very high speed data transmission. Cable designed for cable television, CATV, achieves transmissions of 350 - 400 million bits per second at lower losses than other grades of coaxial cables [27].

As many as 100 devices per segment can be supported by 50-ohm cable [48]. The maximum distance for a typical 50-ohm cable is a few kilometers, but segments may be connected using repeaters to form a larger system. Thousands of devices can be connected by 75-ohm cable; however, using high

data rates with this cable may produce technical problems [48].

Another possibility for PC-based CAD systems transmission media is fiber optics. Fiber optics technology is changing rapidly; because of this it may be used more heavily in the future. Fiber optics is useful for special installations that require high speeds over long distances. It is not, however, practical for the average installation. Fiber optics is more commonly used as a point-to-point link between local networks in several buildings.

An optical fiber cable consists of three sections: the core, the cladding, and the jacket and is cylindrical in shape [48]. The inner-most layer is the core. It includes one or more very thin strands made of glass or plastic. Each strand is covered by its own cladding, also made of glass or plastic. The cladding has optical properties different than the core. The jacket is the outermost layer. It may surround one or a bundle of cladded strands. The jacket is for protection against damage from outside sources.

Infrared light is a technique using electromagnetic waves for the transmission of digital data. Microwave and laser are also techniques for transmitting electromagnetic waves. All three are very useful for connecting networks between buildings where it is sometimes difficult to string actual wires. They are not appropriate for connecting PCs and a file server into a basic PC-based CAD system. Installation is relatively easy for all three. Transmitters and receivers are installed in sight of each other [48]. For microwave, these must be on the outside of the building. For laser and infrared, these may be on the outside of the building as with the microwave or they may be located to transmit through exterior windows. Digital signals from one to three million bits per second can be transmitted over electromagnetic media.

The transmission media helps determine the maximum operating speed of the network. Typical speeds range from 2 to 10 million bits per second [11].

Even though coaxial cable can transmit much faster than twisted pair, and fiber optics can transmit up to 10 times faster than coaxial, the cost of installation and the future expense of maintenance makes twisted pair the most common medium chosen. Cabling can be of very low cost if twisted-pair telephone wire that is already installed is used. Selecting the proper cable may not be a choice of the system designer. Some vendors require specific types of media. For instance, AT&T Information Systems' StarLAN can use either telephone wire or special wire designed to improve performance [11]. IBM also uses twisted pair wiring for its token-ring network, but this is a special type of shielded twisted-pair which may cost even more than coaxial cable to install [11].

A PC-based CAD system's actual operating speed is largely determined by the way the software interacts with the network and the access speed of the file server [11]. It may be wiser to spend money on better software and a faster computer for the file server than to spend money installing

expensive media when a usable medium already exists.

4.3.2 Topology

The topology of a system refers to the configuration used to interconnect all of the pieces. The earlier CAD systems were usually set up as centralized systems utilizing a star network [42]. The network consisted of a single large computer with peripheral "dumb" workstations which could not function on their own. These systems were built to take advantage of the centralization which provided excellent security, uniform procedures, and easy access to a project's files from several workstations. Centralized systems, however, have several handicaps. If the computer fails, the whole system fails. Each terminal must have its own costly communication line connected to the computer. And the centralized system reduces direct control over the users' working environment.

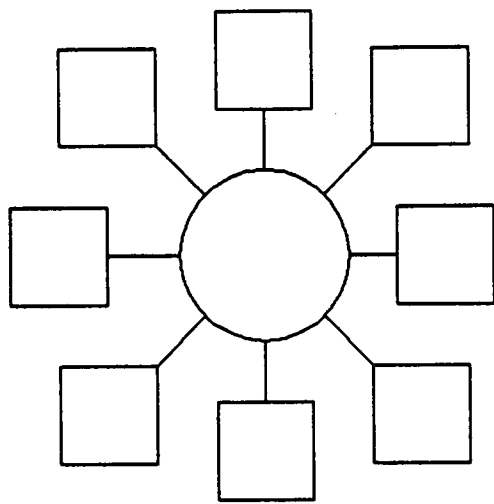
In recent years, the move has been toward decentralized systems [42]. This allows the users more control over their own computers. The

decentralized systems distribute the processing among several smaller computers. The users do not communicate directly with the main computers; instead they use remote processors such as PCs. These take care of some of the tasks, such as calculations for redrawings, relieving the main computer of some of the load and improving performance. A PC-based CAD system is a decentralized system where most of the tasks are performed at the workstation level, thereby reducing the need for a high performance network.

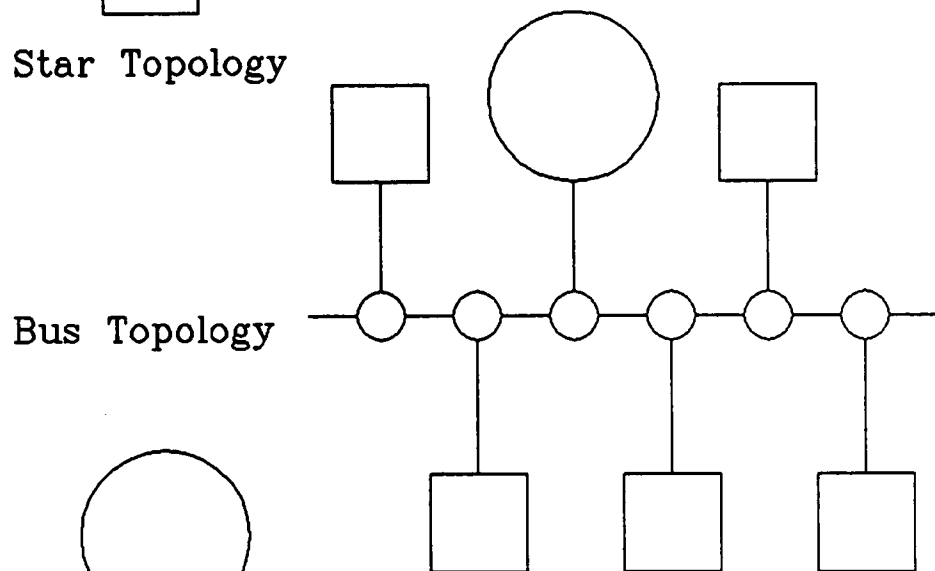
There are three basic types of topologies used in PC-based CAD systems: star, bus, and ring. Figure 4.1 illustrates these.

4.3.2.1 Star Topology

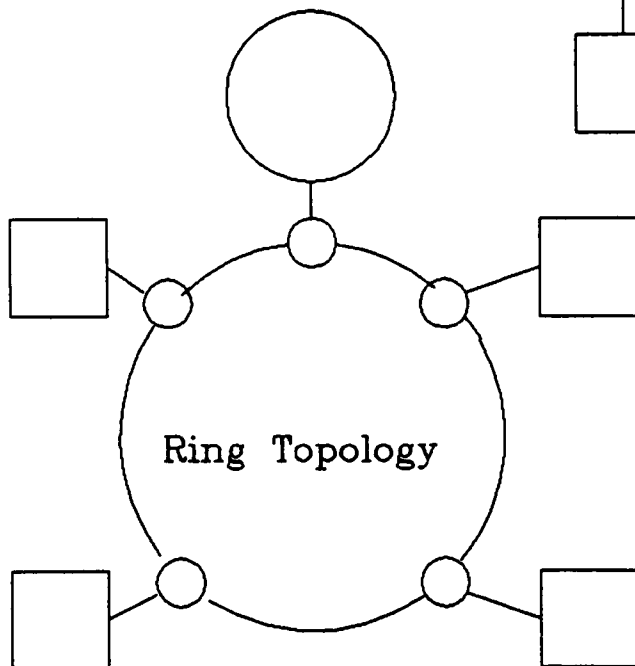
In the decentralized star network system, all of the PCs are connected as nodes to a master central computer called a file server. Each PC can function on its own. If the central file server fails, each individual workstation can continue to work although the user will be denied access to the



Star Topology



Bus Topology



Ring Topology

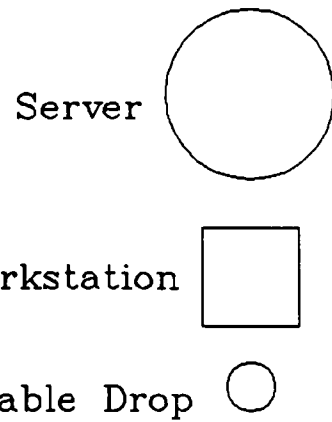


Figure 4.1. Basic Topologies

central storage. If a PC fails the rest of the network can continue working; only the failed workstation is out of order.

Two major drawbacks exist with the star network. The first is the cost. Individual cables must be provided from either the server or a wiring hub to each PC workstation. Since cabling may be costly, this increases the cost of the system. Second, the span of the system is limited by the length of the connecting cables, which can be limited due to the data speeds involved.

4.3.2.2 Bus Topology

A bus topology does not require that cables be installed from each PC to the central computer [42]. The workstations attach directly to a linear transmission cable. This is why the bus topology requires less wiring than a star topology and, therefore, costs less. A transmission from one workstation can be received by any other workstation, allowing peer-to-peer communication with other workstations, thereby freeing the central computer of this task. However, because all nodes share a common

transmission link, only one line can transmit at a time [48]. Bidirectional traffic control, either in the form of protocol shared by all attached nodes or by some centralized control scheme, is required. This creates a more complicated system at the workstation end of the network. Packet transmission is typically used for this communication. Each packet of data must have the the address of the destination workstation. These packets of data may be interleaved with other packets on the bus. The other major drawback of the bus topology is the inability to locate easily a break in the cable. A break in the bus can render the total bus inoperative.

4.3.2.3 Ring Topology

In the ring system, as is the bus system, the need to run cables from each workstation to the central file server is eliminated [40], thereby saving some of the cabling cost. The ring topology, however, requires more cable than the bus topology. The ring network also provides

communication from each workstation to all other workstations on the ring without going through the central computer. Packet transmissions are used in the ring topology, as in the bus topology [48]. The major difference is that the ring system is designed in a ring or circular configuration. The data packets can flow only in one direction around the ring. As a packet passes a workstation, the workstation reads it and transmits (or repeats) it to the next one if that workstation is not addressed. Each workstation can begin repeating as soon as it begins receiving, keeping the system running at full speed.

4.3.2.4 Topology vs. Media

The topology of a network affects the cost and ease of maintaining and troubleshooting the system more than it affects the speed. However, the choice of topology and transmission media are not independent. For the star network, twisted pair is more suited. For the bus and ring networks either twisted pair or coaxial cable is appropriate.

Point-to-point links are used in the star topology to connect two devices to the central file server as well as in the ring topology to connect adjacent repeaters. Multipoint links are used to connect multiple devices in the bus topology. Twisted pair cable, coaxial cable, and fiber optics are all suitable for these links. The choice of the topology will affect the choice of the transmitting media and vice versa.

4.3.3 Network Interface

The device used to connect the various pieces of equipment to the transmitting medium in a PC-based LAN is called the network interface. There are four methods used to connect the PCs to a network. The simplest is known as the zero-slot, or RS-232C, LAN which uses the RS-232C port on the PC for all connections. Slightly above the zero-slot LAN is the Data Switch LAN which also uses the RS-232C wiring but has security and data-switching processing outside the PC so as not to load down the PC as much as the zero-slot LANs. The next,

and most commonly-used method for PCs, is a LAN using Network Interface Cards. These are inserted into each PC's expansion bus. The most complex and expensive method of interfacing that of separate boxes called Network Interface Units (NIUs) or Bus Interface Units (BIUs). The PCs connect to the NIU or BIU, thereby freeing itself from the burden of network operations.

4.3.3.1 Zero-Slot and Data Switch LANs

Zero-slot LANs put all of the workload onto the processor of the individual PCs, thereby slowing the processing ability of the PC. They are primarily used for transferring files, but some zero-slot products do a good job of allowing a few users to share resources such as printers. Data switches relieve the PC of some of the processing load by using a separate box outside the PC for security processes and data-switching tasks. Data switches make connections similar to those of the telephone. They connect any two devices on request via their ports until the connection is dropped by

either side [12].

The zero-slot LANs and the Data Switching LANs are very inexpensive, but the price of reduced speed and capabilities make the RS-232C-based LANs poor choices for PC-based networks. Table 4.3 lists benchmark tests made on three zero-slot LANs (e.g. EasyLAN by Server Technology Inc., IDEAShare by IDEAssociates Inc., and LANlink by The Software Link Inc.) gives an example of their speeds [13]. In Test 1, three users requested the same 120 Kbyte file. Times were measured from the first stroke of the return key to the delivery of the file to the last machine. Test 2 depicts a situation where the server is preoccupied with compiling a program while two remote stations ask for different 100 Kbyte files. Test 3 shows the times required by the server to recalculate a spreadsheet while transferring 100 Kbyte files to two remote stations. Test 4 shows the times required by the server to transfer 100 Kbyte files to two remote stations while recalculating a spreadsheet. Test 5

shows the server recalculating the spreadsheet without interference from other stations. All tests were made using an IBM PC-XT as the host, a Zenith Corp. Z-150 as one station, and a Quadram Corp. Datavue 25 as the other station.

Table 4.3. Zero-slot Benchmark Tests [13]

	EasyLAN	IDEAshare	LANLink
Test 1	335	125	95
Test 2	422	130	145
Test 3	6	82	112
Test 4	248	130	150
Test 5	4	4.5	12.5

(Approximated times in seconds.)

With declining costs of higher-speed LANs, the Network Interface Card LANs become the more commonly used method of interfacing PCs.

4.3.3.2 Network Interface Cards

The network interface card is a circuit board that attaches to the expansion bus of the PC. The board performs communication and processing tasks. The processor's power is added to the interface card to improve the network's performance. Since the medium access method is associated with the network interface, the type of card to be used will be limited by the medium access method chosen by the designer of the system.

There are many packaged LANs which use network interface cards to connect the PCs to the transmitting media. These packages range from LANs which allow networking capabilities without a dedicated server to LAN products which require a server to be a dedicated machine. The LANs are usually based on IBM's Disk Operating System (DOS). Some allow any PC to act as the server; the server PC can also act as a workstation while performing server duties. The typical step in the installation of a LAN which uses a network interface card is:

- 1) Copy the network software to a subdirectory on the PC acting as the server.

- 2) Install the Network Interface Cards.
- 3) Connect the wiring (transmitting medium).
- 4) Arrange for sharing of resources [12].

4.3.3.3 Separate Interface Units

Separate boxes, the NIUs or BIUs, used to interconnect the workstations to form a network require a cabinet and power supply. These cause them to be more expensive than the network interface cards. The higher cost is a major disadvantage of the standalone devices, since PC-based systems are meant to be low-cost systems. However, there are two major advantages of this type of interface:

- 1) The NIU or BIU units are connected to the workstation by the RS-232C cable; therefore, almost any RS-232C type device can be connected.
- 2) The separate boxes free the CPU of network responsibilities, thereby allowing the processor to work at its optimum speeds.

4.3.4 Media Access Methods

The media access method, or protocol, is the method used by PC LANs use to regulate their transmissions. The choice of the topology and medium normally determine the choice of the media access method. If network interface cards are used to connect the PCs to the transmitting medium, then care should be taken to choose a the card that performs with the appropriate media access method.

The three basic types of media access methods are polling, Carrier Sense Multiple Access (CSMA), and token-passing. The polling method is not very appropriate for decentralized networks used for PC-based systems. It is used in centralized networks where a master station sends a message to each workstation asking that station if it has anything to transmit. CSMA and token-passing are more commonly used and better suited for PC-based systems.

With the CSMA type protocol, a node sends only if the medium is clear, i.e., when no other node is transmitting. It listens for a carrier that indicates that the medium is being used and transmits in the

absence of this signal. A problem arises when two nodes transmit at exactly the same time: the messages will collide. Collision Detection (CD) was added to the CSMA protocol, creating the CSMA/CD protocol, to permit each node to detect a collision, halt transmission, delay an amount of time (usually random), and repeat the message. The throughput of this access method lessens with increased activity (or network load) because collisions increase, and these collisions take time to resolve. Generally, as the number of nodes increase the network load will increase, and the throughput of the system will decrease after passing through a peak. The CSMA/CD protocol is used most often with the bus topology. Ethernet, a product developed by the Xerox Corp., is one of the most well-known networks using CSMA/CD type protocols; however, many other networks use it.

In token-passing, a message token is passed from one node to the next giving the holder of the token a turn to transmit. When a node has a message to transmit, it captures the token to prevent others

from transmitting. It immediately retransmits the token with a "busy" bit set. Once the node is finished with its transmission, it passes the token to the next node in line.

Token-passing can be used with both bus and ring topologies. For the ring topology, token passing is simple. Each node accepts the token from one side and passes it to the node on the other side. Nodes can be easily added to or deleted from the network without interrupting the networking operation. The ring topology with token-passing does require special protection against loss of the token. A timeout circuit can be used to correct this problem. One node is designed as a monitor. Its timer is set to be greater than the time required for the token to complete one loop around the ring. The time is reset after each valid token is passed. If the time expires, the monitor issues a new token.

For the bus topology, token passing becomes a little more complicated. Logic must be programmed into each node directing it where to send the token

message. This creates an imaginary logical ring of transmissions. Because each node is given an explicit address to which it sends and receives the token, adding and deleting nodes require address changes in order to maintain the logical ring.

For both types of token topologies, complex rules prevent a node from utilizing the system too long. The throughput of a system will increase as the activity of the network increases. Once a node has passed the token, the token must be passed to all other stations on the ring before that node can transmit again. Therefore, if a system is not being used often, the throughput for that system will be relatively low due to the delay caused by the token circulation. For a typical system, the throughput of the token-passing access method will increase as the activity of the network increases until a point where it levels off. Performance does not decline as the medium saturates.

In choosing whether to use the CSMA/CD or the token-passing protocol the following summary may be helpful. The CSMA/CD protocol has been in use for some time and is widely used and proven. It utilizes

a simple algorithm. Its performance is good for low to medium traffic networks. The National Bureau of Standards conducted studies comparing CSMA/CD access method and the token passing method, both using the bus topology. They found that with network loads of 40% or less capacity, CSMA/CD provided equal or better performance than the token passing access method [15]. If the installation is not heavily used, the CSMA/CD protocol may be a wise choice. The token-passing access method has been in use long enough to be considered a proven system, but it is a much newer technology than is CSMA/CD. Since fewer installations exist, less information is available for this protocol. The token-passing access method is better for high traffic systems and is therefore a good choice for many PC-based CAD systems.

4.4 Data Access Time

Data access time actually consists of two times: (1) the time required by the central file server to locate stored information once it has been requested and (2) the time required to store information. These times will depend on the computer (usually a PC) used

as the file server, the network operating software, and the storage devices connected to the file server.

4.4.1 Server

The speed of a server will depend on all of the demands placed on the computer used as the server. If these demands are too great, the data access time will be slow. For this reason, it is generally considered best to use a computer dedicated only to the server functions of the PC network. Some networks use as the server a main-frame or minicomputer that is used for other computing purposes. Some PC LANs use a PC that is also used as a workstation. Neither of these network designs provide optimum performance. The server will be required to perform other duties, resulting in a degradation of the performance of the network. For these reasons, a dedicated computer for the server is the best choice to ensure adequate response times.

The same computer may be used as a file server, a print server with one or more printers attached, and as a communications server. Whether to use one PC for all server purposes or to divide the server's

workload between several PCs will depend on the application. A typical LAN overloads a 80286-size server at about 40 users [17]. However, if the users of the system access shared files frequently, (as they do in many CAD applications), a 20-user system may require several servers. Discovering an application's accessing needs and choosing a properly-equipped server to handle these needs will determine the data access time.

There are three ways to acquire a PC-type server: (1) a PC can be customized with add-ons; (2) a PC can be purchased with server features; or (3) a proprietary unit, supplied by LAN OS vendors, can be purchased to perform the server duties. Larger computers may also be used as the server for the LAN.

No matter which type of server a system designer chooses, particular features should be included. The CPU should have a fast clock speed, and the faster the better. A 10 MHz or 12 MHz 80286 CPU will be the minimum for a small system of 20 regular users [17]. If a LAN is especially busy, a faster clock speed of 16 MHz, 20 MHz, or 25 MHz will be required.

During a transfer operation, additional clock cycles may be needed if there is insufficient time to complete an individual transfer. These additional clock cycles are called wait states. The number of wait states will affect the processor's speed. The fewer the wait states, the faster the processor can perform. Having no wait states is best; two wait states are too many [17].

Cache Memory will further speed the server's processing times. The server can run faster by caching its hard disk, because fetching data from cache memory is quicker than retrieving the data from a disk. Some vendors supply systems which use a disk controller with a dedicated cache of high-speed RAM to further enhance the server's performance.

Another option to consider with regard to a server's performance is a back-up power supply. No one can work on a system that is down. An uninterruptable power supply is also useful to safeguard data and hardware. These can keep a server running for up to an hour after main power is lost; they can also close open files and shut down the system gracefully so as not to damage any

of the stored data [17].

Expandability is another important feature to look for in a server. This may or may not affect the speed at which the server performs, but it is a necessary consideration. For expandability, the server should have a sufficient number of ports for expansion.

4.4.2 Storage Devices

To insure adequate speeds for a PC-based CAD system, a server should have one or more fast hard-disk drives. If a mainframe computer or minicomputer is used as the server, there are plenty of large capacity, fast disk drives available. For a PC server, however, care should be taken in choosing the proper disk drives. The average seek time of the disk drive is very important. A 20 millisecond (ms) to 30 ms average seek time is usually adequate. A 40 ms time is too slow for most applications. For high volume of traffic, a 16 ms or 18 ms drive may be needed [17]. Examples of disk seek times are shown in Table 4.4. [44]. Test 1 measures the time to perform a random sector read using DOS disk access. Test 2 measures the time to

perform random seek using the disk's Read-Only Memory-Basic Input/Output System (ROM-BIOS). The tests were measured in milliseconds (ms) and performed 1000 times each.

Table 4.4. Average Disk Seek Times [44].
(milliseconds)

Brands	Test 1	Test 2
IBM PC AT 20-Mbyte drive	43.50	37.35
Emulex ATS-170 (Emulex Corporation)	29.79	33.98
Emulex AT-380 (Emulex Corporation)	26.48	18.62
Storage Dimensions AT 160F (Storage Dimensions)	26.24	36.89
IDEAssociates Diskit A 120 (IDEAssociates Inc.)	25.96	39.42
Alloy ID-160 (Alloy Computer Products Inc.)	25.80	39.43
Priam ID 130 (Priam Systems Division)	24.98	26.66
Core HC150 (Core International)	20.28	17.39

The disk drives are not the only consideration when choosing disk systems. The disk controller is an electronic component used to convert the operating system commands into special instructions needed by the disk drive to find information. The controller will affect the usage of the disks. Hardware packages are available which supply drives and controllers together or they may be purchased separately. The most important aspect to consider when choosing a controller for a disk drive is to make sure that the controller interface matches that of the disk drive. A good option for the controller is the ability to daisy-chain several drives. This allows for system growth; storage can be added as needed. When disk drives are daisy-chained, they work as if they are one logical unit. Speeds will not be hampered unless too many disk drives are daisy-chained together, creating the possibility of time-consuming searches through the disk.

The required size of the disks' storage will depend on the number and size of shared files on the server. The general formula is 5 MBytes of storage per year per user [17]. This is considering an

average installation. More storage will be needed if there are large stored files or a large number of stored files, such as those in many CAD networks. Most hard disks for PCs range in sizes from around 20 MBytes to around 150 MBytes; however, many larger disks are also available. Getting the largest storage per disk is not a requirement for speed. Disks can be added to increase storage, if care is made for expansion when originally designing the network.

Backup storage should also be attached to hold all the necessary backup copies of the files. A 60 MByte tape drive is the minimum size backup unit for most PC systems. A 150 MByte tape drive is better. Backup software will be required to execute the backup operation. This software should: (1) be compatible with the LAN operating system; (2) be capable of backing up all system files; (3) run while the server is on line; and (4) perform reliably while unattended [17].

Another type of storage, the WORM (Write-Once Read-Many), is an optical disk drive that can hold extremely large amounts of data. These are not

replacements for the hard disk drives used for current files nor are they replacements for the tape drive used for periodic backup files. The WORM drives are designed for permanent storage such as archiving of final drawings. The data is burned into the disk, making the files virtually tamperproof [34]. Some WORM devices can hold as much as 1 gigabyte of data per cartridge. They have improved greatly in the last year, but they still have many flaws. They are generally easy to install, but getting the drives set up so that DOS can recognize them is sometimes difficult. Some of the WORM systems require large amounts of hard disk and RAM space to operate. Some are difficult to manage, and most do not have security features. The WORM drives are, however, improving in all of these features.

The most important characteristics to look for in regard to performance of WORM disks are: (1) a low amount of RAM consumption, (2) a low WORM overhead on the disks, and (3) efficient use of cache memory. WORM drives are good choices for archiving of files, especially if there is a large

number of files to be stored; however, they should not be used for back-up or working file storage. Erasable storage devices are more appropriately used for these other storage requirements.

4.4.3 Network Operating Software

There are major differences in the many network operating systems available on the market. The ease with which they can be installed and managed varies widely. There are also many options available with the different operating systems. The designer's objective is to find the system which best suits the application. The computer being used as the server and the network operating system must be compatible. No matter what the application, however, the network operating system should perform the same basic functions: provide access to the appropriate networks resources, applications, and files, as well as provide the security controls of the users' access to these.

Most of the network operating systems utilize three major boards: Ethernet, Token-Ring, and Arcnet by the Standard Microsystems Corp. They may be based on DOS, OS/2 (Multitasking Operation System designed

for the IBM PS/2 type Computer), or may be a proprietary operating system. The many options normally provided include those listed in table 4.5.

Table 4.5. Options of Network Operating Systems

-
- 1) on-line help with and without network
menues,
 - 2) management of different versions of DOS,
 - 3) trouble shooting disk problems and keeping
track of the problems,
 - 4) handling print spooling,
 - 5) declaring disk space per user,
 - 6) changing priority of jobs,
 - 7) running CPU in protected mode,
 - 8) automatic disk caching management,
 - 9) insuring data security,
 - 10) tracking security,
 - 11) communication programs,
 - 12) capability to reshuffle resources,
 - 13) monitoring connectivity to workstations,
 - 14) allowing users to take over the screen
and keyboard of another user,
 - 15) and services which make it possible to
attach devices like gateways to connect
to other networks.
-

Of the many options available, choosing a network operating system which uses the smallest amount of RAM and has caching management software are two very important features to consider in regard to speed. The hard disks are usually the slowest part of the data transmission devices. Therefore, providing cache management software will greatly improve the performance of the server [12]. If a 80386 processor is used as the server, care should be made in choosing the network operating system to insure that the software package was designed with the computer in mind. Some packages utilize the 80386 machines better, thereby increasing the performance of the system. Network software is changing rapidly, therefore many improvements are sure to come in the future.

Performance is an important feature to consider when choosing the software, but other features should not be overlooked. Whether a system can be managed with ease, installed with ease, and will perform well, will certainly affect the overall system more. If the network operating software performs its duties properly, it will not influence the data access time

as strongly as the power of the computer chosen for the server and the amount of cache memory of the server.

4.5 Workstation Display Time

Display monitors are sometimes overlooked when system response times are considered. They, however, may noticeably affect the response times. It takes time for a file to be displayed once the workstation's CPU begins calculating the display characteristics. There are a variety of monitors, and each performs at different speeds. The two most common type monitors are Video Graphics Array (VGA) and Enhanced Graphics Adapter (EGA) developed by IBM [35]. The monitor chosen will dictate the resolution and number of colors used for the display. The VGA monitors with their higher resolutions are the better choice for CAD installations.

To reduce display times, graphics processors are required to speed the drawing and redrawing of displays especially when zoom viewing is used. Not all monitors come equipped with a graphics processor, therefore, this is one characteristic to consider in

the monitor's choice.

Another factor that will affect display times is the amount of memory of the workstation. The memory should be sized to hold a file and still have enough left for processing. This allows not only for faster drawing of the file the first time but also for faster redrawing. Cache memory, as mentioned in section 4.2, CPU Time, will also greatly improve display times.

4.6 Peripheral Access Time

The time taken to print or plot a file will depend on whether the printer/plotter is attached directly to the workstation which has the file information or whether the network will be required to send the file information to the print server. In the first case, the response times of the network will not be affected except for the particular workstation. This workstation may be tied up for long periods while the file is being printed. The printers used at this level are generally slow speed and used only for the particular needs of the users at that workstation.

Most of the time, if a large file needs to be

printed or plotted, higher-speed printers that are networked through a print server will be used. The print server may be interconnected to the file server or may be a separate server. In either case, time is required to access the server via the network. In most cases, the server's CPU will translate the data to a form usable by the peripheral equipment. This data will then be queued in a buffer associated with the peripheral unit until it is free. The buffer must be sized properly to hold all files waiting to be processed so as not to tie up the server. The buffer size is one important feature to consider when choosing a printer/plotter. Another feature to consider is a reprint capability so that retransmitting of files will not be required for additional copies. Anytime the server or network is used unnecessarily, the response time is reduced.

There are four basic types of printer/plotters: the dot matrix, the electrostatic, the pen, and the laser printer. Each has its place in a network. The dot matrix is usually used for individual workstations or a small group of workstations and for draft copies.

The electrostatic printers are usually used for draft prints or plots. The pen and laser printers are usually used for final drawings. The most important features to consider in regard to speed for any of these are the buffer size and the speed of printing.

CHAPTER 5

A Specific System

(A System for the Tennessee Valley Authority
Department of Power Engineering and Construction)

5.1 Introduction

In November 1986, the Power Engineering's Fossil Engineering and Hydro Engineering Projects of the Tennessee Valley Authority began investigating the possibilities of establishing CAD capabilities for their engineers and technicians. They wished to perform these capabilities with a minimal cost. The study group later expanded to include Power Construction and all other Engineering groups in the department of Power Engineering and Construction (PE&C).

The group outlined the following criteria for a CAD system.

- 1) It must use one standardized software package for all the groups of PE&C.

The software must:

- a) be from an established and reputable vendor,

- b) support all disciplines,
 - c) be compatible with outside
(vendors') software,
 - d) allow for growth, and
 - e) support networking.
- 2) The hardware configuration must be designed to fit the software.
 - 3) A centralized file facility must be established for file storage, retrieval, archiving, plotting, and file management. The central facility will also provide a communication interface for drawing and data exchange.
 - 4) The network must provide a means of interfacing with three installations in other TVA departments. (This requirement was dropped after an extensive reorganization within TVA.)
 - 5) The system must be capable of future implementation for transmitting and receiving large raster files.

The study group concluded that a PC-based CAD system would fulfill their need. They recommended that PCs be used for workstations, the workstations

to be networked with a central file server computer, and AutoCAD software, a product of the Autodesk, Inc. To aid in the research phase of the system, TVA hired an outside firm, Black & Veatch, to help establish the division's needs.

5.2 Black & Veatch Recommendations

In April 1987, PE&C contracted with Black & Veatch (B&V) Engineerings and Architects of Kansas City, Missouri. The firm also recommended the use of PCs as workstations, a computer for a central server facility, and AutoCAD software. These would form a decentralized PC-based workstation environment. A high-speed local area network (LAN) should be used to tie together the workstations with a central computer and plotting facilities.

AutoCAD was chosen as the software for a variety of reasons. TVA had three other network systems in place: (1) an Intergraph network, (2) an Auto-trol Technology Corporation system made up of four Apollo Computer based workstations, and (3) a network using IBM equipment and CADAM INC. software. AutoCAD was determined to be the better choice over these three systems. Cost was the first reason. An AutoCAD

workstation can be purchased for \$4000 to \$25,000 compared to \$20,000 to \$60,000 per workstation for the others. Secondly, AutoCAD fulfilled the other requirements set by TVA's original study group. AutoCAD is a proven system. With thousands already installed, many vendors find it to be an acceptable format. It supports networking with an easily-learned programming interface, AutoLISP. B&V recommended the purchase of 30 copies of AutoCAD even though, as mentioned in the next paragraph, they recommended the use of 60 PC workstations. The 30 copies were derived with the assumption that the copies of AutoCAD could be stored on the central file facility and be accessible by any workstation as needed.

The central facility was to provide two important functions: to serve as a storage device for all files in progress and to provide connections to support systems such as archiving and accounting. The server also required a communications interface to the plant operations by connecting to a network designed by the Prime Computer Inc., PrimeNet, already in place. The PrimeNet network is used over TVA's microwave communications network which runs at a speed of 9600 baud.

After studying the drawing activities of PE&C,

B&V discovered that approximately 1200 new drawings were created each year and approximately 3100 previous drawings were updated. The drawings ranged from 160 KB to 2 MB in size. Using these approximations and the following assumptions, B&V was able to calculate the number of necessary workstations for the network. B&V's assumptions are as follows:

- 1) The average drawing would take four days to complete. This would include initial creation and all edits for all revisions.
- 2) The average workstation would have 80 percent utilization.
- 3) There were 200 working days per man per year.

Using this information, B&V's calculations led to a requirement of 30 PC-based workstations for the preparation of new drawings. The following formula explains B&V's calculations.

$$\frac{(1200 \text{ drawings/year} * 4 \text{ days/drawing})}{(200 \text{ days/year} * .8 \text{ utilization})}$$

equals 30 workstations [3].

An approximation of 30 additional PC workstations would be required to scan, view, and edit electronically the 3100 previous drawings. However, because the technology to scan drawings and turn them into CAD drawings is still changing and improving drastically, the purchase of the 30 additional workstations and the raster scanner equipment should be postponed. More PCs may also be required for administrative purposes. B&V suggested that a reassessment of the required number of workstations be performed six months after their installation.

The PCs used for the workstations should be a 32-bit processor and be capable of multi-tasking. The workstation should also include a medium resolution display, 480 x 600 pixels, a menu tablet, and a network interface. Three types of plotters should be considered for the system: (1) high-quality pen plotter with the capability to produce ink drawings on mylar (a TVA standard) should be purchased for final plots; (2) an electrostatic plotter, which is much faster than the pen plotter, should be purchased for draft prints and for checking and reviewing prints; (3) several small printer/plotters should be purchased

for the various engineering departments.

The recommended AutoCAD software PC-based workstations networked to a central computer and plotting facility would provide the capability for new drawing creation. It would also allow the flexibility for future expansion and possible integration of other CAD-related capabilities such as raster editing. A schematic of the B&V recommended system is shown in figure 5.1 .

5.3 PE&C System Description and Plans

To produce the desired CAD capabilities in a systematic manner, PE&C chose to follow a three-phase development plan. The first phase was to obtain minimal CAD capabilities for the creation of new drawings. Twenty-five PC-based workstations, CAD software, and a central facility (server) necessary to network the workstations would be purchased in this phase. Phase 1 would also provide documentation to justify the implementation of the system. Phase 2 entails the installation of 15 additional PC-based workstations and support software to be used for electronic revision of old drawings. The purchase of scanning equipment to convert old drawings to raster

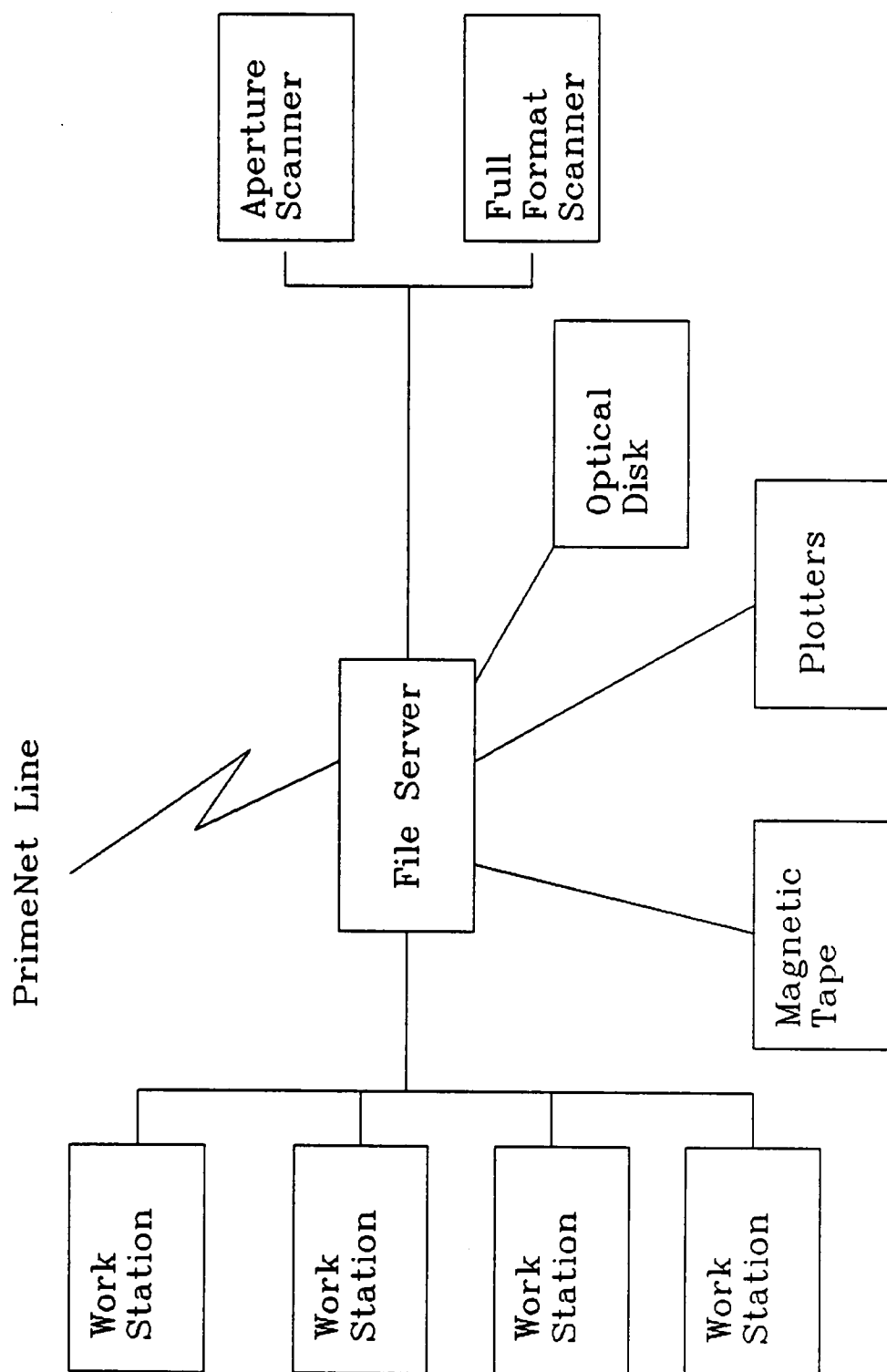


Figure 5.1. System Overview by Black & Veatch [3]

images would also be required in this phase. Phase three requires the purchase of 10 additional PC-based workstations and support software to obtain the full capabilities of the system. These include production of new drawings, revision of old drawings, and full bi-directional communication with other organizations.

5.4 Alternatives Considered

Three alternatives were devised to accomplish the system's needs. Alternative one was to use a total PC-based system with 32-bit 80386 type PCs used for the workstations and the servers. This alternative utilizes an IBM token ring network to connect the system. A gateway would be used to connect the systems to other TVA systems and the TVA main frame. Alternative two was to use an Ethernet system utilizing a Prime 4150 computer as the server and 32-bit 80386 type PCs as workstations. Alternative three is to use an IBM token ring local area network to connect high-capacity PC nodes. The 32-bit 80386 type PCs will function as interim-level file servers with a local SNA channel-attached 3174 control unit. The TVA mainframe host computer will function as the primary file server. Alternative one

was considered a heavy possibility in the early stages, but PE&C now believes that, with 800,000 drawings to manipulate, this alternative may not be feasible. PE&C is now leaning toward alternative two, the Ethernet system, but still holds a possibility for the other two alternatives.

To accomplish phase one of the system, TVA set out to purchase IBM or IBM-compatible 32-bit PCs. TVA is required to establish specifications for a system to be purchased and giving the purchase to the lowest bidder. Tandon Corp. (TANDON) won the contract to supply TVA with 25 IBM AT class PCs. They are not, however, 32-bit processors; they are instead 16-bit 80286 processors. A summary of the TANDON PCs is listed in Table 5.1. These are equipped with a 30 MB hard disk drive, two floppy disk drives (a 360 KB and a 1.2 MB), a color monitor, keyboard, and a digitizer. Version 3.3 MS DOS was included as the operating system. Release 9 AutoCAD Software was purchased for CAD capabilities and Automenu was purchased for a low-cost front-end interface for the user. Software was also purchased to provide a usage log for the CAD workstations.

Table 5.1. TANDON 80286 Features

Feature	Specification
Processor	80286
Clock Speed	8 MHz
Standard Memory RAM on Motherboard	1 MB
Extendable RAM	16 MB, 2 MB per slot
Math Coprocessor	80287
Cache	Software available but not purchased
Ports	One serial and one parallel
Hard Disk	30 MB
Floppy Disk	a 360 KB and a 1.2 MB

To help upgrade the system to more closely meet the specifications requested by PE&C, some of the 80286 PCs are being replaced with TANDON 80386 PCs. PE&C hopes to replace all of the 80286 PCs with 80386 32-bit processors. Table 5.2 lists the TANDON 80386 features. These do not have the cache memory requested by PE&C, but they have more of the PE&C features requested than do the 80286 PCs.

Table 5.2. TANDON 80386 Features

Feature	Specification
Processor	80386
Clock Speed	16 MHz
Standard Memory RAM on Motherboard	1 MB
Extendable RAM	16 MB
Math Coprocessor	80387
Cache	Software available but not purchased
Ports	one serial and one parallel
Hard Disk	40 MB
Floppy Disk	one 360 KB and one 1.2 MB

5.5 File Server

The first alternative requires the purchase of additional 80386 computers to function as the servers for the system. The second alternative requires the purchase of a Prime Computer Inc. (Prime) departmental computer to function as the server for the system. The system will be connected by either an IBM Token Ring network for the first alternative or an Ethernet network for the second alternative.

Tests were conducted on the IBM token ring and on a network using a Prime Computer with Ethernet using transmission control protocol/internet protocol (TCP/IP) software protocol. Delivery times (ranging between 1 to 2 minutes) of drawings to workstations for 2 MB files using these two system were considered acceptable. No tests have been conducted for alternative three at this time. Some of the organizations of PE&C are widely dispersed, therefore they have no means to channel-attach to the 3174 control unit used in the third alternative. This may make inadequate the drawing delivery times to the remote sites. Alternative three has other drawbacks. PE&C would be required to develop high levels of software since the necessary software for this type of system has not yet been developed. Also, some functions of the raster editing are currently PC hardware dependent within TVA, and the use of a host virtual disk is not allowed. With this limitation, the host computer would not be able to perform the raster-image editing required to achieve

the long term goals of the CAD network.

No matter which alternative is chosen, the central facility is a very important part of the system and will impact the response time for the user. The central facility is required not only to provide the means to connect all existing and future CAD workstations but also to link to other internal and external organizations. To accomplish these two requirements, the central facility must perform as a central file server, a printer/plotter server, link as a node to an existing Prime Computer Inc. network, serve as a short-term archiver for drawings in progress, and connect to TVA's host computer complex to archive final drawings. The server computer will be required to transfer from 160 KB to 2 MB size drawings to the workstations in a reasonable response time. A reasonable response time will be that of handling 15 concurrent accesses within 20 seconds.

For present and future needs, the Central facility will be required to support the equipment listed in Table 5.3.

Table 5.3. Equipment for CAD Network

-
- 1) 55 PC-based CAD workstations,
 - 2) 100 PC-based drawing review workstations,
 - 3) 3 CalComp, A Lockheed Company, Pen Plotters, models 1041 and 1043,
 - 4) 1 Versatec Inc. 200 dots per inch (DPI) Electrostatic Plotter, model 8536,
 - 5) 1 CalComp 400 DPI Color Electrostatic Plotter,
 - 6) 9 Dot Matrix Draft Printers,
 - 7) 1 High speed 1000 lines per minute (LPM) Printer,
 - 8) 2 to 4 High speed tape drives, (for alternative one)
 - 9) and possibly additional mass storage devices (disks).
-

The server must be capable of keeping the operating system, spoolers, PE&C developed programs, symbol and menu libraries, and several hundred drawings on-line at one time. This would require an estimated 1 gigabyte of mass storage with expansion to three or four gigabytes. Since the amount of

mass storage on a server's CPU varies by vendor, additional controllers may be necessary to supply the needed mass storage.

5.6 CPU and Printer

The CPU must be capable of handling 32-bit and 64-bit arithmetic operations following the Institute of Electrical and Electronics Engineers (IEEE) floating point format, have memory management capabilities, and be able to run a Fortran-77 compiler. It would also be advantageous for the CPU to provide a virtual environment with optimized data paging. Peripheral support is also an important consideration for the system to provide sufficient response times. The operating system should be capable of monitoring peripheral devices to determine activity and error rates and to free hung devices without affecting the systems activities.

The 9 Dot Matrix Printers will be placed around the network to be shared by workstations within a group. A PC-based printer server may be used to control these. The other plotters will be attached to the main server computer. A possible

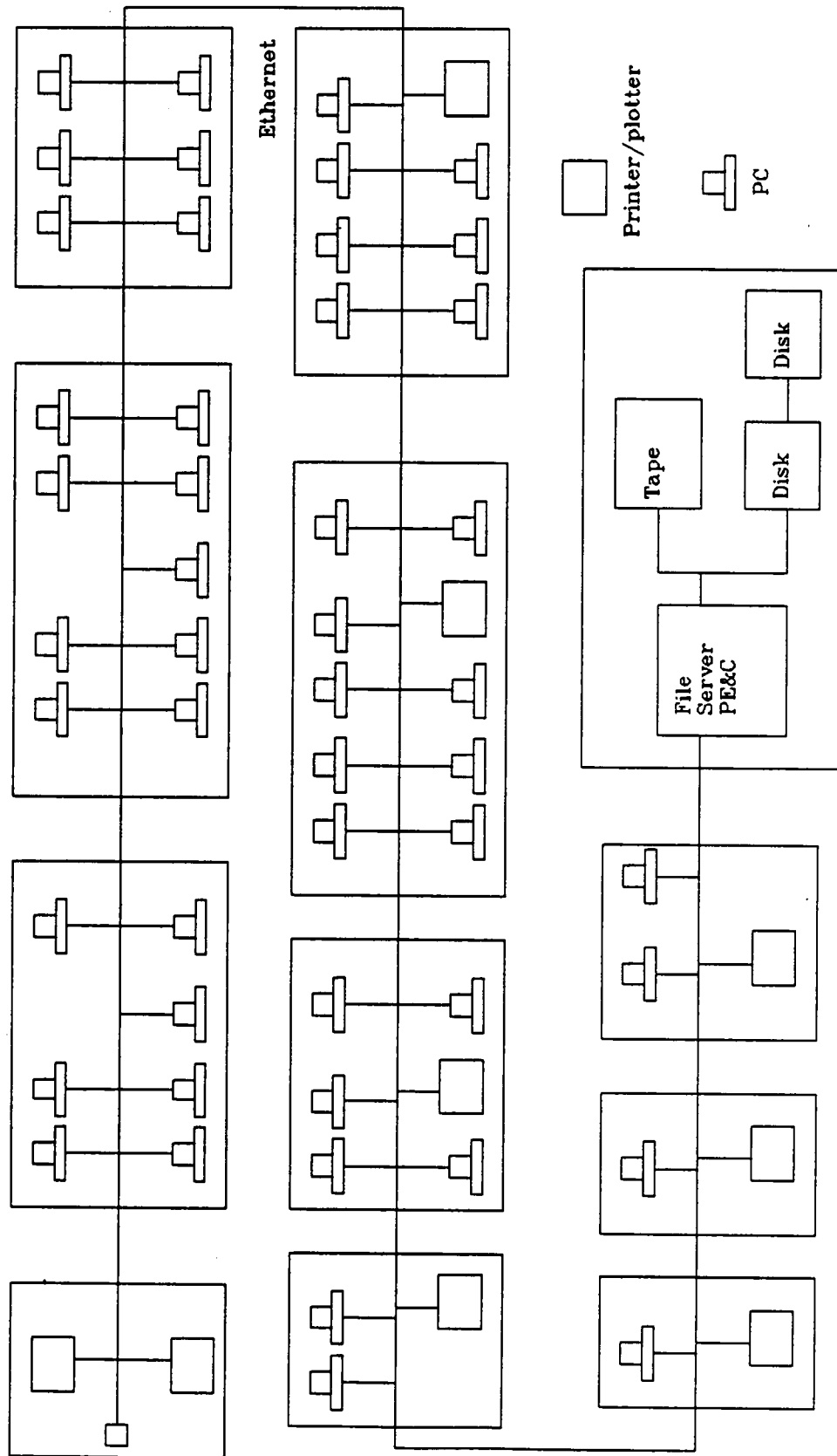


Figure 5.2. Possible Configuration [50]

configuration of the system is shown in figure 5.2.

5.7 Summary

PE&C is still in phase one in the developmental stages. The department has, however, begun researching the scanning equipment to be used for the raster conversions of existing drawings mentioned as part of phase two and hopes to purchase this equipment soon. Money is the prime reason for the delay of the installation of the system. PE&C must wait until funds are budgeted for their project before purchases may be made. The developers noted, however, that the fast improvements in technology in PCs and PC CAD related equipment is one major benefit of the delay. Scanning devices have improved greatly over the past few years and faster PCs can now be purchased with little increase in price over the original estimates. With the increased performances of PCs, alternative 1, which uses a PC for the server, is still a possibility. It could use an 80486 machine or maybe something better by the time the network is installed.

As with many departments within a large organization, PE&C found that they could not hope to

design the best system possible in regard to response times. Other factors, such as: existing networks, existing equipment, money cuts, and departmental reorganizations, all contributed to the development of the system. PE&C was able to purchase AutoCAD, the chosen software, but has had to settle for lesser than desired pieces of equipment for the workstations. This has reduced the CPU response time. Of the other four response timing points mentioned, the workstation response times were also hampered by the reduced power of the workstaton PC. The Peripheral printers and plotters are working with adequate buffers, but the real figures for the Peripheral Access time will not be determined until the system is finally networked. The Transmission times and the Data access times can not be determined until the network is in place either.

CHAPTER 6

Summary and Conclusions

Since PC-based CAD systems, like all networked systems, are very different depending on the individual installations, there is intuitively no set system that will perform best for all applications. The most important aspect of the system that will affect both the performance and useability of the system is the graphics software. There are many available software packages that perform well. This paper made no attempt to discover which software package is the fastest or which suits the PC-based type systems best.

There are many other aspects to consider with regard to the performance of a PC-based system. The first target of such a study is the PC to be used for the workstations and servers. The obvious choice is to purchase the most that can be afforded. The 80386 machines are close enough in cost to the 80286s to purchase the faster and better-equipped 80386 computers for both the workstations and the server. It may be even more advantageous to purchase a more powerful PC such as the 80486 based computers which

utilize on-chip cache memory. Even though the 8 Kbyte cache seems small compared to the possible 256 Kbyte of the 80386, it is much faster. Future research may determine the fast 8 Kbyte on-chip cache of the 80486 produces faster response times than the larger cache memory of the 80836 requiring a cache controller. A larger computer may be necessary for the server if the system is quite large.

Other than the graphics software, the server's ability will make the biggest difference in the system's performance. Whether one machine is used as a file server, print server, and communications link, or a separate computer is used for each will not affect the speed of the system. This decision will depend on the number of users and the spread of the network's activity. As long as the machine or machines are sized to handle the workload, either method will perform adequately. However, it very undesirable to use as the server of a PC-based system, a computer that is also used for other computing purposes. The server, no matter which type machine is chosen, should be equipped with a fast clock speed, 16 MHz as the minimum. To enhance the file server's abilities, the computer should have cache memory; the more the better. Cache memory will

greatly improve the fetching of data from the disks. Fast disks, with a minimum of 20 to 30 ms seek times are desirable. The faster 16ms seek time drives, if affordable, would help speed times even further.

The management software chosen will affect the speed of the server as much as its abilities of the server. Care should be made when choosing this important piece of software. The software should be compatible with the computer used as the server, use small a amount of random access memory (RAM), and have cache management to perform at its best. To function well as the print server, the computer should be sized to handle the flow of files being processed for printing and plotting. To ensure that the server is not bogged down with files waiting to be printed, the printers should be equipped with adequate buffers to hold the data files waiting to be printed.

The PCs used for the workstations should be at least 80286 processors or comparable. They should be equipped with a minimum of an 8 MHz clock, and have a Math coprocessor. Cache memory and a faster clock speed will greatly increase performance. The storage devices associated with the workstation PCs should be

compatible with the CPU, or the ability of the CPU will be lost waiting for the disk to perform. The response time is also affected by the monitor used with the workstation PC which determines the amount of time taken to draw and redraw the figure on the screen. The most important characteristic to consider when choosing a monitor with regard to speed is to use a monitor equipped with its own graphics processor. This additional processing power will reduce the drawing and redrawing times. The VGA-type monitors generally meet best the needs of the CAD systems because of their higher resolution. Another important feature to consider when choosing a PC to be used as both the workstation and the server is a computer that is designed to be upgraded. This way, as the system grows the PC can be modified to ensure adequate speeds without purchasing new machines.

The PC LAN topology will not affect the speed greatly. Both, the Bus and Ring topology will perform with adequate speeds to provide good response times. The choice between the two will depend on the application and the required compatibility with the other networks already installed within the environment of the PC-based network. This choice will

also depend on the medium access method chosen for the system. If token-passing is chosen, then either the bus or ring topology may be used. If CSMA/CD is chosen then the bus topology will be required. If the system is not heavily used, CSMA/CD protocol will usually be faster. If the system is heavily used, the token-passing protocol will usually be faster. The type of medium used to interconnect most PC-based systems is twisted pair. Coaxial cable may be faster, but because of the increased cost, it is not generally used when the server is also a PC. High-speed fiber optics is sometimes used to connect PC-based systems to other networks.

To ensure the fastest response times allowable for a particular PC-based system, the first requirement will be to study the needs of the system. The subsecond response times of large mainframe systems may not be achievable with the total PC-based systems, but the PC-based systems certainly have their place in many of today's design departments. The much lower cost of these systems allow them to enter offices that would not find CAD capabilities economically feasible in the past. As the equipment,

software, and LAN technology for PC-based systems improve, the response times of these systems will also improve. Because the equipment and software of PC-based systems are changing weekly, the network should be designed to anticipate change. And because the speed of the system is less than can be achieved with the higher cost mainframe and minicomputer systems, the network should be designed to achieve the maximum speed allowable.

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