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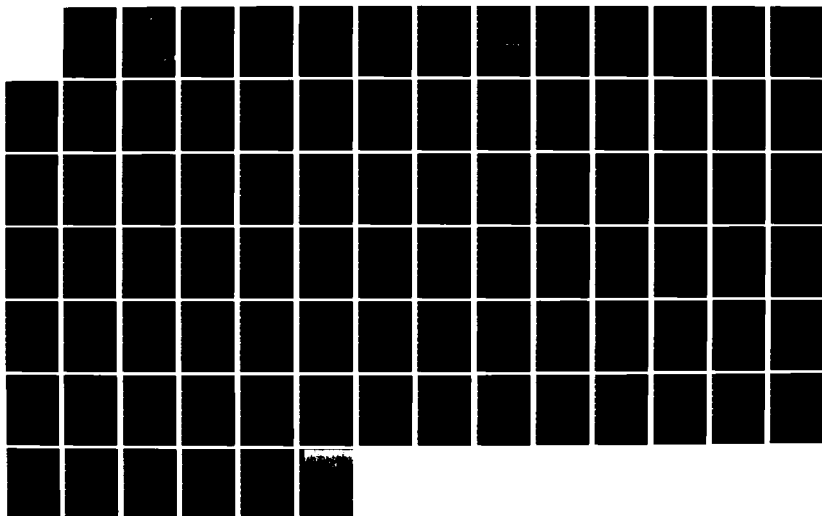
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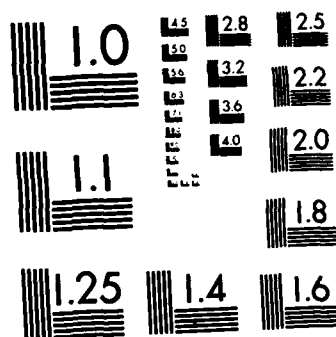
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FOR THE BASE CIVIL ENGINEERING
TECHNICAL DESIGN SECTION

William M. Duncan, Captain, USAF

LSSR 15-83

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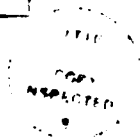
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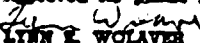
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The design workload on the Air Force Base Civil Engineering Technical Design Section has increased significantly in the past few years due to increased project funding in the Operations and Maintenance budget. This research project was an effort to determine if computer-aided design (CAD) can increase the productivity of the base designers to enable them to meet this increased design requirement. CAD was differentiated into three components - computer drafting, computer assisted engineering analysis, and automated preparation of contract documents - and each component was evaluated for its applicability in the design section. All areas of CAD were found to improve design section procedures and could increase the productivity of the design section personnel. The capability for engineering analysis and automated contract document preparation will be available on the Work Information Management System (WIMS) computer. Computer drafting systems are available commercially and appear to be economically feasible for most Air Force technical design sections.

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COMPUTER-AIDED DESIGN APPLICATIONS
FOR THE BASE CIVIL ENGINEERING
TECHNICAL DESIGN SECTION

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Engineering Management

By

William M. Duncan, BS
Captain, USAF

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CHAPTER I

INTRODUCTION TO THE RESEARCH

Purpose

The purpose of this research effort was to analyze the preparation of engineering designs within an Air Force base level Civil Engineering Technical Design Section and to identify the existing computer-aided design systems that would be effective in the base design section.

Although the design section is responsible for much more than just engineering designs, this report focuses only on that aspect of the design section responsibilities in order to limit the scope of the analysis. Additionally, recommendations are made about the implementation of computer-aided design into the base level technical design section.

Background - Design Process

An Air Force installation could be considered a small city with an airport. The same engineering problems that affect any city also affect an Air Force base.

New facility construction, facility rehabilitation, alterations and modifications of facilities, and maintenance and repair of existing facilities each require varying degrees of engineering services. All work that will be

accomplished by civilian contractors requires complete sets of plans and specifications as part of the contract documents.

All engineering design services affecting the installation are the responsibility of the design section. Facility design projects get their start in the technical design section. The entire design will normally be accomplished by the base engineers and technicians. However, when design work is contracted to a civilian architect-engineer (AE) firm, an Air Force project engineer must work with and assist the AE from the beginning to the end of the project to insure that all of the project requirements are included in the design.

Additionally, design section personnel provide engineering consulting services to all base agencies, assist the Civil Engineering planners in developing projects for the in-house work force, accompany shop personnel to jobsites to help advise on technical engineering problems, and assist the contract management section with contract surveillance.

These tasks and others that are levied upon the technical design section personnel require a staff of engineers and technicians in many engineering disciplines (or specialties) comparable to the staff of an architect-engineer firm.

Civil engineers are responsible for the structural design of buildings, airfield and vehicular pavement

analysis and design, water supply and wastewater disposal system design, and most other design work dealing with the physical features of facilities.

Mechanical engineers design heating, cooling, and ventilation systems, high temperature water heating systems, and other systems that meet environmental requirements within facilities.

Electrical engineers are responsible for the design of the electrical and lighting systems within facilities and for providing electrical power distribution to facilities, including emergency electrical power to essential facilities such as the hospital and the control tower.

Architects tie the concepts of the civil, mechanical and electrical engineers together into a facility package that meets the needs of the user while presenting an aesthetically pleasing design.

Draftsmen develop the final engineering drawings that identify the specific location and details of the project. Additionally, draftsmen are also responsible for surveying proposed construction locations for project suitability.

Secretaries or clerk/typists provide typing support for the production of project specifications and other contract documents.

The chief of the technical design section is responsible for coordinating the activities of all of the

personnel in the design section to insure that the contract plans and specifications for numerous projects are completed on time and of sufficient quality for satisfactory contract completion.

Descriptive Model of the Design Process

The design section receives a design requirement usually through one of three methods: 1) A base agency requires engineering design work; 2) design work is required to support a mission change or; 3) design work is required to support projects initiated by base engineering personnel (recurring work such as painting, pavement sealing, roof repair, etc.).

The chief of the design section decides if the design work can be accomplished by the base engineering staff based upon their expertise and the available design manhours, or if the design should be accomplished by an architect-engineer firm. Regardless of the design method, the design chief assigns a project engineer to design management.

Engineers from other engineering disciplines are assigned to work on the project with the project engineer. These engineers perform structural, mechanical, and electrical analyses to determine the specific engineering requirements of the project.

Analyses are accomplished using standard engineering practices. "Number crunching" is usually accomplished on

desk-top calculators, although some design sections use programmable calculators or personal computers.

These analyses, done in parallel with preliminary drawing layout and specification outlining, determine the general quantity and quality of materials and workmanship required for project construction.

To provide the details for the plans, or quantity portion of the design, the engineer must work closely with the draftsman. The engineer provides a "rough" preliminary layout or sketch to the draftsman and explains what is required on the drawing. The draftsman then produces an engineering drawing. This drawing is reviewed by the engineer, changes made, and returned to the draftsman for revision. This change process may happen several times depending on the complexity of the project, the skill of the draftsman, and the changes that are generated by outside sources (such as the originator of the design requirement).

As the plans are being developed, the engineer is preparing an outline of the specifications that will be required for the project. Specifications are required for materials and work methods to identify the quality required for the project and to form the basis on which the construction contractor prepares his bid.

Specification writing usually involves some form of the "cut-and-paste" method where the engineer compiles the contract specifications by combining pertinent portions of

cld, local specifications with guide specifications, product literature, and new written text to meet the requirements of the current project. The secretary, or typist, types the specifications, sends them to the engineer for corrections and/or revisions, then retypes the revised copy.

Like plans, this change process could occur many times. Until the late 1960's and the advent of the word processor, each revision required a complete retype of that portion of the specification. Many design sections without word processors still produce project specifications in this manner.

Inaccurate editing of old specifications (or the lack of adequate guide specifications) can lead to inconsistencies in contract specifications that result in confusion among bidders, contractors and other users. This confusion may cost the government money due to change orders, or result in the government not getting the required product. For example, an old specification that is adapted to a new project may reference a certain strength concrete in one part of the specifications that is inadequate for the new work and a higher strength concrete in a newly developed part of the specification. If the concrete section of the old specification was inadvertently left unchanged, the government may have to issue a change order to get the higher strength concrete or may have to accept the concrete provided by the contractor if it meets the minimum requirements of the specifications, even if the concrete

does not meet the real requirements of the project.

After the project engineer and the supporting engineers complete their respective project plans and specifications, the project engineer compiles these documents into one project package. The project engineer reviews the package to insure all project requirements are met and to insure that all portions of the project are compatible. If changes are required, portions are returned to the support engineers for revisions.

The completed package is forwarded to the design chief where it is again reviewed in detail to determine if all project requirements are satisfied.

Justification for the Research

Since the late 1970's, project funding in the Civil Engineering operations and maintenance budget has increased from approximately \$150M (\$150,000,000) per year to \$415.2M in the 1981 fiscal year (FY 81) and \$527.7M in FY 82. Much of the base design work for projects was contracted to architect-engineer firms due to the significantly increased workload on the base design section and a limited number of design section personnel. Consequently, fees for AE design services have increased from less than \$8M per year in the late 1970's to \$26.5M in FY 81 and \$38.5M in FY 82. (25)

Increased productivity of the design section personnel has the potential for reducing the amount of design work that is contracted to AE firms.

In a study conducted by the U. S. General Accounting Office (75:5-7), architect-engineer firms cited numerous reasons for using computers as an aid in the design process, many involving time-saving and money-saving parameters. If these computer-aided design techniques are applicable to the tasks accomplished by the base design engineers, and can increase the productivity of the design engineers, then many of the funds currently expended for AE design services could be diverted to other uses.

CHAPTER II

SCOPE OF THE RESEARCH

Problem Statement

The Air Force design engineer still uses the same techniques for producing facility designs that have been used for years: that is, manual preparation of structural, mechanical, electrical and architectural analyses; Manual preparation of specifications; rough sketches to the draftsman for developing engineering drawings; manual preparation of cost estimates and manual searches of facility as-built drawings.

These methods have been improved by such devices as desk-top calculators, word processors, and new types of drafting equipment. However, even the increases in productivity that have been made possible by these new "tools" still falls considerable short of the productivity increases needed to meet existing design requirements.

This research effort attempted to provide a comprehensive look at the availability and applicability of computer hardware and software that may improve the design process to better meet the objectives of the technical design section - high quality, on time plans and specifications.

Research Objectives

The specific objectives for this research effort were as follows:

1. Determine the current state-of-the-art computer-aided design hardware and software systems.
2. Determine which, if any, of these design systems are applicable to the engineering requirements of the technical design section.
3. Make specific recommendations regarding what computers are needed at base level for computer-aided design.
4. Provide an analysis of the economics of computer-aided design versus traditional design methods as it applies to the technical design section.

Limitations

This research effort focuses specifically on uses of the computer as a design aid to the design engineer or architect and includes all facets of engineering design from preliminary engineering analysis to completed contract documents.

Computer-aided design is differentiated into its three component subsystems - computerized drawing production (computer drafting), computer assisted engineering analysis, and automated text preparation of contract documents (word processing) - to determine which components of CAD are

applicable for use in the base technical design section.

Research Questions

The following research questions were addressed in this research report:

1. What design section procedures can be accomplished/improved by the use of computers?
2. What equipment (hardware) and programs (software) are private firms currently using to meet similar needs?
3. What size system is required for a "typical" technical design section?
4. What is the cost effectiveness (in terms of productivity) of computer-aided design versus the present system of manual preparation of designs, specifications, and contract documents?

Methodology

The methodology was designed to provide answers to each of the research questions put forth previously. Answering these questions was the basis for achieving the research objectives.

Research Question No. 1

"What design section procedures can be accomplished/improved by the use of computers?"

A study of the applicable Air Force regulations and

manuals (86, 88, and 89 series), interviews with base and major command personnel, and personal experience provided the data for the descriptive model of the design section that was presented in Chapter I. Design tasks performed by the technical design section personnel - drawing development and production, engineering analyses, and contract document preparation - were then compared to similar tasks presently being accomplished with computers by architect-engineer firms and by other Department of Defense components.

The design section procedures that are amenable to computerization are presented in the first section of Chapter IV.

Research Question No. 2

"What equipment (hardware) and programs (software) are private firms currently using to meet similar needs?"

A conference on "Computers/Graphics in the Building Process BP '83" and a review of current literature were the main sources of data on existing computer systems that are in use by private firms for computer-aided design. Data presented by representatives from the computer industry, as well as follow-up interviews with these representatives and interview with representatives from AE firms, were also used to determine what hardware and software systems are being used today. These systems are identified in the "Capability Today" section of Chapter IV and are evaluated for their use to perform tasks required of the design section.

Research Question No. 3

"What size system is required for the "typical" technical design section?"

The three components of CAD were evaluated separately to determine what computer capabilities are required for each CAD subsystem.

Each subsystem was evaluated to determine which elements of CAD are applicable to base level engineering design and what computer capabilities are needed to implement the applicable CAD subsystems at base level.

A review of computer industry and building industry literature provided a basis for comparing numerous types of computer systems. This data and interviews with personnel from AE firms identified what type systems are being used by civilian firms for computer-aided design.

Telephone interviews (2; 3; 6; 12; 17; 19; 34; 54; 59; 61) were conducted with base and major command personnel to determine the specifics of the "typical" technical design section. The results of these interviews are shown in Tables 2.1 and 4.1.

Finally, computer use by civilian firms was investigated to determine what computer systems would be most appropriate for the "typical" technical design section.

Results of the research in this area are included in the "Air Force Applicability" section of Chapter IV.

Table 2.1
Design Section Manning

Base	Designers	Technicians	Ratio
Ellsworth	11	9	1.2
Dover	13	8	1.6
Hurlbert	11	6	1.8
Kirkland	18	13	1.4
Malmstrom	9	10	0.9
Grand Forks	10	8	1.3
Barksdale	10	8	1.3
Blytheville	8	5	1.6
Columbus	8	5	1.6
Dyess	8	7	1.1
Little Rock	15	11	1.4
Travis	15	10	1.5

Research Question No. 4

"What is the cost effectiveness (in terms of productivity) of computer-aided design versus the present system of manual preparation of designs, specifications, and contract documents?"

U. S. government studies and surveys, building industry surveys, manufacturers' literature, and interviews with employees from the Department of Defense, AE firms, and computer companies, provided estimates of the productivity increases for each element of CAD that have been realized by firms using computer-aided design.

Each CAD subsystem was included in an economic analysis to determine the cost effectiveness, in terms of productivity increases and manhour savings, of computer-aided design for the technical design section. This analysis is included as Chapter V.

The answers to all of the research questions provided the basis for determining what, if any, computer system (or systems) is economically feasible for implementation into the technical design section.

CHAPTER III

LITERATURE REVIEW

Introduction

The purpose of this chapter is to trace the development of computer-aided design in the building industry.

This task was accomplished by reviewing literature published by the building and computer industries, interviewing personnel from the U. S. government, architect-engineer firms, and computer manufacturers, and reviewing various feasibility studies on the use of computers for engineering design applications.

Due to rapid advances in computer technology, the reviewed literature was constrained to data published since 1980.

Background - Computer-Aided Design

Computer-aided design was previously defined as the use of computers to help the designer develop any portion of a project package including drawing production, engineering analysis, and preparation of specifications and other contract documents (such as cost estimates, programming documents, bid documents, etc.).

The design is not created by the computer since

design responsibility rests with the designer, not the machine (8:14). Instead, the computer acts as an extension of the designer's thought process and is used as a tool, much as the designer may use a pencil (15:74; 46:67).

Drawing Production

The first use of computers to generate drawings was in 1950 at the Massachusetts Institute of Technology. This system was very crude and significant advances in computer generated graphics did not occur until the middle 1960's when major research was implemented by such organizations as General Motors, Bell Telephone Laboratories, and McDonnell Douglas. As a result of this research, computer graphics came into use as a design tool in the early 1970's, predominantly in the electronics field (15:74).

From 1973 to 1982 computer graphics as a design tool grew at an annual rate of nearly 130 percent, mainly in the manufacturing and machine design fields (15:74).

In the middle 1970's, computer manufacturers that had specialized their computers in other fields, such as circuit boards, integrated circuits, mapping, etc., began to develop computer drafting systems for the architect-engineer community (9:18).

These first systems were strictly two-dimensional systems that used storage tube displays to create graphics by exciting phosphors on the screen of a cathode ray tube

(CRT). The entire image had to be redrawn anytime a deletion was made (51:45). These first graphics systems, as with any of the early computer systems, would be considered very slow when compared with today's systems (1:1; 9:18).

As more computer companies entered the AE marketplace in the middle 1970's and early 1980's, computer drafting systems increased in sophistication. The speed of the systems increased many fold as microcircuitry based computers became prevalent. The storage tube CRT's were replaced by raster CRT's that allowed for instant deletions and multiple colors. (51:45)

Three-dimensional models (both wire diagram and solid models), standard symbol libraries, automatic subsystem interference checks, multiple overlays (or layers), text integration with the computer graphics, moving images, and automatic dimensions (as well as many other features) are all currently available on various computer drafting systems depending on the complexity of the software and the capabilities of the hardware (1:2; 51:45; 71).

In a 1981 Sweet's Catalog survey of 2500 architects and engineers (38:23), only nine percent of the firms surveyed owned computer drafting systems. These numbers increased to 14 percent in 1982 and were predicted to increase to about 20 percent by the end of 1983 (43:120). Even though computer drafting gives good productivity

gains, the high cost of sophisticated drafting systems made these systems affordable by only the larger design firms (38:23).

Engineering Analysis

At about the same time that major research on computer graphics began, computer applications for engineering analysis were also being investigated.

Computers are extremely well suited for certain purposes, one of the main ones being computational mathematics (57). Thus the computer was an ideal tool to be used for rigorous "number crunching" formulas required for much engineering analyses (53).

Major structural, mechanical, and electrical analysis programs were first developed in the middle 1960's and were used on the mainframe computers of that time (53). In the late 1970's and early 1980's, as computers rapidly increased in computing capabilities and decreased in size and costs, many programs were developed for structural design and analysis, energy analysis, heating, ventilating, and air conditioning (HVAC) load calculations, electrical load calculations and many other specific engineering uses (48:72).

Many of the larger and more complicated programs, such as STRUDL (Structural Design Language) and BLAST (Building Loads Analysis and System Thermodynamics), were designed for mainframe computers and must still be run on

mainframes or large minicomputers (7:81; 53). However, a large number of engineering design and analysis programs that once ran solely on mainframes have now been modified to run either partially or wholly on small minicomputers, microcomputers, or even on personal computers (7:81).

Computers increase the speed of making an analysis, thus allowing the designer to look at several design options to provide the most efficient design for the project (14:35; 75:6). As engineers and architects become more familiar with the operations of the computer, they are able to write their own analysis applications programs to help solve specific design problems (35:41).

At present, all types of computers - mainframes, minis, micros, and personals - are used for engineering analyses (7:81).

In the Sweet's Catalog survey that was previously cited, engineering design analysis was identified as the major application of computer use by designers (38:23).

Contract Document Preparation

As with other areas of computer-aided design, computer preparation of contract documents got its start in the middle 1960's. At that time IBM Corporation introduced the Magnetic Tape Selectric Typewriter, the forerunner of the word processor. (28:10-11)

Although the IBM typewriter was not a computer per se, it led to the development of stand alone word processing

equipment and to the development of word processing software for use on microcomputers, minicomputers and mainframes (65:587).

Word processors have been used extensively in business since the early 1970's (28:10-11) and have more recently been accepted into the building industry.

All project text, whether programming documents, specifications, bid documents, or contract forms, can be created, duplicated, stored and retrieved using word processing equipment.

According to a 1982 survey of 3000 architects, engineers, and contractors conducted by Building Design and Construction magazine (48:71-72), 26 percent of the architects and 45 percent of the engineers responding indicated that word processing equipment was available in their offices.

Summary

According to the 1981 survey conducted by Sweet's catalog, almost 30 percent of the 2500 most active architects and engineers were using computers in some way by 1976 (38:19).

By 1982, Building Design and Construction magazine reported that 70 percent of the engineering firms in the building industry and 40 percent of the architecture firms were using computers for at least one of the three areas of CAD (48:70).

Reasons cited by designers for not using computers are the very high costs of the equipment and the scarcity of applications programs (23:12; 38:19).

Because much of engineering is computational oriented, engineers could see productivity gains using computers more readily than architects (38:19). Large engineering firms were first in the building industry to use computers in an extended manner since large funded projects made the investment in computers budgetable by these larger firms (7:80).

Smaller firms that could not afford the high cost of purchasing their own computer either used a time sharing approach with another firm's computer or continued to operate in a completely manual mode (7:80).

In the 1982 survey conducted by Building Design and Construction magazine (48:70-71), larger firms were still the most likely to be using computers. Almost all of the larger engineering firms with more than 25 employees were using computers (48:70-71).

Merrill Lynch (43:120) conducted a recent survey and reported that the architectural and engineering segment of the computer-aided design market has been the fastest growing segment of the overall CAD market with a 46 percent growth rate in 1982 alone. "A further 50 percent growth in 1983" is expected (43:120).

Every firm has its own reasons for using computers. Some firms use a computer system because of possible

productivity increases for their personnel; others because of increased standardization; and others because they feel it will aid in their marketing efforts (49:148).

In a survey conducted by the U. S. General Accounting Office of 745 design firms that did business with the Federal Government (27:14), the primary reasons cited for using computers were:

1. To carry out tasks which are inefficient using manual techniques;
2. To improve the quality of designs;
3. To reduce design costs;
4. To speed up the design process.

In comparison to manual methods, computers are allowing designers to produce higher quality, more efficient designs in a shorter period of time (75:1).

CHAPTER IV

RESULTS OF THE RESEARCH

Computerization of Design Section Procedures

The base technical design section is responsible for all engineering design services for the base. The descriptive model presented in Chapter I identifies the requirements for developing project designs. These include drawing development, engineering analysis, specification writing, and other contract document preparations.

In telephone interviews with several base design chiefs (2; 3; 12; 17; 19; 34; 54; 59; 61), it was determined that approximately 30 to 60 percent of the base designer's time is spent on design work, depending on the time of year and design workload (see following table).

Table 4.1

Time Factors for Base Designers

Base	Percent of Total Time on Design	Percent of Total Time On Drawing Development
Ellsworth	50	23 to 38
Dover	50	15
Hurlbert	40 to 50	12 to 15
Malmstrom	40 to 50	12 to 15
Grand Forks	30 to 60	15 to 30
Barksdale	35	29
Columbus	50	38
Dyess	60	27

This range corresponds favorably with an Air Force

Civil Engineering and Services Management Evaluation Team (CESMET) study which found that 45 percent of the base designer's time is spent on design work (32:60).

Drawing Production

One of the major benefits of using computers in design is being able to speed up tasks that are repetitive in nature (72). Contract drawings that must go through several revision cycles are often ideal candidates for automation (23:25; 72; 78:18-19).

A computer drafting system lets the designer use the capability of the computer to store reusable data (23:25; 70:47) and allows each person on the design team to use the same data for their portion of the design (14:35; 71).

With traditional manual drafting methods, each change to a drawing requires redrawing part or all of the plan. This is time consuming and often tedious, but must be continued until the contract plans are finalized (30:42-43). However, computer drafting systems alleviate the manual redrawing of plans. Changes can be made in minutes electronically and the "drawings" view on a CRT. Hard copy "blueprints" are only produced as needed, or for the final contract package (30:43; 57; 72).

Although most drafting is accomplished by the draftsman, it still takes considerable time to transfer design information from the designer's mind to the draftsman. Hand drawn sketches, preliminary designs,

details, and notes account for a large percentage of the designer's time (14:36; 23:7; 24).

Based on the data presented in Table 4.1, it is assumed by the author that the base designer spends approximately half of his design time developing the drawings for a project.

A designer can produce a preliminary design drawing on the computer in about one half the amount of time that it now requires to layout by hand (57; 72; 74:4-1,4-2) taking advantage of the computer's capability to do such things as translations, rotations, scalings, repetitions, patterning, and instantaneous line production (51:41). Additionally, the designer can study a wide variety of design alternatives easily by altering the preliminary drawing on the computer. This capability to make changes literally at the push of a button provides the designer great flexibility in making design decisions (14:35).

If design projects involve changes to existing facilities (the kind of project most prevalent for the base designer) that have already been stored in computer memory, the designer can immediately call up the stored drawings for design analysis and revise the drawing to conform to the new project (78:17-22).

As a drawing is input into the computer, many computer drafting systems allow the user to assign certain attributes to the graphics data. For example, attributes attached to a

line may represent an interior wall, including its length and material. Upon completion of the drawing, or set of drawings, these attributes can be compiled to assist the designer in providing a cost estimate or materials schedule for the project. (39:141)

Once the data is input into computer memory, all members of the design team can have simultaneous access to this common database (14:35; 71). An engineer or architect can move a wall and all related disciplines would know immediately simply by reviewing the computer database for the project (1:2).

A large number of design decisions that traditionally have been made at different times by different people can now be made in concert with one another (71). Using the computer, designers

can share their information more easily, draw on many of the same resources to make decisions that affect each other's work and eliminate much of the confusion previously inherent in many building projects where coordination led to time consuming checking and rechecking [14:35].

Design conflicts between the various different drawings (structural, mechanical, electrical) can be quickly and easily checked by using the layering capability of most computer drafting systems (23:25; 51:45). The designer can combine the computer drawings from the different disciplines into one drawing by overlaying, then a visual check can be made for conflicts. Several of the more sophisticated computer drafting systems will automatically identify

conflicts by flashing at all locations where more than one object is occupying any point on the combined drawing thus allowing the designer to immediately identify potential design conflicts (23:25).

Conflict avoidance can reduce the potential for change orders once the project is under construction (23:24-25).

Although computer drafting systems offer definite advantages to the designer over the traditional manual methods of plan development, the major productivity increases of a computer drafting system are realized when the draftsman uses the system to develop complete contract drawings from preliminary drawings (44:100).

At the offices of Skidmore, Owings and Merrill, one of the largest AE firms in the world, the largest use of computer drafting is for contract drawings developed by the draftsmen. This is also the case for the architect-engineer firm of Everett I. Brown Company where the computer drafting system is used 95 percent of the time by draftsmen (44:100).

While productivity increases for the designer in developing initial project plans may be no more than 2:1 (57; 72), productivity increases for the draftsman may reach as high as 20:1 depending on the complexity and repetitiveness of a drawing (70:51; 72:50-51). Average productivity increases for computer drafting over manual drafting is 3:1 to 4:1 (33; 56; 60:19; 78:38).

The designer normally provides the draftsman with drawings, sketches and calculation sheets to complete the contract drawings, such as framing plans, elevations, etc. (14:36). In a medium sized project, there are "literally thousands of occasions" where errors can occur, either in a misunderstanding between the architect or engineer and the draftsman, or in simple arithmetic errors (15:76).

However, if the designer developed the preliminary drawing on the computer or if the drawing is a modification to a drawing already in the computer database, the draftsman has only to call this data from storage and make the appropriate changes (23:25; 70:47).

Automatic dimensioning, standardized details, standardized notation, multiple drawing overlays, text-graphics interface, instantaneous line production, patterning, rotations, and many other attributes of a computer drafting system, all improve the productivity of the draftsman in developing completed contract drawings for a project (15:75; 51:41; 70:49; 72).

Computer drafting systems increase accuracy, provide quicker drawing completion, standardize construction details, and generally produce higher quality drawings than are available using manual techniques (9:18; 37:35; 44:101).

Engineering Analysis

Engineering analysis for the base level designer is often significantly different from the analysis performed by

the civilian engineer or architect. The civilian designer is normally responsible for complete analyses of structural, mechanical or electrical systems for new facility construction, while base designers seldom design complete new facilities (2; 3; 12; 17; 61).

Large new facility construction for the Air Force is almost always the responsibility of the U. S. Army Corps of Engineers or the Naval Facilities Engineering Command as the design and construction agents for the Air Force on military construction projects. All construction projects costing over \$1,000,000 must, by law, be included in the Military Construction Program (MCP) and be designed by one of these agents (76:4-1). Base designers are mainly involved with renovation or maintenance and repair projects (2; 3; 12; 17; 34; 61) or with minor construction projects with a scope of less than \$1,000,000.

Less than 10 percent of all projects designed by the base engineers involve new building construction. Almost all construction design work involves renovation or alteration work to existing facilities (2; 3; 6; 12; 17; 19; 34; 54; 59; 61). Therefore, the type of engineering analysis normally required by the base designer involves space utilization, maintenance and repair of existing facilities, energy utilization, environmental considerations, and engineering analysis of changes and alterations to structural, mechanical, and electrical systems of the existing base facilities.

Analysis of changes to existing facilities can include a significant amount of computational work if there are major changes to structural, mechanical, or electrical systems.

Any task involving extensive "number crunching" can be improved by using computers to do the calculations thus freeing the designer to use his time for other design work (57).

The computer allows the designer to examine multiple alternatives in the same amount of time that it once took for a single design option. The designer can then choose the most appropriate and efficient system or design option. (14:35)

In a 1981 study conducted by Daniel J. Borda of Arthur D. Little Incorporated, Cambridge, MA (72), 95 firms reported productivity increases from 1.5:1 to 20:1 for computer versus manual techniques for engineering analysis. In that study, average productivity increases for computer-aided engineering analyses were approximately 6:1 over manual methods (72).

Contract Document Preparation

As was identified earlier from a Building Design and Construction magazine survey, 26 percent of the architects and 45 percent of the engineers have word processing capability in their firms (48:71). However, at this time less than 50 percent of the Air Force bases have word

processing capability in their technical design sections (79).

From this same survey, almost 23 percent of the civilian architects and 34 percent of the engineers use some type of automated specification system (48:72).

Complete sets of master specifications from the American Institute of Architects (AIA) and the Construction Specifications Institute (CSI) are available for use on most word processing systems (31; 69; 70:47). Local master specifications may also be developed to store on a computer with word processing software or for stand alone word processing equipment.

Using these master specifications, the designer can call up pertinent guide specifications and alter them to fit the current project. New text can be added anywhere in the specification and the "new" specification can be stored indefinitely by project number, project name, project type or almost any other identifier that the specification writer requires (20).

The use of one set of master specifications by all engineers at a base would lead to more standardization between contracts and could help reduce errors and omissions in project specifications. The use of automated master specifications can potentially do away with the manual "cut-and-paste" method of reworking old project specifications.

The preparation of other contract documents can also

be improved by using word processing equipment.

Forms, approval documents, reports, and all other text for contracts can be accomplished more effectively on word processing equipment than on conventional typewriters.

In a 1982 survey conducted by Grafcon Corporation, Tulsa, OK (33), civilian firms utilizing word processing were achieving increases of 8:1 for text preparation that included contract documents.

Summary

All design section procedures necessary to provide complete project designs (drawing production, engineering analysis, and contract document preparation) can be improved by using computers in the design process. The amount of improvement depends on the specific application, but productivity increases range from 2:1 for preliminary drawing development to 6:1 for engineering analysis and 8:1 for preparation of written material.

Capability Today

There are numerous computer manufacturers currently providing computers to the architect-engineer community (39:138-146; 48:71; 72). These computers range from personal computers and small microcomputers to large minicomputers and mainframes.

Due to high costs, only the very large companies

were originally able to afford computers (7:80; 38:19). Smaller firms were left with time-sharing another firm's computer or using a service bureau (7:80; 48:72)..However, smaller firms have been able to purchase computers as efficiency in the semiconductor industry started a downward trend of prices for microprocessors and semiconductor memory devices that led to low cost microcomputers and lower prices on larger minicomputers and mainframe computers (38:19; 51:45).

Drawing Production

The most varied area of computer-aided design is in computer drafting systems.

Until recently (within the last two years) computer drafting systems were restricted to large computers because of the amount of active memory required to process complicated architectural drawings (57; 72), therefore the first sophisticated drafting systems were developed for large minicomputers.

Applicon, Auto-Trol, Calcomp, Calma, Computervision, and Integraph all produced these highly sophisticated systems that are still considered the top end of the computer drafting systems (39:142; 50:17; 72).

These systems normally retail for at least \$200,000 for a single work station and CPU and can cost over \$500,000 for a multiple work station system with peripherals (plotters, printers, digitizers, etc.) and software

(30:43; 33; 50:18; 57; 72).

Intergraph, Auto-Trol, Calcomp and Computervision account for most of the installations of these top of the line systems (39:145).

All of these computer drafting systems have software that provides automated drafting, text-graphics interface, attribute assignment, three-dimensional modeling, and other sophisticated graphics programming (33; 55; 57; 58; 72).

Many new vendors have entered the computer graphics field by offering low cost systems based on small minicomputers or microcomputers (10:141; 29:82; 39:138; 72). A. M. Bruning, Arrigoni, Bausch and Lomb, Engineering Systems Corporation, Grafcon, and McAuto are just a few of the companies that provide complete, minicomputer based drafting systems for less than \$100,000 (72).

Arch-CADD Systems, Cascade, Summagraphics, T and W Systems Incorporated, and Carrier Corporation have all marketed microcomputer based systems that sell for less than \$40,000 (39:138; 42:39; 72).

Apple, T and W, and Victor Business Products have marketed microcomputer drafting systems that sell for less than \$15,000 (10:41; 21; 29:82).

The lower priced systems are generally capable of two-dimensional drafting, text-graphics interface, and limited attribute assignment, and normally will only support one work station. The mid-priced minicomputer based

systems (less than \$100,000) have many of the features normally found in the top of the line models and will often support more than one computer drafting work station (39:138-140; 72).

Since lower priced systems have only recently been introduced into the AE marketplace and their use is presently limited (57; 72), no studies on the use of these systems were found in the literature. Productivity increases that were cited previously for computer drafting and that are used in the economic analysis in Chapter V are based on the expensive, sophisticated systems that make up the majority of the systems in use (39:145). The author assumes that similar productivity increases will be possible using the less expensive systems.

Two-dimensional architectural drawings can be developed on computers with as little as 64K bytes of main memory (29:79). Three-dimensional systems require more active memory because of the larger database required for three-dimensional drawing development (57; 72).

Solids modeling and completely integrated CAD systems with multiple work stations require a CPU of at least two megabytes to insure that system speed is not degraded significantly when more than one user is operating on the system (52; 53). And while three-dimensional modeling is a benefit for architectural concept design and civilian marketing potential (39:143), at least 95 percent of all architectural and engineering drawings are two-dimensional (51:43).

In addition to the central processing unit, other hardware is needed for a complete computer drafting system. A typical interactive drafting system also includes input devices (keyboards, digitizers, menu tablets), output devices (plotters, CRT's, printers), and mass storage devices (discs, magnetic tapes) (72; 78:11). The keyboard, CRT and some type of storage is normally included with any drafting work station.

The digitizer is an optional device for inputting data from existing drawings into computer memory. It is essential for developing a database for existing drawings (70:47). The time required to input an existing drawing into a computer database can be considerable. At present, there is no easy and quick way to accomplish the conversion of existing facility drawings into a computer database. (33; 57; 72)

The menu tablet is a table of frequently used commands that can be summoned at the touch of a button (such as 'draw line'). This device increases the user's productivity by shortening the time required to input commands into the computer. (78:11)

Plotters produce drawings by transforming the computer data into a "blueprint" by plotting the data onto paper, mylar, vellum, or some other medium (78:29).

Pen plotters produce drawings with great accuracy and can also produce drawings in color. Electrostatic

plotters are much faster than pen plotters, but do not produce as high a quality of drawing, cannot produce color, and are generally more expensive than pen plotters (39:146; 51:45).

Mass storage devices (disc storage and magnetic tape) are used to record information outside the active memory of the central processing unit. Disc storage provides random access to data and is much faster than magnetic tape, where data must be accessed sequentially. Disc storage is also more expensive than magnetic tape storage (78:30).

A mass storage medium is also used to provide "back-up" for the computer database in case of the non-intended destruction of data on a primary disc or tape carrying important information (such as all drawings for a project). Duplicate tapes can be produced by the computer , at regular intervals and these tapes can be stored in a safe location, thus providing access to the computer based information even if the primary tapes or discs are inadvertently erased, destroyed by fire or some other disaster, or if a computer problem causes information to be lost. (41:92; 74:2-1)

There are many manufacturers of peripheral equipment for computers. Peripherals must be matched to the particular computer drafting system, although computer manufacturers will do this when they supply a complete drafting system to a client (57; 72).

Although prices of computers have fallen considerably in recent years (38:19; 57; 72), peripherals, being primarily electromechanical in nature, have not declined significantly in price. Sophisticated computer drafting equipment is still expensive (38:23) and firms can expect to pay at least \$25,000 for high quality peripheral equipment that is suitable for producing contract drawings (44:101-102).

Software for computer drafting systems is normally supplied by the computer manufacturer or by a software development firm, the most common being a systems vendor (36:35).

Systems vendors are generally consultants that select various equipment and develop appropriate software, then provide a complete turnkey system to a client (36:36). As the name implies, a turnkey system includes the computer, software, and all peripherals necessary to set the system up and immediately start operating (57).

Other software developers only supply programs, not complete computer drafting systems. Their software is generally developed for a specific system, but is adaptable by the development firm to other systems. (35:41).

Many firms are developing their own subprograms for their computer drafting systems to suit the particular needs of their office, although the development of in-house programs is usually more expensive than purchasing off-the-shelf software (35:41; 47:92). A 1982 survey by

Sweet's Catalog (35:41) showed that the average architectural-engineering firm spent about twice as much on in-house development of software as they did on off-the-shelf programs.

Engineering Analysis

According to the Building Design and Construction magazine survey cited earlier, the most popular general computing system for design calculations among architects and engineers is the Radio Shack TRS-80 microcomputer. Other popular brands of computers used by designers include systems by Apple, Wang, IBM, Digital Equipment Corporation (DEC) and Hewlett-Packard (48:71). Most of these systems are based on microcomputers and retail for under \$20,000 (7:80; 29:82; 57; 72).

Technical programs, including structural analysis, energy analysis, electrical load analysis, HVAC calculations, and mechanical analysis, make up the bulk of computer programs being used by civilian architect-engineers (48:72). Most of these programs are being used on microcomputer systems (48:71; 70:49), although highly complex design and analysis programs must still be run on large minicomputers or mainframes, usually in a time-share mode (7:81; 53).

According to a 1982 Sweet's Catalog survey, programs for microcomputers were most often developed in-house while highly complex analysis programs were provided with the

computer system or through a software development firm (35:42-43).

Contract Document Preparation

IBM, Wang, and Lanier are the most popular brands of stand alone word processing equipment that engineer and architect firms are using for text preparation. Xerox and DEC are also popular brands. (48:71)

Word processing software is almost always supplied by the manufacturer of the computer hardware or is integral to the stand alone equipment (16; 26). Most word processing software provides for text creation, editing, storing and retrieval, spelling checks, moving text, scrolling, custom programming (e.g. developing report formats), and automatic pagination (16; 26; 66).

Federal Government Software Availability

In addition to civilian sources of software, agencies of the Federal Government have also developed extensive libraries of computer programs.

The Corps of Engineers, through the Construction Engineering Research Laboratory (CERL), have developed software for several analysis and graphics applications as well as a complete computerized specification writing system called EDITSPEC (20; 67:140-146). Most of these programs were developed for mainframe computers, but are being modified to be used, at least in part, on microcomputers and are available to other federal agencies (53).

The Naval Facilities Engineering Command (NAVFAC) also has a library of technical programs that have been used for computer-aided design. Their guide specifications are available on computer discs that are compatible with Wang word processing equipment. The technical programs and specifications are also available to other federal agencies. (4:220; 62)

Many other federal agencies also use computers as design aids. Many of these programs are identified in the Federal Software Exchange Catalog, a federal publication developed as an aid to assist federal agencies in exchanging information about computer software in use throughout the Federal Government (73).

Headquarters Air Force has recently initiated a program to compile a list of software currently being used by Air Force designers to assist in their design efforts. However, this program has not been completed (13).

Industry Problems

One of the major problems affecting all users of computers as design aids is the inability of most computer systems to "talk" to each other (62; 63). Vendors often use unique procedures that prevents their software from being used on another brand computer. Additionally, output from one computer often cannot be used as input for another computer without significant, and often costly, changes (62).

The National Standards Institute is currently working on a language standardization program called the Interactive Graphics Exchange Standard (IGES) that will allow for transfer of data between CAD systems of various manufacturers (46:66; 63). Although most major vendors support the program, complete transfer of data between systems is still, and will continue to be, a problem until the program is complete (46:66; 62; 72).

Summary

There are many computer manufacturers and software developers supplying equipment and programs to the architect-engineer community as design aids.

Engineers are using computers, especially microcomputers, increasingly for engineering design and analysis. Both engineers and architects are heavy users of word processing equipment to produce specifications and other contract documents.

Computer drafting systems are still expensive, although lower priced systems have recently been introduced by many manufacturers. Because of the cost, computer drafting systems have not been used by most design firms, although the number of firms with computer drafting systems is expected to climb significantly in the next few years.

Software for computer-aided design systems are available from equipment manufacturers, independent

software developers, and in-house programmers with in-house programming being the most expensive way to obtain software. Federal agencies can also take advantage of the software that has been developed by agencies throughout the Federal Government.

Headquarters USAF is compiling a list of software programs currently being used by base designers for engineering design work that will eventually be available to all bases. Other engineering design programs are available from the U. S. Army Corps of Engineers and the Naval Facilities Engineering Command. Much of the software used by other federal agencies is listed in the Federal Software Exchange Catalog and can be made available to base designers.

The selection of hardware and software by civilian firms depends on the needs and financial position of the firms.

Air Force Applicability

Drawing Production

The only component of computer-aided design that will not be available to some degree to the base designer via the Work Information Management System is computer drafting.

Computer drafting systems vary tremendously in their capabilities and their costs.

The size of the central processing unit required for engineering drafting depends on the complexity of the

software and the amount of detail (i.e. number of data points) on a drawing. Two-dimensional drawings normally take much less computer capacity than three-dimensional drawings (53; 58).

Regardless of the sophistication of the computer drafting system, a substantial amount of storage is required to record drawings. The 300 megabyte disc storage used with many Computervision drafting systems will store 500 to 1000 D size (22" by 34") or E size (30" by 42") drawings, depending upon the complexity of each drawing (58). An Air Force base may have several thousand record drawings that would need this type of storage.

A "typical" base design section usually has about 20 designers and technicians (including draftsmen), with approximately a 1.5:1 ratio between designers and technicians (see Table 2.1). Some larger bases (such as Kirtland AFB) have considerably more than 20 and some small bases (such as Blytheville AFB) have considerably less than 20 people (6; 61).

However, there is no set suggested number of computer drafting work stations based upon the number of personnel in a design office (33; 57; 72).

For example, an AE firm in Florida has 10 graphics work stations to support a work force of 150 personnel (39:143) whereas another firm with six personnel has a similar system with three work stations and two more on order (33).

The number of work stations in a civilian firm depends on the workload of the firm and the number of personnel who will use the system, as well as system cost (33; 45:149; 57; 72).

One common point among almost all civilian firms using computer drafting systems is that these systems are used by the draftsmen for multiple shifts, usually at least 12 hours per day (15:77; 29:79; 35:41; 40:29).

Engineering Analysis

Analysis programs are used by most engineering disciplines and are available on all sizes of computers (48:71-72; 57; 72). The complexity of the program and the size of the database required for the program determines the amount of active memory needed in the central processing unit (52; 53).

The one megabyte central processing unit and 300 - 500 megabytes of mass storage that will be installed in each Base Civil Engineering organization via the Work Information Management System (WIMS) should be sufficient for handling virtually all individual engineering analysis programs that the base designer might need (52; 66). However, a single complex analysis program or many individual analysis programs may degrade the speed of the system to all users, therefore, these type programs should only be run when the system is at minimal use (such as after normal duty hours) (66).

Contract Document Preparation

All contract documentation can be prepared on word processing equipment, usually much quicker than on conventional typewriters (70:47). Additionally, if automated specification software is obtained, the base designer can have a complete set of master specifications available at his fingertips (20; 31; 69).

WIMS will provide word processing capability to all Civil Engineering sections, including the design section. This system will be highly sophisticated with features such as automatic spelling checks, text movement within a document (cut-and-paste), automatic pagination, scrolling, programmable tables, report formatting, and many other features that will make this system an aid to producing contract documents. The system also has the capability of accepting software for an automated specification system. However, the capacity of the system and the number of users on the system may limit its use as a design aid. (18:14; 66)

Summary

The base technical design section will have some computer-aided design available upon implementation of the Work Information Management System. This will include the capacity for engineering analysis programming and word processing for the production of contract documents.

Automated specification writing software is not

currently programmed for WIMS, but is available either commercially or from other Department of Defense agencies.

The one area of computer-aided design that will not be available on WIMS is computer drafting.

There are numerous computer drafting systems with varying degrees of sophistication available in the civilian marketplace.

Since approximately 95 percent of all contract drawings are two-dimensional, non-isometric drawings, the less sophisticated computer drafting systems may be acceptable for use in the technical design section.

There is no specific system or certain number of work stations that can be recommended for a "typical" design section based on the number of personnel in the section. The size of the system, the number of work stations, and the types of peripheral devices would depend upon the workload for the design section, the number of personnel, and the number of hours that the system would be used.

CHAPTER V

ECONOMIC ANALYSIS

Introduction

This chapter attempts to determine if computer-aided design is cost effective for base level design and will focus on productivity gains that can be achieved in the three areas of CAD. The potential benefits of using the computer capability provided by WIMS for some phases of CAD (i.e. engineering analysis and contract document preparation) will also be discussed.

Increased productivity can be defined as the amount of time savings that can be obtained by accomplishing a task in a more efficient manner, in this case by using a computer. It can be further defined as a ratio of the task time required using manual methods divided by the task time required using computer methods. For example, if it takes a designer 10 hours to develop a preliminary design manually and five hours to develop the design using a computer, the productivity increase is

$$10 / 5 = 2 ,$$

or the designer can expect a 2:1 increase in productivity for this task by using a CAD system. (72)

The cost effectiveness of using a computer will be determined based upon manhour savings.

Based on telephone interviews with design chiefs from various bases (2; 3; 12; 17; 19; 34; 54; 59; 61), a Corps of Engineers study (20), an Air Force CESMET study and a previous thesis effort (32:60), the base designer spends the following approximate percentages of his time on various areas of design:

Drawing development - 22.5%
Specification development - 13.5%
Engineering analysis - 7% .

These percentages will be used in the economic analysis for computing manhours savings.

Drawing Production

Some of the primary benefits of a computer-aided drafting system to the design engineer or architect is in developing preliminary drawings that provide a common database to all members of the design team (14:35), obtaining rapid completion of contract drawings from the draftsman (72), and being able to quickly check for interference between building subsystems (23:25).

The first two benefits can be quantified by documented productivity increases that have been achieved by users of CAD systems. The benefits of interference checking are not directly quantifiable, but the reduction in design conflicts can help reduce expensive contract change orders (23:25). Each "layer", or drawing, can be electronically superimposed on any other layer (or layers) and visually checked for interference between subsystems (51:45). A

study by the Navy (23:25) indicated that savings of 5 to 10 percent in construction costs can be obtained by using a computer-aided design system for interference checking to eliminate design conflicts and subsequent change orders to contracts.

An Air Force CESMET study found that base designers spend an average of 45 percent of their time on design work (32:60), of which approximately half of this time is spent on drawing development (see Table 4.1).

It has been reported that designers have been able to achieve approximately a 2:1 productivity increase for developing sketches and preliminary drawings on CAD systems (74:4-1). Since approximately 22.5 (45% x 50%) percent of the designer's time is spent on drawing development, considerable design manhours may be saved by using a CAD system for drawing development.

Using the Air Force manpower standard of 1742 productive manhours per year per employee, the total savings in design manhours for developing preliminary drawings that can be achieved for each designer using a CAD system is as follows:

$$TS = 1742 \text{ hrs/yr} \times TD \times PFE \quad (4.1)$$

where

TS = Total designer manhour savings for preliminary drawings

TD = Percent of designer's time spent on drawing development

PFE= Productivity factor for preliminary drawing development
(Equal to one minus the inverse of the productivity increase)

$$\begin{aligned} TS &= 1742 \text{ hrs/yr} \times 22.5\% \times (1 - 1/2) \\ &= 196 \text{ hours/year/designer.} \end{aligned}$$

This amounts to the equivalent of almost six additional work weeks per year for each designer using a computer drafting system.

Additionally, with a productivity increase of 2:1 for developing preliminary drawings, any portion of the hours that are saved that are used for further drawing development will provide twice the product in the same amount of time when compared to manual techniques of drawing development.

Similarly, savings in drafters manhours can also be computed for CAD versus manual drafting.

About 85 percent of a draftsman's time is used directly for drawing production and can therefore be directly converted to time on a computer drafting system (23:18).

Draftsmen have been able to achieve an overall productivity increase for all types of drawings of approximately 3:1 to 4:1 (23:15; 39:140; 56; 57; 72; 74:4-2). An average of 3.5:1 productivity increase will be used for this analysis.

Using the same manpower standard as before, the total number of drafting manhours that can be saved for each draftsman using a computer drafting system is as follows:

$$DS = 1742 \text{ hrs/yr} \times DT \times PFD \quad (4.2)$$

where

DS = Total drafter manhour savings for drawing production

DT = Percent of drafter's time spent on drawing production

PFD= Productivity factor for drawing production
(Equal to one minus the inverse of the productivity increase)

or,

$$\begin{aligned} DS &= 1742 \text{ hrs/yr} \times 85\% \times (1 - 1/3.5) \\ &= 1058 \text{ hours/year/draftsman.} \end{aligned}$$

These savings are the equivalent of over 31 additional work weeks per year for each draftsman.

Additionally, if all of these saved manhours are used for further drawing production on the computer drafting system, an amount of work equal to approximately 3700 (1058 x 3.5) manual drafting hours can be accomplished by each draftsman with no additional manhours expended.

That is, an additional 2.125 manyears worth of work can be accomplished each year by each draftsman using a computer drafting system.

There are benefits other than productivity increases that result from using a computer drafting system. Better quality drawings, standardized details between projects, shorter project span times, reusable databases, visual interference checking, error reduction, and a common database that can be shared by all members of the design team are a few of the intangible benefits arising from using a computer drafting system to assist in project

development (9:18; 11; 14:35; 33; 68:2.3).

Also, there are certain disadvantages inherent in implementing a computer drafting system. The initial cost of the system (including facility modification costs, if necessary), maintenance costs, updating software, production during downtime, and changes in managerial procedures are a few disadvantages (37:39; 68:2.4). The initial inefficiency of using a computer drafting system may also be considerable since full mastery of a computer drafting system generally takes from three to six months (1:2; 9:18; 44:102; 51:41). The amount of time necessary to digitize existing drawings into the computer database can be tremendous (68:3.18) and may be one of the biggest drawbacks of implementing a computer drafting system into the technical design section.

When developing the justification for a computer drafting system, all advantages and disadvantages must be considered. Use total net benefits to justify a computer drafting system; that is, net benefits = cost benefits (manhour savings) + intangible benefits - true computer costs (22:63).

Engineering Analysis

In all of the information that was reviewed, productivity increases for engineering analyses using computers was based on new facility construction and is not directly applicable to most projects developed at base level.

The base designer does not accomplish many large new facility designs. Instead, renovation and maintenance and repair projects for existing facilities make up the bulk of the projects produced in the technical design section (2; 12; 17; 19; 59).

Highly computational analysis for any type project would be greatly enhanced by using a computer to assist with the "number crunching" (57). If required, the computing capacity to perform computer analysis will be available on the Work Information Management System (66), although the base designer would have to develop or obtain the programs necessary to perform the analysis.

The benefits of an increased quality of design and the ability to analyze several different design options in a short period of time, although not directly quantifiable, may be the greatest benefits to the base designer using a computer for engineering analysis.

Contract Document Preparation

Productivity for all areas of text preparation within a Base Civil Engineering organization can be improved with the word processing capability that will be available on WIMS (66).

The base designer spends a large amount of his time (about 30 percent of his design time) on specification development (32:60).

In a Corps of Engineers study, automated specification software on the computer increased the designer's productivity by 2:1 when compared with the present "cut-and-paste" method of specification preparation (20).

Again, using the Air Force manpower standard, the total number of specification preparation manhours that can be saved by each designer using an automated specification system can be computed as follows:

$$SS = 1742 \text{ hrs/yr} \times \text{ATD} \times \text{ST} \times \text{PFS} \quad (4.3)$$

where

SS = Total designer manhour savings for specifications

ATD= Percent of designer's time spent on design

ST = Percent of design time developing specifications

PFS= Productivity factor for specification development
(Equal to one minus the inverse of the productivity increase)

or,

$$\begin{aligned} SS &= 1742 \text{ hrs/yr} \times 45\% \times 30\% \times (1 - 1/2) \\ &= 118 \text{ hours/year/specification writer.} \end{aligned}$$

These savings are equivalent to over three work weeks per year for each specification writer.

If the approximately 118 hours that are saved are used to produce more project specifications on an automated specification system, an amount of work equivalent to almost 236 (118 x 2) manual specification preparation manhours can be accomplished without increasing the number of working hours for the designer.

If automated specification software is used on the WIMS computer, it should also be able to increase the typing productivity of the clerk/typist by at least 2:1 when compared to manual typing of specifications (20; 32:63). The preparation of all other contract documents and office text can also be improved by using the word processor on the WIMS computer (66). Productivity increases of up to 8:1 for computer versus manual preparation of text have been obtained by some design firms (33).

Summary

A substantial number of manhours can be saved by the base design section personnel by using computers to assist in the development and production of contract drawings and specifications. Additional manhours can be saved by using the computer to perform complex engineering analyses, when required.

Since there are no two designers, draftsmen, engineers, or architects who approach a problem in exactly the same way (5; 24; 51:43; 53; 73), and since no two designs take the same amount of time (12; 17; 34; 59), the increased number of designs and the savings resulting from fewer AE contracts cannot be directly computed. The Base Civil Engineer and the chief of the design section would have to estimate the increased design load that could be accomplished by the in-house personnel based upon projected manhour savings and additional equivalent manhours made

possible by using computer-aided design.

The capacity for word processing and engineering analyses will be available to all designers upon complete implementation of WIMS. The decision to acquire automated specification software can be based on the manhour savings identified in equation 4.3 and productivity increases for the clerk/typist.

The justification for obtaining a computer drafting system can be based on the manhour savings computed with equations 4.1 and 4.2 and the additional equivalent manhours that result by full utilization of the computer drafting system. For example, a draftsman using a computer drafting system can perform the equivalent of 350 manual drafting hours in just 100 hours on the computer.

In a 1982 feasibility study completed by Headquarters, Air Training Command, it was estimated that 40 percent of the AE contract expenses for design work (\$1,573,000 for FY 82) for the San Antonio Real Property Maintenance Activity (SARPMMA) could be eliminated by increasing the productivity of the design section by obtaining a five work station computer drafting system (64; 77:Section 9B; 78:Appendix B).

Each base should estimate the number of additional designs, and thus the decrease in AE design work, that can be accomplished with the availability of a computer drafting system. If a base has a significant backlog of design work or a large number of AE design contracts each year, a

computer drafting system would possibly be justified. However, if all design work is currently being accomplished in-house, a computer drafting system may not be economically feasible without a decrease in personnel.

Additionally, the intangible benefits, such as the increased quality of contract drawings and a reusable database for future projects should be considered when investigating the acquisition of a computer drafting system.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATION

Introduction

This research effort was concentrated on answering four reseaech questions in an attempt to determine if computer-aided design can significantly improve the productivity of the base level technical design section personnel.

Summary of the Research

Computer-aided design was defined in this research as the use of computers to develop any portion of a project package, including drawing production, engineering analysis, and contract document preparation.

All of these design section procedures necessary to provide complete project designs can be improved by using computers in the design process.

Civilian firms are using a wide range of hardware and software, produced by numerous manufacturers, to perform engineering analysis, develop project drawings, and prepare contract documents. The most prevalent use of computers, particularly microcomputers, by engineers is for engineering analyses while architects main computer use is with dedicated word processors for preparing written text.

Because of the high initial costs, computer drafting systems are used by only a small percentage of civilian AE firms, although the number of AE firms obtaining computer drafting systems is expected to increase significantly in the next few years as lower cost systems are introduced into the marketplace.

There is not a specific "size" computer needed for any particular portion of computer-aided design. The minimum requirements of the computer depends on the complexity of the task and the sophistication of the hardware and software.

The computer that will be available to the base design section via the Work Information Management System will provide full capability for contract document preparation and the capacity to program the types of engineering analyses typically accomplished at base level. However, computer drafting will not be available through the WIMS computer system.

Since almost all contract drawings produced at base level are two-dimensional, the less sophisticated, less costly, computer drafting systems would appear to be acceptable for use in the technical design section. It is assumed by the author that these two-dimensional systems will provide productivity increases similar to those that have been achieved on more sophisticated systems.

Regardless of the productivity gains of a particular type computer drafting system, it would take a considerable

number of manhours to transfer (digitize) all base drawings into a computer database.

The size of the system, the number of work stations, and the types of peripherals would depend on the workload for the design section, the number of personnel, and the number of hours the system would be in use each day.

Most firms using computer drafting systems employ them for multiple work shifts to gain the maximum benefits from the system. The design section should also use multiple shifts if a computer drafting system is implemented at the base.

A substantial number of manhours can be saved when computers are used in all phases of the design process.

A 2:1 productivity increase for the designer in the preparations of specifications is possible. Additionally, productivity increases of up to 8:1 may be achieved by design section personnel for producing other contract text.

Complex engineering analyses can also be accomplished on the WIMS computer if adequate software is available. Computer analyses accomplished at base level should provide an increased quality of design.

A computer drafting system can provide a 2:1 productivity increase for the designer in developing preliminary project drawings and approximately a 3.5:1 productivity increase for the draftsman in producing completed contract drawings. These productivity increases equate to a significant number of saved manhours that

could be used to develop more designs.

Whether a particular computer drafting system is economically justifiable for a specific base depends on the design workload for the base.

This increased design production and the potential decrease in AE design contracts, along with the intangible benefits arising from using a computer drafting system, should be evaluated together to determine the net benefits of any computer drafting system to decide if it is justified for a specific base.

Based on the estimated manhour savings presented in the economic analysis in Chapter V, the author concludes that a two-dimensional computer drafting system is economically justifiable for any base with a substantial budget for AE design contracts or a large design backlog.

Conclusions

Automated specification software should be added to the procurement of the Work Information Management System and each base designer should have access to the WIMS computer for specification preparation and engineering analyses.

A test program should be immediately set up at a base, or several bases, to determine what actual benefits can be realized by using an interactive, two-dimensional computer drafting system.

Recommendation

Recommend research be conducted to determine to what extent computer programs are available in the Federal Government for use by the designer on the WIMS computer and how these programs can assist the designer in developing project designs.

GLOSSARY

Central processing unit (CPU): The main calculating section of a computer system.

Computer-aided design (CAD): The use of computers to help develop contract drawings, engineering analyses, and contract documents.

Computer remote terminal (CRT): An input and output piece of equipment, not at the immediate site of the computer, which permits additional input, queries for data, or output at a separate location.

Design Section (also called the Technical Design Section): The section within the base civil engineering (BCE) organization that is staffed with engineers and engineer technicians and that is responsible for developing plans and specifications for all real property facilities' projects at a particular base.

Design engineers: Engineers who are employed in the design section and who are responsible for the technical preparation of contract documents for facilities' projects.

Hardware: The physical parts of any computer system to include the central processing unit, computer remote terminals, printers, plotters, and all other mechanical, magnetic, electrical, or electronic devices of the computer system.

Interactive operation: On-line operation that provides a human-computer interface such that each entry elicits a response from the computer. It is called the "conversational mode" since the user can present a problem to the computer, get results, ask for variations of the results, get immediate answers, etc.

Mainframe: The central processing unit that is the heart of a large, general purpose computer system. It does not include the interface (computer remote terminals) or peripherals. The mainframe computer has extensive computing and data manipulation capabilities.

Main memory (also called active memory): The primary storage facility forming an integral physical part of the computer and directly controlled by the computer. All data in the main memory is automatically accessible by the computer.

Minicomputer: A computer with a large capability for manipulating data and performing arithmetical and logical operations on data. The minicomputer typically has a storage capacity greater than 128K words.

Microcomputer: A small, programmable general purpose business computer typically used for dedicated applications with storage capacity from 48K to 256K words of storage.

Personal computer: A small, inexpensive computer typically used for home or small business applications with storage capacity from 4K to 64K words of storage.

Peripheral equipment (also called peripherals): External (to the computer) devices performing a wide variety of input, output, and other tasks. On-line peripherals are connected electronically to the computer. Examples are printers, plotters, magnetic tape, etc.

Productivity increase: The savings achieved by accomplishing a task in a more efficient manner. For example, if it takes a draftsman 20 hours to complete a drawing manually and 10 hours to complete the same drawing using a CAD system, the productivity increase is 2:1 (derived by dividing 20 by 10) for that task.

Software: The non-physical components of a computer system. Software programs are stored sets of instructions which govern the operation of the computer system and make the hardware operate.

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