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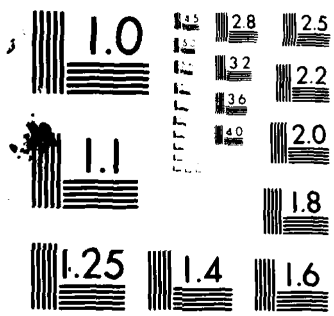

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Wright-Patterson Air Force Base, Ohio

AUTOMATED DRAFTING AND DESIGN
FOR THE BASE CIVIL ENGINEER

Mike V. Roberts, Captain, USAF

LSSR 88-81

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 88-81	2. GOVT ACCESSION NO. AD-A111 386	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AUTOMATED DRAFTING AND DESIGN FOR THE BASE CIVIL ENGINEER		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mike Roberts, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication and Humanities AFIT/LSH, WPAFB OH 45433		12. REPORT DATE September 1981 13. NUMBER OF PAGES 66
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

22 JAN 1982

Fredric C. Lynch

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs
Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE AFR 190-17.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Automated Drafting and Design
Interactive Graphics System

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Gary Nichols, Major, USAF

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

This thesis presents the results of a survey of twelve interactive graphics systems manufacturers and develops a simple model for economic decision analysis. The survey information includes costs of the systems, training times, and software available. From the survey information and extensive literature review, an analysis is developed to determine the feasibility of developing guidelines for each design office to determine whether it could justify automatic drafting. The model is based on: 1) the salaries of design engineers authorized in the design section, 2) the salaries of site developers authorized in the site development section, 3) the amount of time spent on design work and drafting, and 4) the cost of the interactive graphics system used to produce the designs and drawings.

LSSR 88-81

AUTOMATED DRAFTING AND DESIGN FOR THE BASE CIVIL ENGINEER

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

Mike Roberts, BA
Captain, USAF

September 1981

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This thesis, was written by

Captain Mike Roberts

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

DATE: 30 September 1981

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ACKNOWLEDGEMENTS

The author wishes to express his deep appreciation to his Thesis Chairman, Major Gary Nichols, of the School of Civil Engineering, who encouraged me along the way and provided excellent guidance. The author also wishes to express his gratitude to Major John Folkson for his aid and guidance.

The author wishes to express a special note of appreciation to Mr. Marc Waldbeck, of the Radio Shack Computer Center, for allowing me to use their daisy wheel printer to type the final draft of this thesis.

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CHAPTER I

INTRODUCTION

Statement of Purpose

The underlying theme in the mission of Air Force Civil Engineering is to provide maintenance, repair, and alteration of existing real property facilities. The Base Civil Engineering (BCE) organization is structured to provide the required work on real property facilities through the use of assigned military and civilian craftsmen and also through contracts with civilian construction firms (14:2).

The purposes of this thesis were to 1) investigate the preparation of construction drawings; engineering designs; airfield pavement drawings; and utility, contour, future construction, and Air Installation Compatibility Use Zone (AICUZ) maps by means of an automated drafting system, and 2) determine whether any benefits can be derived from adopting the use of automated drafting methods.

Background

The Present System

The majority of BCE design and drafting tasks are located in the site develpoment design sections. The base level site development sections are currently using manual methods for producing construction drawings, utility, future construction, contour and Air Installation Compatibility Use Zone maps, and airfield pavement drawings. The contour and Air Insatllation Compatibility Use Zone maps are especially time consuming because of the many points which have to be accurately plotted on the drawings. The base level design sections are also using manual methods for work such as heating, ventilating and air conditioning design, plumbing design, lighting and power plan design, structural engineering, and architectural design. The majority of this work is repetitve and time consuming. Most of the symbols used on drawings are standard throughout the industry and could be loaded into a computer for instant placement on a drawing.

The utility and future construction maps often entail erasing portions of existing drawings to make changes. The changes to utility maps consist of adding new or deleting removed utilities from the map. The future construction maps are constantly being up-dated to add proposed new construction, to delete disapproved new construction, or updating identified proposed construction to the status of an existing structure. These changes cause wear and tear on the drawing surface and also make it necessary to redraw parts of lines which should not have been erased to make the change. In addition valuable time is used to make the changes.

Many times contour maps are not drawn because of their time consuming nature to produce, especially for small projects. Other times the maps are not drawn as accurately as the data would allow because of time constraints of the project.

The construction drawings consist of many repetitve details such as: door and window heads and jambs, wall sections, roof flashings, drywall details, and many others which are too numerous to list here. These details and other drawings are currently redrawn for every new set of construction drawings. Some site development sections have been known to trace details from existing construction drawings in an attempt to save time.

The current manual method of producing the Air Force BCE drawings described above is tedious, repetitive, time consuming, and therefore, above all, expensive. Expensive because so much time is used redrawing or tracing details which are standard for the construction industry. Time is also used to post changes. Tedious because the contour and Air Installation Compatibility Use Maps maps must be done freehand or with french curves to draw lines through many data points to get an accurate map. These maps are also time consuming because of the way they have to be drawn by hand.

The Proposed System

An interactive graphics system would help to alleviate many of the problems involved with the manual system. It is capable of supporting both drafting and design.

Computer-aided design or interactive computer graphics connotes a close interaction between a human and the computer through the use of visual displays, keyboards, special computer languages, and other human-computer interfaces. The human is able to communicate with the computer and to receive a direct response from it. This two-way communication may be graphical or pictoral in nature. For example, the designer or draftsman may generate a picture on the cathode-ray-tube display by using a light pen. As a result of previous programming, the computer understands the picture, makes calculations based on it, and presents answers or a revised picture to the designer within a few seconds. The designer or draftsman can then accept the data or revise it further, as he wishes (12:1).

An interactive graphics system is capable of aiding in the production construction drawings, utility, future construction, contour, and Air Force Installation Compatibility Use Zone maps; and airfield pavement drawings. The system is also capable of aiding in the design of: 1) heating, ventilating, and air conditioning systems; 2) plumbing systems, 3) lighting and power systems, 4) structures, and 5) architectural designs.

Industry has been using interactive computer graphics for several years in numerous design applications such as: printed circuts, integrated circuits, layouts of department stores, structural engineering, architecture, lighting plans, plumbing, and airplanes. As computer hardware prices come down, more and more users with more and more applications appear, checkbooks in hand. For these users, graphic systems are more than toys: they are cost-effective tools for product design, process control, research, and a multitude of other tasks, old and new (13:72).

> "The cost-effectivness of such systems is well established; users expect productivity gains of 300 to 500 percent in design work. For example, General Electric Co.'s Aircraft Engine Group uses interactive graphics to link jet-engine design with manufacturing, cutting production lead time substantially [13:72]."

General Motors already has more than 1000 interactive graphic stations on its premises to assist in automotive design and engineering, and recent Ford Motor Company television commercials have shown interactive graphic stations in action (13:72).

Objectives

The objectives of the proposed research were to determine the feasibility of using an automated drafting system in base level site development sections, the feasibility of using the associated computer as a design aid for the engineers, and develop an economic analysis procedure for the major commands and bases to determine the economic feasiblity of adopting an automated drafting system.

Research Questions

More specifically the objective of this thesis is to answer the following research questions:

1. What hardware and software is available on the commercial market for both drafting and designing?
2. Would the automated system be easier and faster to use than a manual system?
3. How easy is it to train personnel?
4. What are the relevant costs involved in purchasing and maintaining or leasing the equipment?
5. Should each base have a system or could bases within a major command share a centralized system?
6. What is the life-cycle-cost of an automated system versus the present manual system.

Methodology

Data Collection Plan

A letter was sent to the companies listed in Table 1.1 requesting information on the availablity of equipment, costs of the system, length of time for training, etc (See Appendix A). In addition, an interview was conducted with a local vendor's representative and will be presented in Chapter II.

Collection of data on the amount of time devoted by site devlopment and engineering to drafting and design work, at every base, would take a considerable amount of time and is beyond the scope of this research. A methodology was developed to aid the BCE in collecting the required data and an economic analysis procedure was developed to aid in determining the life-cycle costs for the purchase of the automated drafting/design system.

Economic Analysis Procedure

An economic analysis has been developed for determining the life-cycle cost comparison of the present manual drafting/designing system versus the proposed automated drafting/designing system. A present worth economic analysis was used so the comparison could be made in todays dollars. The analysis procedure is based on: 1) the salaries of design engineers authorized in the design

Table 1.1
Manufacturers Contacted for Information

Applicon	32 Second Ave 01803	Burlington, Mass.
Auto-Trol	5650 N. Pecos no zipcode	Denver, Co.
Calma	707 Kifer Rd 90486	Sunnyville, Ca.
Computervision	201 Burlington Rd 01730	Bedford, Mass.
H. Dell Foster	PO Box 32581 78216	San Antonio, Tx.
Information Display Inc	150 Clearbrook Rd 10523	Elmsford, Ny.
M&S Computing (Intergraph)	PO Box 5183 35805	Huntsville, Al.
Synercom Tech	6300 Shillcroft 77036	Houston, Tx.
Wang Labs	One Industrial Ave 01851	Lowell, Mass.
Autographic (User)	1200 Milan 77001	Houston, Tx.
Computer Graphics	899 Logan no zipcode	Denver, Co.
Utility Data Corp	1111 Fannin no zipcode	Houston, Tx.

section, 2) the salaries of site developers authorized in the site development section, 3) the amount of time spent on design work and drafting, and 4) the cost of the interactive graphics system used to produce the design and drawings.

The basis of comparison was the manual preparation of design analyses and manual preparation of drawings. The procedure was based on the following assumptions:

1) All equipment may be leased or purchased. The cost of the lease would be spread over the its life. The purchase price was spread over the equipment's seven year life at an interest rate of ten percent to determine the annual cost.
2) Costs were compared on an annual basis.
3) Costs of paper and supplies were assumed to be the same whether the system is manual or automated and were ignored in the analysis.
4) The salaries were computed by grade of the design engineers and site developers for an average base.
5) The industry standard was used to compute the savings of manhours (See Chapter II).
6) The computer was located at the base, because of the number of workstations required.

Decision Criteria

The size of the system to be used will vary from base to base so the economic analysis was set up for general use. Some minor modifications may be necessary such as: 1) the addition of the cost of the facility to house the computer, 2) the actual manhour savings based on local data and, 3) the actual automated drafting system chosen.

In addition to the software available from the manufacturers, the Air Force has available thirty-seven computer programs for solving enginnering problems (See Appendix B). These programs could provide additional savings in manhours over the programs from the manufacturer. Some of these programs may be interfaced with the manufacturer's programs to provide for more efficient designs.

Tabulation of Survey Data

The data received from the responding manufacturers were used to establish a basis for recommendations which were made on the use of automated drafting systems for preparing drawings and design analyses. Tables were constructed to show the manufacturer's responses to the questions about system costs and system training.

Synopsis of Chapters

Chapter II presents the literature review and answers to the first five research questions. Chapter III presents the econmic analysis procedure and an example of the procedure. Chapter IV presents the conclusions and recommendations.

CHAPTER II

LITERATURE REVIEW

Introduction

The purpose of this chapter is to answer the first five of the six research questions, presented in Chapter I, and to provide other pertinent information through the review of books, reports, magazine articles, manufacturer's literature, and information gathered from interviews with company representatives. The research questions are: 1) What hardware and software is available on the commercial market for both drafting and designing?, 2) Would the automated system be easier and faster to use than a manual system?, 3) How easy is it to train personnel?, 4) What are the relevant costs involved in purchasing and maintaining or leasing the equipment?, 5) Should each base have a system or could bases within a major command share a centralized system?, 6) What is the life-cycle cost of an automated system versus the present manual system? The last research question will be answered in Chapter III. Some of the other considerations are: 1) the environmental requirements for the data processor and 2) the length of time required for setting up a data base. The environmental requirements will be discussed in conjunction with research

The literature search was limited to post-1978 due to the rapid technological advances in the computer industry.

The majority of the books available were pre-1978 editions and were out-of-date when compared with the current magazine articles and manufacturer's literature. For example, one book (11) was describing the great expense of a refresh raster-scan workstation due to the memory required to operate the screen. The price was $500,000. A similar type workstation is now available for $38,000 (2). The books are listed under related sources in the bibliography.

The reports available through the Defense Techinical Information Center were either out-of-date because of advances in technology or were about batch systems for cartography. This thesis is investigating the use of an interactive graphics system for drafting and design, which allows immediate input and manipulation of data by the engineer or draftsman. Therfore, these reports proved to be unusable for this research. The reports are listed under related sources in the bibliography.

The magazine articles proved to have the most useful and up-to-date information concerning interactive graphic systems aside from the information provided by the manufacturers. These articles tend to be less biased towards the time and cost savings of the interactive graphics system and will offset the bias of the manufacturer's literature. A summary of the magazine articles will be presnted followed by a summary of the information gathered from the manufacturers.

Review Results

Question Number 1

What hardware and software is available on the commercial market for both drafting and designing?

The hardware used for interactive graphics is basic to all of the companies contacted. The software is the biggest difference among vendors (8). The basic interacive graphics system is a turn-key system which comes with all of the hardware and software necessary for the user to turn the system on and use it (8). The typical system consists of a minicomputer, disk drive, tape drive, workstation, plotter, line printer, and an alphanumeric terminal (13). The workstation typically consists of two cathode-ray tubes, a keyboard, and a digitizer. The keyboard and digitizer are used to input and edit graphical data. The plotter is used to produce hardcopies of the graphical data once the data has been input and edited. The alpahnumeric terminal is used to input non-graphical data such as notes for the drawings. The engineer can write the notes, show the draftsman where they go on the drawing and then give them to a secretary. The draftsman puts a marker on the drawing for the location of the notes and the secretary uses the alphanumeric terminal to input the notes using the same mark the draftsman used on the drawings. When the drawing is produced the notes will be in their respective places on the drawing (2). The line printer is used for output of non-graphical data such as reports, bills of material, and cost estimates.

As stated above, the main difference among vendors is the software. Some vedors are set up strictly for cartography, e.g. Keuffel & Esser, while other vendors are set up for cartography, design, and drafting, e.g. Applicon.

The typical interactive graphics software package is designed for use on a specific minicomputer, allowing for rapid execution of the program. According to Mr. Graff (2), it took Intergraph Corporation several hundred manhours to convert their software package from a DEC PDP 11/70 operating system to a DEC VAX 11/750 operating system. Therefore, it would be difficult to use software from one vendor on another vendor's hardware, unless the hardware is the same.

There are software packages available which have some degree of hardware independence, but these are slow in execution and are not feasible for true interactive graphics (10).

Graphic systems do not always come with full-blown application software. Typical graphics software development facilities are hard to use, and typical application programs are difficult to debug (13:77). Turn-key systems are advisable for all but the most advanced end users (13:77). Interactive graphics system vendors have recognized this problem, and turn-key systems are readily available for many applications, eliminating the need for development of graphics software by the user (13:77). See Apendix C for an overview of the basic software package available from Intergraph. The vendors are usually willing to prepare customized software or modify existing software to meet the users specific needs.

"As in all data-processing systems, the key to success in interactive graphics is good software... [13:90] ." In many cases the vendor furnishes the software in all major catagories, leaving the user little more to do than turn the key and go (See Table 2.1). The user may be held responsible for software maintenance, unless he has a contract for maintenance with the system vendor or a third party.

The Air Force "owns" several software packages which, in many cases, can be interfaced with the software

Table 2.1
Software Packages Available From Applicon and Intergraph

Applicon	Intergraph
Wiring Diagrams	Drafting
Elementary Diagrams	Mapping
Electrical One Line Diagrams	Aerial Photograph Mapping
Electrical Physical Drawings	Civil Engineering Mapping
Piping and Instrumentation Diagrams	Utility Mapping
Piping Drawings	Electrical Design
Process Flow Diagrams	Engineering Design
General Arrangement Drawings	Electrical Wiring
Civil Engineering Drawings	Mechanical Drafting
Structural Drawings	Heating, Ventilating, and Air Conditioning
Architectural Drawings	Utility Substation Design
Bill of Material Generation	Electrical Schematics
Interconnect Take-offs	Electrical Distribution and Analysis
	Architectural Engineering
	Isometric Piping
	Plan Evaluation and Analysis
	Structural Design and Analysis
	Facility Planning
	Facility Management
	Facility Design
	Land Management
	Roadway Design
	Network Analysis

available from the vendors to aid the design process. See Appendix B for a listing of these programs.

The following examples give an idea of the applications for which interactive graphics may be used.

Civil Engineering. One structural engineering company uses interactive graphics for stress analysis and interactive design of beams, columns, and slabs. Load combinations can be analyzed by the computer and the deformations plotted. Another civil engineer is monitoring effluent from a sewage treatment plant into a local bay. The results of the measurements are plotted for further environment impact analysis (4).

Mechanical Engineering. One company uses an interactive graphics system to design the tooling for its highly specialized product line. Another company uses a digitizer on orthogonal drawings to produce a 3-D image for study by the engineer. The interactive system can be used to design and draw piping, and heating, ventelating, and air conditioning systems.

Electrical Engineering. The engineer can use the interactive graphics system to design lighting plans and electrical circuts. It can also be used to design sub-stations.

The hardware and software are available as turn-key packages and should be purchased as such. There would be too many problems involved with trying to program an individual software package specifically for the Air Force.

Question Number 2

Would the automated system be easier and faster to use than the manual system?

On the average, an interactive graphics system can provide a three hundred percent increase in productivity of an engineer or draftsman (2). The three hundred percent increase is conservative. Depending on the application, a time savings of ten- to fifteenfold is possible (2). For example, Edison Brothers expects the automated system to be able to do three hours of work in only one. This means a typical mechanical and electrical plan that now takes 120 to 150 hours to complete can be done in 40 to 50 hours once the automated drafting system is operating at full speed (1). The Jet Propulsion Laboratory uses interactive graphics support for microelectronic design. "This interactive capability has increased design productivity by a factor of 8:1, according to Gomez <3:141>." Yet another example, the cost effectiveness of computer aided design systems is well established; users expect productivity gains of three hundred to five hundred percent in design work (13:72).

The largest and fastest growing interactive graphics display application is computer aided drafting and design. A draftsman using such a system can produce from five to fifteen times the amount of work he could produce using traditional techniques (10). The updating of existing drawings shows greater productivity increases than those in which most of the drawings produced are originals.

As you can see, the three hundred percent increase in productivity is generally the lower end of the range with fifteen hundred percent being the upper end of the range. Therefore, it is reasonable to assume a three hundred percent increase in productivity for a cost analysis. However, since much of the work done on maps and existing drawings is revisions, productivity gains of five hundred or seven hundred percent may be reasonable. Each organization will need to decide which productivty figure or mix of figures they wish to use. Using the analysis from Chapter III, a three hundred percent gain in productivity from the use of an interactive graphics system, in effect, would cost $34,229 more than the present system, excluding the cost of the computer facility. Similarly, a five hundred percent increase would cost $10,876 more, and a seven hundred percent increase would cost $636 more.

Question Number 3

How easy is it to train personnel?

According to Mr. Graff (2), anyone who has a desire can be trained to use the interactive graphics system, whether he be a high school dropout or a college graduate.

The training period ranges from two-three days to four-six weeks depending on the vendor and the software. The typical training period for Kueffel & Esser is two to three days (9), whereas Intergraph has an average training period of one week per software package (2).

The initial training does not adequately cover all the nuances of the system, so time should be allowed for the user to become familiar with the system. Any organization which buys an interactive graphics system should understand it takes a six to nine month development and learning period on it before management should expect great improvements (1).

One thing to keep in mind when looking at an interactive graphics system for the Air Force is the movement of people. The initial training included with the purchase or lease of the system will only train those personnel at the base when the system is purchased. If each base or major command buys a different system, then personnel will have to be retrained each time they are reassigned. If there are a variety of systems in the field, it would create problems for the 2770th Technical Training

Group at Sheppard AFB, Texas, because they would have to know where the personnel will be assigned, so as to provide training for the system at that base. It would be best if one system could be bought Air Force wide. If it is not possible to confine the purchase to one system, the purchase should be confined to two or three systems to limit the need of retraining personnel.

Question Number 4

What are the relevant costs involved in purchasing and maintaining or leasing the equipment?

The relevant costs are: 1) hardware costs, 2) software costs, 3) training costs, and 4) cost of the environmentally controlled facility for housing the data processor.

The cost of a turn-key package, which includes all of the hardware and most of the software necessary to do interactive graphics, ranges from $150,000 to $800,000 (See Table 2.2). The cost depends on the number of workstations, software packages, plotters, disk drives, tape drives, line printers, and alphanumeric terminals desired.

The typical software package from Intergraph Corporation costs $5,000 for the initial purchase with a fifty percent discount on additional purchases of the same software package (2). The price is not for actual ownership of the software, but rather the liscense to use the software. The software costs of the other vendors is unkown as the vendors provided only turn-key costs.

Table 2.2
Interactive Graphics System Costs

Manufacturer	System Cost
Applicon	Did not provide cost data
Calma	$200,000 (single station) $750,000 (five station)
Computervision	$300,000 and up
Keuffle & Esser	$150,000
Intergraph	$180,000 and up

The initial training will be done by the manufacturer and is included in the purcase price of the system. So, the cost for the initial training will be the salaries of the personnel receiving the training, as explained in Chapter III. It is beyond the scope of this research to detrmine the cost for follow-on training of new personnel.

Perhaps one of the most important costs aside from the interative graphics system is the cost of the environmentally controlled facility to house the data processor. The cost of this facility will vary greatly from location to location, depending on the availability of existing facilities. The facility typically must meet the following requirements:

> "Adequate, reliable power must be supplied to drive the system. Air conditioning must be capable of keeping the CPU room below 70F, and the air intake to the disc drive below 65F. A virtually dust-free environment must be provided [8:27]."

The CPU is the Central Processing Unit consisting of the data processor, disc drives, and tape drives; it does not include the workstation, alphanumeric terminal, line printer, or plotter.

Since the cost of the environmentally controlled facility is highly variable it was not considered in the economic analysis example, but it must be considered by the individual organization doing an actual economic analysis.

Question Number 5

Should each base have a system or could bases within a major command share a centralized system?

This will depend upon the situation at each base. For example, Wright-Patterson AFB would probably require two, seven-workstation computers. Whereas some of the smaller bases might not be able to justify a complete interactive graphics system for their own use, but could justify a workstation and plotter along with the shared cost of the data processor. The central computer could serve bases in a major command or a geographical area.

Data Base Problem

The system is far from hassel-free. For one thing, development of the data base is an extremely long process. It took Hallmark Corporation five to six months to develop its input before the company began to use the computer (1). By the same token, it would take the Air Force several months to input all of the base maps.

Conclusions

As you can see, there are many things to keep in mind when considering the purchase of an interacive graphics system. The five research questions answered in this chapter are the major considerations, along with the sixth research question which will be answered in Chapter III through the development of an economic analysis procedure.

CHAPTER III

ECONOMIC ANALYSIS

Introduction

The purpose of this chapter is to present an economic analysis procedure developed for comparing the costs of the manual system versus an interactive graphics system, on an annual basis. Indirect costs factors are also presented for consideration. An analysis example is presented to show how it works.

There are at least seven benefits to the procurement of an interactive graphics system. The benefits are: 1) direct-cost benefits, 2) product quality, 3) shorter project-span times, 4) better interfacing of programs, 5) "the only approach", 6) 3-D design enhancement, and 7) manpower augmentation (CAD/CAM:48-56). The direct-cost benefits are of most importance to this thesis and will be presented first. The six indirect-cost benefits will be presented following the economic analysis example.

An economic analysis procedure was developed to aid the Base Civil Engineering (BCE) organizations in determining the life-cycle costs involved in the purchase of automated drafting/design equipment. The life-cycle cost method was chosen for three reasons: 1) the Air Force traditionally uses this method, 2) the costs are more easily compared to annual wages, and 3) it is difficult to determine the actual payback period. The analysis was set up for general use at all bases, but some factors will vary from base to base. Some of the variable factors are: 1) the number of engineers and site developers authorized, 2) the grades and salaries of engineers and site developers authorized, 3) the actual amount of time devoted to design and drafting, 4) the cost of providing facilities to insure a proper operating environment for the hardware, 5) the size and cost of the hardware, and 6) the cost of the software needed for each base.

An example of the economic analysis was done to show how the procedure works. The cost of providing facilities to house the data processor was not used in the example because the costs vary tremendously from organization to organization, e.g. the computer might fit in an existing computer facility, or the computer could be put into a facility modifed to house it, or the computer may have to be housed in a new facility. This must be considered when doing the actual analysis.

The costs used for the computer hardware and software, in this example, were provided by Intergraph

Corporation; these costs were determined to be representative of the industry. According to Mr. Graff (2), the average computer life is seven years, because the cost of maintaining the computer after seven years would typically be more than the computer is worth. Intergraph Corporation also provided the industry standard for the savings in manhours accomplished through the use of automated drafting/design procedures. The use of Intergraph information and costs was for example purposes only, and it is NOT the intention of this thesis to edorse any company.

Development of Equation Parameters

The percent of an engineer's time spent doing design analyses and the percent of a site developer's time spent drafting were, by necessity, estimated in order to demonstrate the procedure. The actual percentages should be determined by each BCE organization, using the following method:

Go to the Industrial Engineering Section and request a Base Engineer Automated Management System (BEAMS) product which provides the documented number of hours spent on design and drafting. The design time should not include specification preparation. If the product does not exist, request Industrial Engineering to set up a program on BEAMS which will provide the necessary information. The study should be accomplished during a period which would provide a representative sample. Another source for the data base would be HQ USAF Civil Engineering and Services Management Team, but this would be a generalized percentage for the entire Air Force.

The percentage used for the economic analysis example was based on the following:

> "Results of HQ USAF Civil Engineering and Services Management Evaluation Team visits to 19 bases in 1975, 1976, and 1977 reveal that an average of 45 percent of an engineer's time is spent doing actual project design 5:60 ."

The annualized cost of engineering design can be exprssed as a manual engineering system cost equation of the form

$$ME = E * TE * SE \tag{3.1}$$

where

ME = manual engineering system cost
E = number of engineers per grade
TE = percent of time spent on design
SE = salary per year per grade

Since the majority of the site developer's time is used for drafting, 80 percent was chosen as the amount of time they spend on drafting. Surveying, military duties, training, and extra duties make up the remaining 20 percent.

The annualized drafting cost can be expressed as a manual drafting system cost equation of the form

$$MD = D * TD * SD \qquad (3.2)$$

where

- MD = manual drafting system cost
- D = number of draftsmen per grade
- TD = percent of time spent on drafting
- SD = salary per year per grade

Equations 3.1 and 3.2 were used for each grade to determine the actual costs per year for design and drafting.

The capital recovery factor, (A/P, i%, N), is used to determine the amount of each future annuity payment required to accumulate a given present value. In other words this factor finds an annualized cost (A) using the present cost (P), an interest rate (i%), and a period of time (N). In the case of this example, it was used to annualize the cost of the interactive graphics system over its seven year life. The cost was annualized to permit a comparison with the annual salaries of the engineers and draftsmen.

The following equation was used to determine the annual costs of an automated drafting and design system for each Base Civil Engineering organization. The equations were based on a seven year life and ten percent interest. The uniform series capital recovery factor (A/P, 10, 7) was used for the analysis.

$$ADD = (TME * CTS) + (TMD * CTS) + TC + C + M + W + O + X \quad (3.3)$$

where

TME = total manual engineering costs
TMD = total manual drafting costs
CTS = computer time savings factor
TC = training costs * (A/P, i%, N)
C = computer cost * (A/P, i%, N)
M = maintenance costs or 10% of hardware costs per year (G)
W = workstation cost at the base * (A/P, i%, N)
O = annual operating costs ($1,200) (G)
X = cost of facility to house computer

See the example for a full explanation of the terms used above.

Economic Analysis Procedure Example

This example is presented to aid in the use of the economic analysis procedure.

The example was based on a seven workstation computer system for the base. The average number of twelve engineers per base was derived from the information listed in Table 3.1 of "Automated Specification Preparation for the Base Civil Engineer" (5:41-44). The number of engineers was based on three per mechanical section, three per electrical section, three per civil section, and three per architectural section. The example was based on the assumption of eight draftsmen in site development. Since the interactive graphics system allows a draftsman or engineer to do three times as much work (See Chapter II) as a draftsman or engineer using a manual system, the example will be based on the elimination of one-half of the engineers and two-thirds of the draftsmen. The manpower reduction is used only to show the full direct-cost benefits. Due to the ramifications of eliminating so many positions, each base will need to look at how it wants to handle the direct-cost benefits. It may not be possible to delete the miltary positions because of warskill needs. In addition, non-design/drafting workloads may fully justify the retention of all positions with the requisite changes in job descriptions.

The assumed grades of the engineers were as follows: 1) one GS-11 civilian, one second lieutenant, and one first lieutenant for the architectural and civil sections, and 2) one GS-11 civilian, one first lieutenant, and one captain for the electrical and mechanical sections. The site development section was assumed to have one airman basic, one airman, one airman first class, two sergeants, one staff sergeant and two GS-5 civilians. Refer to Tables 3.1, 3.2 and 3.3 for the salaries of these individuals.

Table 3.1
Salaries for Military Engineers

Grade	Yearly	Monthly
O-1	14,055	1,171
O-2	18,923	1,577
O-3	26,199	2,183
O-4	30,637	2,553

(15:94)

Table 3.2
Salaries for Military Draftsmen

Grade	Yearly	Monthly
E-1	7,498	625
E-2	8,333	694
E-3	9,154	763
E-4	10,944	912
E-5	12,680	1,057
E-6	15,123	1,260

(15:94)

Table 3.3
Salaries for Civilians

Grade	Yearly	Monthly
GS-5	14,816	1,235
GS-11	26,870	2,240

(15:45)

Computer System Costs

The following computer system costs, provided by Intergraph Corporation, were used in the example for the economic analysis procedure:

Data Processing System located at the base PDP 11/70 (8-12 workstation capability) with: floating point accelerator, mega byte main memory, file processor, smart disk controller, high speed concentrator	$100,000
Disk Drive (675 mega byte)	34,000
Tape Drive	17,000
Additional Software	50,000
TOTAL	$201,000

Base Level Workstation

Workstations (7) @ $38,000 each	$266,000
Plotter	35,000
Alphanumeric terminal	1,000
TOTAL-------------------------------------	$302,000

Maintenance Costs

Maintenance Costs generally equal ten percent of the hardware cost (2). Therefore, the maintenance cost of the data processing system is $15,100 per year, the maintenance cost of the workstations is $30,200 and the total maintenance costs are $45,300. The annualized costs of the sample system and its maintenance are displayed later in Table 3.7.

Annual Operating Costs

The annual operating costs of the computer are approximately $1,200 per year (2). This is the cost of the power required to run the computer.

Manual Engineering System Costs

The manual engineering system costs were computed using equation 3.1 and are presented in Table 3.4

Table 3.4
Manual Engineering System Costs

CAPT	ME = E * T * S = 2 * .45 * 26,199	= $23,580
GS-11	ME = 4 * .45 * 26,870	= $48,366
1LT	ME = 2 * .45 * 18,923	= $34,062
2LT	ME = 2 * .45 * 14,055	= $12,650
	TME = ----------------	$118,658

Manual Drafting System Costs

The manual drafting system costs were computed using equation 3.2 and are presented in Table 3.5

Table 3.5
Manual Drafting System Costs

A/B	MD = D * T * S = 1 * .80 * 7,498	= $ 5,999
AIRMAN	MD = 1 * .80 * 8,333	= $ 6,667
Alst	MD = 1 * .80 * 9,154	= $ 7,324
SGT	MD = 2 * .80 * 10,944	= $17,511
SSGT	MD = 1 * .80 * 12,680	= $10,144
GS-5	MD = 2 * .80 * 14,816	= $13,335
	TMD = -----------------	$60,980

Training Costs

Initial training costs were based on one week's salary per software package per grade of draftsman or engineer using the software package. One week was used because it is the typical training period for Intergraph software packages. The costs were computed for the personnel left after the elmination of positions. The costs were based on ten programs with the draftsmen being trained to use all of the programs and the engineers being trained to use five of the programs. The example training costs were computed using the following equation and are presented it Table 3.6.

TC = no. personnel/grade * weekly salary * no. programs (3.4)

Table 3.6
Training Costs

GS-11	TC = 2 * 517 * 5 = $ 5,170
CAPT.	TC = 1 * 504 * 5 = $ 2,020
1LT.	TC = 1 * 364 * 5 = $ 3,640
GS-5	TC = 2 * 285 * 10 = $ 5,700
SSGT	TC = 1 * 244 * 10 = $ 2,440
SGT	TC = 2 * 211 * 10 = $ 4,220
TOTAL =	------------ = $23,190

ANNUALIZED TRAINING COSTS = $23 190 * (A/P, 10, 7)
= $23,190 * .20541
= $ 4,764

Table 3.7
Annual Interactive Graphics System Cost

Computer Costs	
	C = computer cost * (A/P, 10, 7)
	C = $201,000 * .20541 = $41,288
Workstation Costs	
	W = workstation cost at the base * (A/P, 10, 7)
	W = $302,000 * .20541 = $62,034
Maintenance Costs	
	M = .10 * hardware costs = .10 * $453,000 = $45,300

Annual Automated Drafting/Design Costs

The automated drafting/design costs were computed using equation 3.3 and the computations just presented. The results are shown in Table 3.8.

Table 3.8
Annual Automated Drafting and Design Costs

For 300 % increase in productivity:

```
ADD = (118,658 * .33) + (60,980 * .33) + 4,764
    + 41,288 + 62,034 + 45,300 + 1,200 + X
    = $213,867 + X
```

Cost Comaprison

Using the analysis, a three hundred percent gain in productivity from the use of an interactive graphics system, in effect, would cost $34,299 more than the present system, excluding the cost of the of the computer facility. Similarly, a five hundred percent increase would cost $10,876 more, and a seven hundred percent increase would cost $636 more.

In this example, the cost of drawing and design preparation by the present manual system is $179,638 per year. The cost of the interactive graphics system is $213,876 or $34,229 more than the present system. This extra cost does not include the cost of the facility to house the computer. Therefore, based on this example, the interactive graphics system is not feasible based purely on direct-costs.

However, much of the major design work is let for contract, because the BCE does not have the work force to do both maintenance and repair work, and major design work. If the interactive graphics system were used, it would allow the present work force to do at least three times as much work and thereby be able to do some of the major design work in-house. This could realize a substantial savings over contracting the design work.

Since the interactive graphics system, in this example, is not feasible based on the direct-cost benefits alone, the indirect-cost benefits should be considered. It is preferable to establish feasibility using the direct cost benefits of increased productivity. However, it is recognized that such benefits, in themselves, may be insufficent for some organizations to justify acquisition of a system. As stated previously, the indirect cost benefits are: 1) product quality, 2) shorter project-span times, 3) better interfacing of programs, 4) "the only approach", 5) 3-D design enhancement, and 6) manpower augmentation.

Product Quality. Consider, for example, the structural design of a building. Through the use of interactive graphics design, it is possible to investigate more alternatives and to evaluate special cases which might cause problems. Potential dangers through the action and interactions of forces can be more thoroughly investigated and therefore provide a higher margin of safety (7:48).

Shorter Project-Span Times. It is apparent in any organization that time is money when everything else is equal. This can be manifested in such ways as lower interest payments on funds borrowed for a project and more efficient use of manpower through scheduling. The ability to respond to special problems is a justification factor which has obvious value but is difficult to quantify. There are many occasions when a rush project comes to the Base Civil Engineer. For example, year end funds become available for a project. If the project has not been designed, the project will not be built this year and may not receive funds for years to come. On other occasions, a new project with a high priority may come to the BCE to be designed and let for contracted immediately. If an interactive graphics system was used, it could allow these projects to be completed on time without much interference to the other projects being designed.

Better Interfacing of Programs. Improved interfacing of programs under computer control at a workstation greatly reduces the repeated manual handling of both input and output data. For example, the Air Force has a program available for design of piping. This program can be interfaced with a vendors graphics program, so that when the engineer has designed the piping system, the draftsman can call up the design on the workstation to aid with preparing the piping drawing. The interfacing of programs such as these would provide for higher productivity.

"The Only Approach". It is probably an overstatement to say many problems can be solved only through interactive graphics systems. However, the statement is basically true and the system readily lends itself to improved techniques. The system would allow for rapid comparisons of many structural designs, this would be too time consuming and costly to do it by a manual method. The system can be used to produce 3-D views of a building for studying its various relationships. However, the value of this potential is abstract and therefore difficult to quantify. To factor considerations of this kind into an interactive graphics economic analysis is a challange that only the most enlightened and boldest of managements will accept (7:52).

3-D Design Enhancement. 3-D design can be a boon to the architect. He would be able to do many designs in much less time than one would take using manual methods. 3-D design could be used to check clearances of structural elements, plumbing, lighting, fire sprinklers, and heating ducts. This check could prevent costly errors in the design process and prevent change orders during the construction process. The potential rewards for 3-D modeling are enormous. High productivty gains are possible. Certain design times will be reduced from weeks to hours (7:53).

Manpower Augmentation. "The effective increase in productivity without additional manpower is one of the most important bases of system justification [7:54] ." Most interactive graphics systems can increase productivity three-hundred to fifteen- hundred percent, depending on the application.

Summary

There are many factors to consider in the cost analysis of purchasing an interactive graphics system. This chapter has presented the major factors and an example of how these factors tie together. The next chapter presentsthe conclusions and recommendations for this thesis.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Introduction

From the outset of this study it has been the intent of the author to look at the major cosiderations of purchasing an interactive graphics system and their implications on the adoption of such a system by a Base Civil Engineering organization. The major considerations were: 1) the availability of hardware and software, 2) is the system easier and faster to use than the present system, 3) the impact of training on personnel, 4) relevant costs of the system, 5) where should the system be located, and 6) the life-cycle cost of the system. Chapter I presented the background and methodology for determining the implication of purchasing a system, Chapter II presented the results of the literature review and information gathered from the vendors, and presented the answers to the first five research questions and , Chapter III presented an economic analysis procedure for determining the life-cycle costs of an interactive graphics system.

The purpose of this chapter is to present the conclusions drawn from the findings in Chapters II and III, to present recommendations concerning the purchase of an interactive graphics system, and to make recommendations concerning training.

Conclusions

The best interactive graphics system for the BCE would appear be a turn-key system with all of the hardware and software in one package. The city of Austin had considered tying the graphics system in with existing hardware, but after extensive research came to the conclusion a turn-key package was the way to go (8). This would prevent any bugs from being introduced by the Air Force trying to do its own programming. It would also prevent "reinventing the wheel", since the programs have already been written by the vendors. Software is already avaiable for most common design and drafting problems. The established vendors can be expected to continue development of additional applications as user demand warrants.

An interactive graphics system is much faster than the manual drafting system. Depending on the application, productivity increases can be three hundred to fifteen hundred percent, with a three hundred to five hundred percent increase being the average. The biggest initial problem is setting up the data base for the maps and symbols, which can take several months; but once the data base has been created the interactive graphics system makes the job easier to do.

Persons with the educational background and currently employed and who have the desire, can be trained to use the interactive graphics system. The training period ranges from two days to six weeks depending on the system and software purchased, but this training does not cover all the nuances of the system. The organization should expect a six to nine month learning period before expecting a significant increases in productivity.

The relevant costs of the system are: 1) hardware costs, 2) software costs, 3) training costs, and 4) cost of the environmentally controlled facility for housing the data processor. The cost of a turn-key system ranges from $150,000 to $800,000 including software. The training costs and facility costs will vary from organization to organization and can be computed by following the guidlines in Chapter III.

The location of the system will depend on the situation at each base. Some bases may require more than one system while others may have to share the system through a centralized computer.

The life-cycle cost of the system will vary from organization to organization and the guidelines of Chapter

III are the recommended analysis procedures. The direct-cost savings may not be the total basis for purchase of the interactive graphics system, so the indriect benefits should be considered as well. Once the organization has examined the direct-costs savings and the indirect-cost benefits it can decide whether or not to purchase a system.

Recommendations

Each base should investigate the use of a turn-key interactive graphics system for drafting and design. A turn-key system should be the only one considered, because it is set up specifically for automated drafting and design. The software available from the vendors has been written and debugged by experts. If the Air Force tried to write its own programs, it would be "reinventing the wheel" at a tremendous cost in time and resources.

The potential for improved productivity is tremendous. The system would open up avenues for doing things not done now. For example, if a water valve breaks, the shop could go to site develpoment and have them call up the nomenclature of the valve on the computer. Then the shop people could go to supply and get the valve before going to the site to replace it.

If the Air Force purchases several systems, the training program for the interactive graphics system could become unwieldly. If there are a variety of systems in the field, it could create problems for the 2770th Technical Training Group at Sheppard AFB, Texas, because they would have to know where the personnel will be assigned, so as to provide training for the system at that base. It would be best if the purchase could be limited to one vendor, but this is probably impractical. The next best solution would be to investigate which vendors provide similar types of hardware and software and proper system requirements. Specifications would define a set of vendors as the sources for the interactive graphics system.

Recommend further research be done on how and where the training programs should take place and the ramifications of purchasing several interactive graphics systems on the training program at the 2770th Technical Training Group.

Recommend a test program be set up at a base or several bases to prove the feasibility of using an iteractive graphics system and document the actual savings the Air Force would receive.

GLOSSARY

Major Command: One of ten listed commanding headquarters has fiscal or technical control over one or more Air Force bases.

Design Section: A technically oriented working group within the Base Civil Engineering (BCE) organization responsible for the engineering management of and the preparation of plans and specifications for construction projects for all real property facilities under the control of a particular Air Force base.

Site Development Section: A technically oriented working group within the BCE responsible for the preparation of plans for construction projects and base maps.

Design Engineers: All personnel employed in positions designated as Engineer or Engineering Technician whose main duties and responsibilities include the development of plans and specifications for construction projects.

Site Developers: All personnel employed in positions designated as site developer whose main duties and responsibilities include the preparation of plans for construction projects and base maps.

Drawings: Includes all plans and maps listed under site developers.

Computer: The data processing system, disk drives, tape drives, and associated software.

Workstation: The graphics hardware used to input data from drawings or sketches.

Plotter: A beltbed plotter which provides line drawings on preprinted and cut-sheet drafting media (paper, mylar, and velum).

APPENDICES

APPENDIX A

LETTER REQUESTING INFORMATION ON INTERACTIVE GRAPHICS SYSTEMS

19 December 1980

Capt. Mike Roberts
7612 N. Swan Lake
Apt. 3-F
Dayton, OH 45424

Gentlemen:

I am a student at the Air Force Institute of Technology working towards a Master of Science in Engineering Management. This degree requires a thesis. I have chosen computer mapping of base utility plans as my thesis topic. The plans are currently ink on mylar or paper.

Any information you can send to me on the type of equipment you have, which would be capable of handling this type of processing, would be greatly appreciated. I need to know: 1) whether or not the system is self-contained, if it is not self-contained, what other equipment is needed, 2) how difficult it would be to train personnel to use the equipment, 3) how the data would be entered into the equipment, 4) how the data would be retrieved for a hard copy, 5) the cost of the equipment, and 6) whether or not a central computer could be used with time sharing terminals at other bases.

Mike Roberts
Captain, USAF

APPENDIX B

LIST OF COMPUTER PROGRAMS FOR SOLVING ENGINEERING PROBLEMS

DCS/ENGINEERING & SERVICES PROGRAM CATALOG (5:160-162)

Program	Description
HSCBI	This program performs calculations for cathodic protection systems using high silicon chrome bearing cast iron (HSCBI) anodes.
PIPLINE	This program uses the Williams-Hazen relation to calculate friction loss in a closed conduit.
ACFTLIMS	Compares maximum weights of civilian and military aircraft with the airfield evaluation report and lists by feature those aircraft the feature will not support.
SEWER	Sizes and sets slopes for gravity sewers, or calculates capacities of existing systems.
OPENCF	Computes flow of water in open ditches.
KVA-EVAL	Computes KVA to verify electric bill.
CONVRT	Converts measurements between scales, e.g. feet to meters.
PAVE-EST	Estimates tons of material and cost to pave a road or parking lot.
LIGHT	Determines the number of fixtuers required for a specified lighting level.
BUSSSHOR	Determines fault current for interior electrical systems.
SHORTCIR	Power system analysis; computes fault currents and bus voltages.
SZSYSPSY	Psychronometric properties of conditioned air -- single zone.
MZSYSPSY	Same as above except for multi-zone air conditioning systems.
SECAP	Determines capacities of wf and i steel beam sections.
MANDSD	Calculates mean, variance, and standard deviation.
HYDRAULC	Hydraulic network analysis; hardy cross method; flow and head loss.

COLUMN	Design of beam-column; ultimate-strength interactive equations.
CIRCLE	Divides a circle into n equal parts; calculates horizontal and vertical coordinates.
CPM	Construction management/project management; critical path technique.
PLOTTO	Simultaneously plots from one to six mathematical functions.
STRESS	Structural engineering system solver; for indeterminant structures.
FLEXPAV	Airfield pavement load capacity evaluation -- flexibile pavements.
RIGIDPAV	Same as above but for rigid airfield pavements.
SPHERE	Solves any spherical triangle.
DSGN-SCH	Engineering Design Schedule--- Compares design workload to manpower availability and computes project start date and project completion date.
SERVCALL	Sorts, selects, and summarizes service call data for analysis.
ABACUS	Equivalent to a high powred desk calculator.
Editor	Information retrieval, text editing, etc.
TRAVANAL	Traverse analysis/data reduction for surveys and layouts.
SLOPSTAB	Slope stability analysis; constructed or natural slopes.
CONTGRID	Continuous girder analysis reactions, shears, and bending moments.
COMPBEAM	Concrete-steel composite beam analysis; computes size and stress.
RENTWALL	Retaining wall design and analysis; cantilever and gravity types.
ERTWORK	Earthwork; preliminary design, and cut and fill quantities.

HORZGEOM	Horizontal geometry; curves, line intersections, subdivisions.
LGHTECON	Determines the most economical lighting system.
VEHICLES	Vehicle use analysis-- This program provides a capability for summarizing/analyzing a large amount of vehicle use data.

APPENDIX C

GRAPHICS SUMMARY OF BASIC SOFTWARE
INCLUDED WITH INTERGRAPHS
INTERACTIVE GRAPHICS SYSTEM

This graphics summary was taken from Intergraph's <u>Organization and Product Overview</u> (6:15-17).

* Custom tailored tutorial dialogue for non-data processing users.

* Security mechanism to prevent unauthorized access or misuse.

* Two display screens for unequaled flexibility in display presentation and data entry.

* Sixty-three Drawing Layers

* Multiple views
  - up to three active background reference files
  - independent layer control for a total of 252 layers
  - up to four views on each screen
  - independent or syncronized control of views.

* User definable units of measurement
  - four billion addressable points for X, Y, and Z coordinates
  - all measurements accepted and presented in user selected units
  - english, metric, feet, inches, meters, miles, etc.
  - automatic conversion between english and metric units

* Nine element classifications
  - primary, construction, pattern, dimension, solid, hole, planar, view relative, snappable

* Eight element styles (hardware)
  - solid, dot, dash, etc.

* Thirty-two displayable line weights

* Many geometric element supported
  - text, line, rectangle, polygon, circle, arc, ellipse, spline curve, spiral, etc.
  - 2D and 3D element definitions
  - closed elements may have positive or negative area

* Geometric element construction
  - by digitizing
  - by drawing on the display screen
  - by geometric relationship

* Element manipulation
  - copy, move, scale, delete, rotate, mirror, partial

delete, drop, modify
-all operation valid for all elements

* Groups of elements
  - -Cells
    - saved, recalled by name
    - maintained in cell libraries
    - recalled via cell menus
    - unlimited complexity
    - expanded within drawing for tailoring and archiving
  - -Symbols
    - saved, recalled by text font
    - maintained in font libraries
    - recalled via symbol menu
    - limited complexity
    - representation globally changed by switching fonts at display or plot time
  - -Graphic groups
    - non-named groups
    - local to a drawing
    - unlimited complexity

* Patterning
  - -linear patterning (fixed and scaled)
  - -area patterning (complex precision figures)

* Automatic dimensioning

* Text operations
  - -125 text fonts
  - -scale, delete, place, edit, bulk load, unit conversion
  - -enter data fields
  - -text nodes
  - -automatic justification

* Operator feedback

* User commands
  - -macro commands
  - -graphic dialogue
  - -program interface

* Interactive measurements
  - -locate
  - -delta distance
  - -angle between lines
  - -distance along element
  - -perpendicular distance
  - -area
  - -perimeter
  - -maximum distance between elements

* Precision input
  - snap, axis, unit, grid, and level locks

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