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ABSTRACT

This guide is one of three developed to provide information and resources to assist in planning and developing postsecondary technican training programs in high technology areas. It is specifically intended for vocational-technical educators and planners in the initial stages of planning a specialized training option in computer-aided design (CAD) and/or computer-aided manufacturing (CAM). (Two companion guides offer generalizable procedures for program development in high technology and curricular information for planning a robotics training program.) The first part reviews the problem, objectives, methods, and outcomes of the project. Information is presented in the second part on industry trends, CAD curricular requirements, and training implications of CAD technology. Emphasis is given to a listing of CAD drafting competencies and a detailed course outline of teaching topics that is oriented toward mechanical and product applications. Part 3 overviews CAM. The general and specific skill requirements of CAM users are addressed, and training guidelines are offered. A basic curriculum for CAM instruction is presented. Current and long-range market trends for CAM are described. Appendixes include an overview of CAD from the user's perspective, training considerations for users of CAD systems, and a survey of Applicon CAD system users. (YLB)

Research & Development Series No. 234

PREPARING FOR HIGH TECHNOLOGY:

CAD/CAM PROGRAMS

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FOREWORD

The graphics capabilities associated with computers have proven to be effective tools for business information management and for presentation of educational materials, to name just two powerful applications. Computer graphics capabilities are also being used as a design tool by an increasing number of manufacturing and service industries. This high technology is termed computer-aided design (CAD).

Computer-aided manufacturing (CAM) uses computers to control various operations of manufacturing machines and machine tools. When these operations are integrated with CAD through a common computer data base and electronic linkages, the design and manufacturing system is called CAD/CAM.

There are only a few fully integrated CAD/CAM systems operating in U.S. industry, to date, largely due to the complex and time-consuming aspects of such mergers. However, the essential elements of these two technologies are already in place in many firms. Even so, changes from traditional drafting and design as well as manufacturing operations to advanced CAD and CAM systems are creating a need for technicians in these specialties. In an effort to provide relevant information to postsecondary education planners, administrators, and instructors of these needed training programs, the National Center for Research in Vocational Education staff has prepared this guide as part of the National Center's continuing research and development work in the area of high-technology training.

The National Center wishes to thank Jack Thompson of Macomb County Community College, Warren, Michigan, for the major contribution of CAD resource material. His course outline and introductory comments comprise the second part of this document.

Part 3, "CAM Guidelines and Specifications," was prepared by Bob Hofmann, Program Manager, Manufacturing Products, General Electric CAE International, Inc. Mr. Hofmann's overview of CAM technology and his perceptions on training requirements for CAM technicians were an important contribution to this work. Our thanks are also extended to Jane Frederick, Manager, Engineering Systems, Mead Digital Systems, Dayton, Ohio; Curt Marshall, CAD Technician, Monsanto Research Corporation, Miamisburg, Ohio; and Russell Moubray, Instructor, Computer-aided Design Program, Sinclair Community College, Dayton, Ohio, for their participation in the DACUM (Developing **A** Curricul**UM**) process to identify entry-level CAD drafting tasks and competencies.

Appreciation is also expressed to Jane Frederick, Mead Digital Systems, and to Michael Crowe, National Center for Research in Vocational Education, for their review of the first draft of the paper. Appreciation is also extended to Russell Jordan, Executive Assistant to the President, Columbus Technical Institute, Columbus, Ohio, for his critical review of the final draft of the paper. Their suggestions were very helpful in improving the final product.

The project was conducted by William Ashley and Robert Abram. Dr. Ashley's background is in industrial technology and in instruction and training development. Mr. Abram has a background in industrial work experience, human factors, and vocational education. Regenia Castle and Carolyn Goodrich provided typing assistance and Beverly Haynes provided word processing for the preliminary and final drafts of this paper. The editors were Catherine C. King-Fitch, Janet Kiplinger, and Connie Faddis of the National Center's Field Services staff.

Robert E. Taylor
Executive Director
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EXECUTIVE SUMMARY

The development of high-technology programs has become a major concern for postsecondary colleges across the country. These institutions expend considerable time and energy obtaining information about emerging technologies. In addition to the scarcity of labor market and economic impact data for some high technologies, there exist considerable limitations on the availability of curricular information and the number of experts and/or experienced workers knowledgeable about new technologies. Hence the primary objective of this guide was to present a collection and compilation of information that could be used to reduce the planning and development burden on postsecondary colleges in terms of the time required to obtain pertinent information about the competencies, courses, and program options for training in computer-aided design (CAD) and in computer-aided manufacturing (CAM). The guide focuses on a set of guidelines and specifications that can be used in the development of CAD and CAM programs.

The methods used for preparing this paper on CAD and CAM guidelines included a review of various published and unpublished accounts of public and private CAD and CAM training programs, user and vendor promotional material and training guides, and published articles on CAD and CAM technology. In addition, site visits were made to companies that use both CAD and CAM systems and to postsecondary institutions that have developed training programs for CAD and CAM technologies.

Five critical observations were synthesized from the review of information and from discussions with users and educators:

- CAD users are currently engaged in in-house training of drafters and designers by means of mostly informal, "one-on-one" instruction with vendor-trained staff.
- Fully operational CAD and CAM technology exists in very few manufacturing facilities, and the need for individuals trained as CAD/CAM technicians is currently unclear but probably within the scope of a two-year postsecondary program.
- Program/course planners of postsecondary CAD curricula view CAD training as supplementary rather than substituting for drafting/design training using traditional tools.
- Standardization of software among CAD turnkey systems remains a problem although the Initial Graphics Exchange Standard is becoming increasingly accepted by vendors.
- CAD and CAM technicians will use similar skills and knowledge to input and access information from a computer data base and to communicate about product specifications.

Part 2 presents information on industry trends, curricular requirements, and training implications of CAD technology. Emphasis is given to a listing of CAD drafting competencies developed by a panel of users and educators, and a detailed course outline of teaching topics. The course outline is oriented toward mechanical and product applications.

Part 3 includes an overview of CAM, defines the four basic subdivisions of this industry, and presents discussions of the roots of CAM technology and its current status in manufacturing. The general and specific skill requirements of CAM users are addressed and training guidelines are offered. Discussions in this part, additionally, focus on sources of training, equipment, and facilities needed, and present a basic curriculum for CAM instructors. Three major industry classifications that share a high interest in CAM technology are identified. Characteristics of each industry type are provided in subsequent discussions. The final section of part 3 describes current and long-range market trends for CAM, includes a table depicting the current CAM market distribution by regions of the U.S., and discusses general trends in manufacturing technology.

Additional information in the guide is contained in five appendices. Appendix A is a listing of project site visits, including postsecondary institutions, robot manufacturers/users, and CAD and CAM users. Appendix B contains a listing of CAD/CAM system manufacturers, including, where possible, the name of each company's chief executive officer. Appendix C is a reprint of an overview of CAD from the user's perspective and discusses in detail its major payoffs and benefits. The reprint in appendix D presents training considerations for users of CAD systems, such as the quantity and intensity of the training required, as well as an effective training program for mechanical engineering applications. Appendix E is a reprint of a survey of Applicon CAD system users and contains an analysis of salary data and job classifications, including principal duties, responsibilities, and qualifications.

PART 1

BACKGROUND

Introduction

This is one of three guides developed to provide postsecondary vocational-technical educators and planners with information and resources to assist in planning and developing technician training programs in high-technology areas. This guide is intended to aid educators and planners who are in the initial stages of planning a specialized training option in computer-aided design (CAD) and/or computer-aided manufacturing (CAM).* A companion guide, Preparing for High Technology: Robotics Programs, offers curricular information for planning a robotics training program. The third guide, Preparing for High Technology: 30 Steps to Implementation, offers a detailed set of procedures for executing rapid program development in general high-technology areas.

Previous research conducted by the National Center** showed that postsecondary institutions expend considerable time and energy obtaining information about emerging technologies. Additionally, their efforts to become informed are constrained by the limited number of experts and/or experienced workers knowledgeable about new technologies who can be approached for advice and information. These and other restrictions often extend the planning and development time required to institute a new training program in a rapidly emerging technology. Hence, the primary objective of the project and this paper was to collect and compile information that could reduce the planning and development burden on postsecondary institutions in terms of the time required to obtain pertinent information about the competencies, courses, and program options for training in CAD and CAM programs.

This guide is divided into three parts. The first part reviews the problem, objectives, methodology and outcomes of the project. The second part presents information on industry trends, curricular requirements, and training implications of CAD technology. The third part contains an overview of CAM technology with an emphasis on training requirements for CAM technicians. Information and materials assembled here come from a number of sources, including several colleges that have been involved in training CAD drafters and CAM technicians, and leading manufacturers and users of CAD and CAM systems.

*When the project began, staff erroneously assumed that the technologies of CAD and CAM were commonly integrated in those firms that had adopted one or the other technology. As project work progressed, staff discovered that this is not generally the case and, in fact, that integrated CAD/CAM systems are thus far rare. This is largely due to the complex and time-consuming aspects of such mergers. However, the essential elements of the two technologies are in place in many firms. This paper therefore does not treat CAD and CAM as integrated technologies, for the most part; rather, information is provided for the development of training programs in each of the two areas, with comments about integration and crossover where appropriate.

**See Abram, Robert E.; Ashley, William L.; Faddis, Constance; and Wiant, Allen. *Preparing for High Technology: Programs That Work*. Columbus, OH: The National Center for Research in Vocational Education, 1982.

The Problem

The past several years have seen this country engaged in a struggle to increase its lagging productivity and maintain a competitive edge in world manufacturing markets. The development and use of high-technology equipment and processes are viewed by many as a means of bolstering productivity and, it is hoped, improving the quality of goods produced as well

Computer graphics is a prime example of a technological innovation that is already having a significant positive impact on the design and manufacture of industrial and consumer goods. It also has had a profound impact on the entertainment industry. Anyone who has seen a *Star Wars* movie or played any of the numerous video games now available has experienced the effects of computer graphics.

Paralleling the general public's current enjoyment of computer graphics as entertainment has been a rapidly expanding application of computer graphics as a design tool by business and industry. Termed computer-aided design (CAD), this application of computer graphics was previously available to only the large aerospace and automotive companies and government labs. Nearly fifteen years ago, only 200 work stations were operating at all these organizations put together. Then, beginning in the 1980s, the number of users began to climb and is now estimated to be more than twenty-five thousand. The rapid increase in the number of CAD users may be accounted for, in large part, by the declining costs of hardware and software and by the relatively recent development of turnkey systems by CAD equipment manufacturers. Such systems are marketed to include powerful software packages with the hardware components. Thus, more companies are integrating CAD technology into their product design and development operations.

Computer-aided manufacturing (CAM) preceeded CAD by about twenty years and currently is widely used in industry. The full integration of CAD with CAM through a common data base is still an emerging technology, but one that has powerful implications for improving manufacturing productivity.

As has happened with other technological innovations, the marketplace of potential CAD/CAM users is not well prepared to integrate such innovations into ongoing production systems. In the case of computer-aided design, the availability of a trained work force to interact productively with CAD systems has lagged behind the development of hardware and software. Training programs to prepare skilled CAD and CAM technicians for jobs in business and industry have only recently begun to appear in postsecondary colleges.

As two-year postsecondary colleges attempt to respond to the need for technicians, they may encounter a number of significant problems. The rapid pace of technological change is a most significant condition, as is exemplified by the fast-spreading adoption of complex, computer-directed technologies such as robots and computer-assisted engineering by major manufacturing industries. The pace of such change requires innovative approaches from schools in gathering up-to-date technical information for planning course content, in upgrading or recruiting needed teaching staff, and in gaining access to highly specific and expensive equipment.

The second condition complicating educational responses is the changing nature and educational requirements of jobs. Examples encountered by two-year postsecondary college faculty include changing roles and skills needed for design and production work in the emerging computer-aided design, computer-aided manufacturing, and robotics technologies.

Because of the speed and revolutionary nature of many new technical advances, access to up-to-date information needed to design core courses and programs is seriously limited. Few experts exist (and fewer skilled workers) who can be approached for advice and information.

A structural problem for programs with public funding is that they must justify their implementations of new programs on the basis of occupational demand. If a school tries to respond early to an anticipated need in the labor market, the statistics may be insufficient for program approval, and if the school delays, the eventual response may not help companies that need qualified technicians in order to adopt emerging technologies. In either case, the lack of trained technicians may be adversely affecting industries' use of new technology and subsequent increases in productivity.

Another structural problem is the burden that the development of new high-technology programs places on schools' staffs. Full-time faculty members have limited time outside their teaching duties to develop and upgrade programs as well as to continue their own professional growth.

Many problems affecting appropriate programmatic response to industry's high-technology skill shortages center around the need for advance information and guidance from technology leaders. This information is needed in order to aid school personnel in planning programs, gathering up-to-date information and advice, finding funding, receiving accreditation, and implementing programs that are of uniformly high quality and relevance and that can become "operational" in time to meet the adoption demands of industry.

Objectives and Methods

This project was conducted by the National Center for Research in Vocational Education to provide guidance and assistance to postsecondary educational leaders and faculty involved in developing and implementing programs in advanced technology. The primary focus of the work was on developing and reporting sets of program guidelines and specifications that could aid in the development of programs in the high-technology areas of robotics, computer-aided design and computer-aided manufacturing. An additional objective was to describe a set of generalized procedures for rapid program planning and development in various high-technology areas. In order to accomplish these objectives, project staff members drew upon the advice and assistance of technical consultants from both education and private industry.

Project staff also conducted a series of site visits to companies that either use or manufacture robots, and CAD and CAM systems, and to postsecondary institutions that have developed training programs in these areas. During the site visits, staff members observed and discussed changes in operational and training requirements for each particular technology.

Specific areas of inquiry included—

- current in-house training procedures and materials,
- training supplied by equipment vendor,
- additional training required for designer/operator positions,
- future training requirements.*

*See appendix A for companies/schools visited.

The project staff reviewed professional journals, user and vendor promotional material, and training guides and published articles on CAD technology in order to determine where CAD training for technicians is offered, the nature of such training, and the equipment available to educators and users. No reliable source giving the total number of colleges with two-year technology programs offering CAD courses was identified.

Competencies for an entry-level, computer-aided drafter were identified with the assistance of both industry and educational personnel at a meeting convened at Sinclair Community College in Dayton, Ohio. The tasks and competency requirements that were developed at the meeting are presented in part 2 of this paper under "CAD Drafting Competencies." A detailed outline of the technical content for CAD courses is also presented. Part 3 contains a discussion of CAM and its many aspects as they relate to the development of a CAM training program.

Additional information is given in the appendices. Appendix A lists the site visit locations. Appendix B lists CAD system manufacturers. Appendices C, D, and E offer reprints of papers that address issues of concern to CAD users and to educators. Specifically, Appendix C presents an overview of CAD from the user's perspective and discusses the technology's major payoffs. Appendix D reports on a survey of Applicon CAD system users and analyzes salary data and job classifications, including principal duties, responsibilities, and qualifications. Appendix E contains an article on training considerations for CAD users (e.g., the quality and intensity of training required) and also describes an effective training program for mechanical engineering applications. Although these reprints focus on user issues, they provide relevant information and insights for postsecondary institutions seeking to plan and implement courses in CAD and CAM. In addition to providing some substantive material for course development, they more importantly reflect user concerns and perspectives regarding acceptable training parameters and a realistic range of operator characteristics.

Critical Observations

The following are insights and perceptions that have emerged from the review of documents, site visits, and discussions with CAD users and educators.

- Many CAD users are currently involved in retraining or inservice training of their staff of designers and drafters. Usually, this training is initiated by the user selecting one or more of its key designers or design engineers for training by the CAD system vendor. These key individuals then act as trainers of other individuals at the user's facility. The training is often unstructured, informal, and conducted "one-on-one" with other designers/drafters.

- The term CAD/CAM is bandied about within both user and education circles, when in fact today almost all systems are CAD, or CAD manually linked to CAM. Preparation of a CAD/CAM technician—if such a position were indeed needed by industry—would seem to require a program greater in scope and requiring more time than the typical two-year associate's degree program offered at most postsecondary schools. A CAD/CAM specialist could be trained in engineering technology programs offered at a two-year institution through an expanded program or through many four-year colleges.

- Program/course planners at all of the postsecondary colleges visited have approached the development of training for CAD technicians as supplementary to, rather than as a substitute for, the design training provided within various application areas. Thus, for example, students enrolled in a design or drafting technology program would become skilled in the board work associated with design, drafting, or technical illustration before receiving instruction on a CAD system. In this fashion, the development of design skills on a CAD system is viewed as providing students with a tool for accomplishing design tasks more quickly and accurately. In some cases, students are able to perform more advanced operations on a CAD system than they were able to perform on a board.

- There is currently little standardization of software among the various manufacturers of CAD systems. Database schemes are disparate from manufacturer to manufacturer. However, an effort toward standardization is being made with the development of a geometric model standard called the Initial Graphics Exchange Standard (IGES). This model, developed by the National Bureau of Standards, allows a design system equipped with conversion software to accept models in the IGES format and produce IGES output. Although the IGES has disadvantages due to its inefficient use of computer memory, it is reported that virtually all CAD/CAM system vendors intend to support it with conversion software.

- It is unclear at the present time the extent to which CAD training needs have emerged for individuals who are involved in computer aided manufacturing operations. Do the operators of computer-controlled production machines, for example, need a background in computer graphics? If so, what type of training is required? Does this potential training requirement suggest the need for a new technician position—the CAD/CAM technician—or is it possible to provide a little CAM background to the CAD technician and a little CAD background to the CAM technician for these people to operate their systems productively? Certainly the answers to such questions are not urgently needed with today's level of manufacturing technology. But as the computer-integrated manufacturing (CIM) concept evolves, such questions may become critical as the boundaries between the roles of designer, machine operator, and engineer begin to fade and new levels of decision making and responsibility emerge.

PART 2

CAD GUIDELINES AND SPECIFICATIONS

Introduction

The drafting and design profession requires an ability to respond to increasing changes in product and tool design and to be able to communicate this information quickly and accurately. With the rapid change and growth of our technological society, a requirement has emerged for drafters to add the computer to their standard tools of triangles, scales, and compasses. Industry, realizing this need, has moved toward integrating computer-aided design into the design and drafting organizations throughout the United States.

Computer-aided design (CAD) denotes the use of a computer as an assistant in the design of some entity. Interactive, computer-aided design is a system that provides visual two-way communication between a person and a computer. Information is either presented or accepted in the form of pictures. This dialogue is such that each unit of input entered elicits a prompt response from the computer.

Designing and/or drafting with computer graphics requires a combination of human skills and machine skills. The ability of the machine to do fast calculations, to rotate or change objects on the screen, and to file and duplicate segments of the drawing gives the designer a very powerful tool. On the other hand, only the designer can recognize certain undesirable juxtapositions of lines, choose between alternatives, manipulate the data, or make aesthetic decisions. Thus, the designer's knowledge and intelligence are needed to augment the machine's speed and computing ability.

Much time is saved by computer-aided design, resulting in increased productivity of up to 50 percent for an experienced CAD designer. The designer/drafter is relieved of the necessity of hand-producing many drawings and changes on drawings that can be made quickly by the computer. However, this does not lessen the designer/drafter's need for knowledge of the principles of drawing and design standards and the design processes involved. In fact, the CAD drafter needs a thorough understanding of the theory of orthographic projection, descriptive geometry, and design processes before successful interaction with the equipment can be attained.

The designer/drafter must combine conventional drawing theory and methods with the proper use of the interactive computer-aided design system. In the process, it will be necessary to integrate theory and practice as well as conventional and interactive techniques.

The designer/drafter must learn how to use the interactive CAD system properly. To use an analogy, the owner of an expensive camera cannot take creative pictures until its technical aspects are mastered. The photographer needs to be able to forget about the knobs and dials and concentrate on the subject matter. The same familiarity with mechanics is essential for the user of an interactive CAD system to achieve creativity. Furthermore, in order to use "chunks" of highly informational content, the designer/drafter, like the piano player or telegraph operator, must often memorize aspects of the encoding sequences before proficiency with the system is realized.

CAD was introduced in the mid-1960s and has shown rapid development during the past fifteen years. The availability of turnkey systems permits the small-firm user to purchase and operate an interactive CAD system without the need for additional investment in personnel to communicate with the system in special programming language. Rather, manufacturers now provide a variety of software packages to allow the user to communicate by keyboard entry or by means of tablet strokes and a menu of design options. These packages contain a wide range of design and analysis options, which are rarely completely exploited by users.

The impact of computer-aided design in the industrial environment has created a definite challenge to the educational community—the immediate training of new personnel and the retraining/upgrading of the in-place work force so that they will possess the skills to effectively use this powerful design tool. The challenge is complex, involving equipment selection and the design of an effective educational package. Both of these factors are tied directly to the industrial community to be served and the nature of the educational institution.

Educational Strategy

The integration model chosen—that is, CAD added to existing courses, separate CAD courses, or a stand-alone CAD program—is the most important single consideration in the introduction of computer-aided design in postsecondary education.

The approach taken, as well as the targeted applications, must drive the selection of equipment—not the reverse. Program areas currently targeted for CAD application include architectural design, machine/mechanical design, electrical technology, commercial art, technical illustration, printing, materials handling, auto body design, and numerical control.

Since CAD system architecture is inextricably coupled with the design and development of the lessons and courses that make up the CAD curriculum, the CAD system manuals should be strongly considered as a starting point in their design, modified to fit the educational delivery system utilized and the targeted applications.

The Relationship between CAD and CAM

The computerized linking of numerically controlled manufacturing systems to CAD is called CAD/CAM, or computer-aided design/computer-aided manufacturing. The term *CAD/CAM* implies a fully computerized system of design and manufacture, but it appears to mean different things to different people. Often the term *CAD/CAM* is applied to a system when, in fact, the CAM component is either not yet in place or not linked by computer to the CAD components. CAM is commonly viewed as computer control of production machines. The emergence of CAM occurred in the mid-1950s when computers became linked in large numbers with recently introduced numerically controlled machines. However, a full-blown computerized CAD/CAM system, sometimes referred to as *CIM* (computer-integrated manufacturing) entails very demanding and time-consuming analysis of manufacturing operations, and few companies have achieved this advanced level of technology.

The well-established application of CAD and CAM systems in industry has stimulated the development of courses and programs in these areas at two-year postsecondary colleges. Although a few postsecondary colleges are investigating the feasibility of a two-year program for CAD/CAM technicians, it is uncertain at this point whether the volume of classroom material and lab experiences that would have to be absorbed in an effective CAD/CAM program could be mastered within the time available for an associate degree program.

For a more detailed discussion of CAM technology and training considerations for CAM technicians, see part 3, "CAM Guidelines and Specifications."

CAD Drafting Competencies

This section presents the competencies required to perform entry-level work as a CAD drafter. The first list presents background requirements in conventional drafting techniques. These are essential knowledge and skills for entry into drafting and design work and thus can be considered part of the total CAD program. The second list, developed by a DACUM panel of CAD users and educators, presents job tasks in which a computer-aided drafter should be competent at job entry.

Conventional Drafting Requirements

The CAD student should develop competence in performing various conventional drafting techniques. The drafter should be able to—

- Use drafting instruments
- Use orthographic third angle projection in the construction of engineering drawings
- Project auxiliary views
- Apply measurement systems
- Apply dimensioning systems
- Construct sectional views
- Execute geometric constructions
- Detail threads and fastening devices
- Construct pictorial views
- Identify industrial processes
- Develop surface and plane intersections
- Apply basic concepts of descriptive geometry

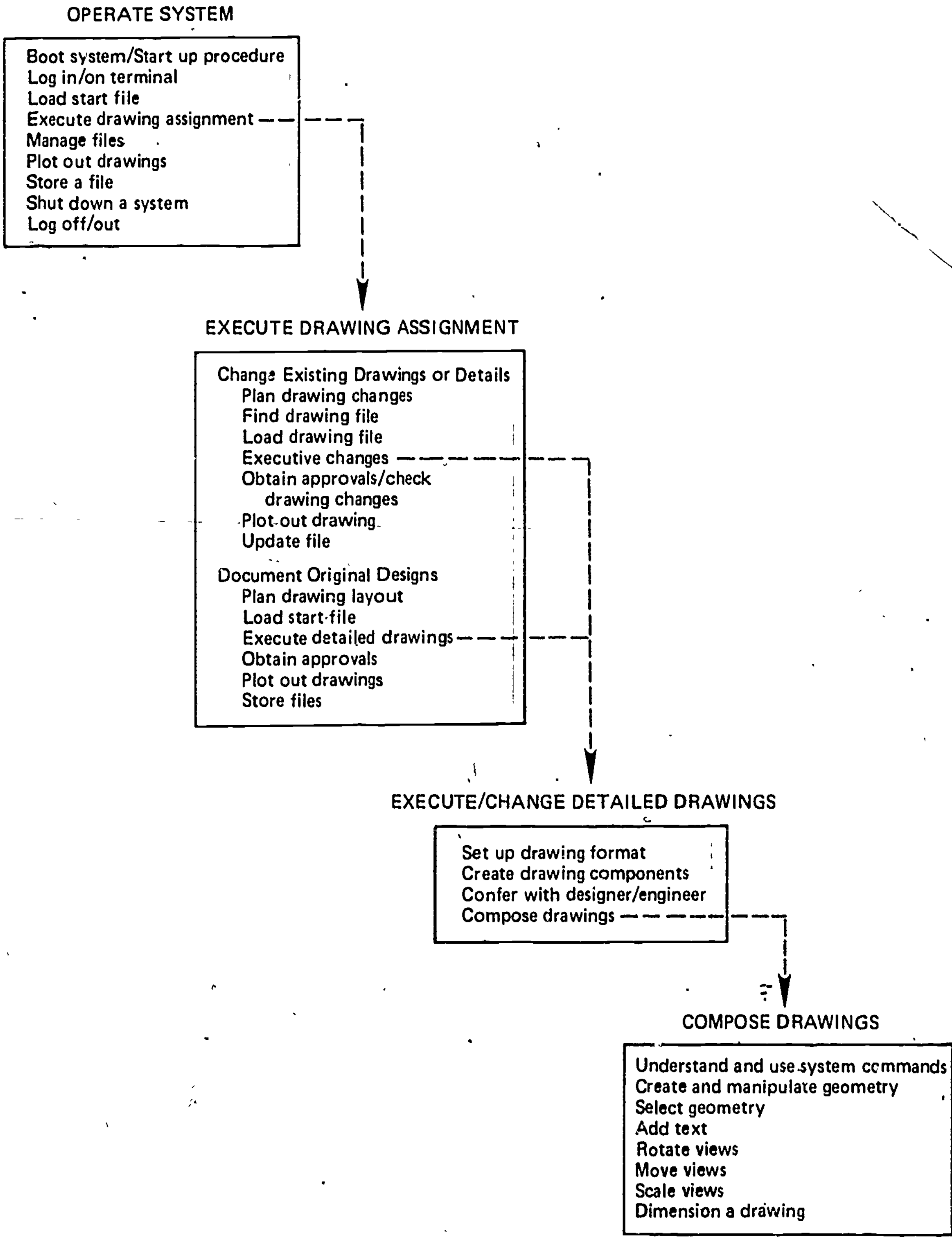

Figure 1. Entry-level Job Tasks for Computer-aided Drafters

CAD Entry-Level Job Tasks

At job entry, a computer-aided drafter should be competent in performing the job tasks shown in figure 1:

Course Outline

The following course outline was developed to be appropriate for any of the CAD turnkey systems currently available. It is realized, however, that some "fine tuning" may be necessary to meet specific needs of local industry. In this regard, the course selection has been kept as general as possible within the mechanical and product application area. This area was selected above others (e.g., technical illustration) because it represents currently one of the largest application areas in the manufacturing sector. CAD courses that address specific applications (e.g., fixture design, die design) have not been included and would require additional course development.

Major Course Topics

I. Introduction to CAD

II. System-Hardware Description and Operation

III. System Operating Modes

IV. Drawing File Structure

V. Command Processing

VI. Command Entry Methods

VII. Creation and Manipulation of Drawing Data

VIII. Intersections

IX. Text

X. Dimensioning

XI. Digitizing

XII. Creating Components (Pictorial Library)

XIII. Display Distances, Angles, and Locations

XIV. Three-Dimensional Data base Concepts

XV. Creating Three-Dimensional Objects

XVI. Cutting Sections

XVII. Projecting Geometry to a Plane

CAD courses beyond this point should be addressed to specific applications (e.g., fixture design, die design).

CourseTopic Breakdown—Mechanical and Product Application

I. Introduction to CAD

A. Man/Machine Interface
B. CAD—Definition and Applications
C. System Architecture

II. System Hardware—Description and Operation

A. Work Station

1. Graphics Display (CRT)
2. Tablet
3. Electronic Stylus (Pen)
4. Alphanumeric Keyboard
5. Function Keyboard

B. Central Processing Facility

1. Central Processor
2. Disk Subsystem
3. Magnetic Tape Subsystem

C. Peripheral Equipment

1. Plotter
2. Hardcopy Unit
3. Alphanumeric Terminals

III. System Operating Modes (varies with each system)

A. Control Mode
B. Edit Mode
C. Edit Component Mode
D. Teach Mode

IV. Drawing File Structure

A. Dictionary
B. Library
C. Drawing Data

V. Command Processing

   A. Syntax
   B. Arguments
   C. Command Execution
   D. Return Key
   E. End of Command

VI. Command Entry Methods

   A. Use of Input Devices

      1. Tablet Operations
      2. Electronic Pen
      3. Function Keyboard
      4. Menu
      5. Alphanumeric Keyboard

VII. Creation and Manipulation of Drawing Data

   A. Logging In (System Entry)

      1. Group, User Concept
      2. Security (Password)
      3. Loading Drawing Files

   B. Use of Operating Modes

      1. Storing Drawing Data (Compact Storing)

   C. Selecting Geometry

   D. Unselecting Geometry

   E. Manipulating Geometry

      1. Using Grid System
      2. Moving Geometry
      3. Undrawing Geometry
      4. Deleting Geometry
      5. Changing Shape of Geometry
      6. Rotating Geometry
      7. Copying
      8. Mirroring
      9. Multiple Copies
      10. Adding Lines

         a. Horizontal
         b. Vertical
         c. Diagonal

11. Adding Arcs
    a. Interior (Less than 180°)
    b. Exterior (More than 180°)
    c. Full Circles
12. Adding Ellipses
13. Scaling Geometry
14. Fillets
15. Line Types
    a. Solid-Single Weight
    b. Solid-Multiple Weight
    c. Centerlines
    d. Phantom Lines
    e. Hidden (dotted) Lines

VIII. Intersections

1. Lines
2. Lines and Planes
3. Planes and Planes
4. Rules and Surfaces of Revolution

IX. Text

A. Character Set
B. Display of Text
C. Text Selection
D. Adding Text
    1. Text in Free Space
    2. Text at an Added Vertex
    3. Text at a Specific Coordinate
    4. Upper and Lower Case Text
    5. Fractions
E. Editing Text
    1. Deleting from Text String
    2. Inserting into a Text String
    3. Text String Modifications
        a. Changing Font
        b. Changing Text Size
        c. Changing Line Weight
        d. Changing Aspect Ratio
F. Manipulating Text
    1. Fitting Text to Available Space
    2. Moving Text

3. Copying Text
4. Rotating Text

G. Alphanumeric Keyboard Characters

X. Dimensioning

A. Standard (Conventional) Dimensioning

1. Selection Process
2. Linear Dimension Addition

a. Horizontal
b. Vertical Dimensions
c. Angled Dimensions

3. Arcs
4. Circles
5. Leader Lines
6. Degree (Angular)
7. Tolerances

a. Plus and Minus
b. High and Low Limit

8. Dual Dimensioning

B. Baseline Dimensioning

1. Extension Line Only
2. Extension Line and Half-Dimension Line
3. Extension and Dimension Lines

C. Modifying Dimensions

1. Extension Line Trimming
2. Text
3. English to Metric Conversion

D. Geometric Tolerancing

1. Symbols
2. Feature Control Block
3. Basic Dimensional Block

XI. Digitizing

A. Digitizing Devices

1. Small Tablet with Integral-Switch Stylus
2. Large Tablet with Integral-Switch Stylus

3. Large Tablet and Puck with Function Buttons

B. Digitizing Commands and Operation

1. Command Format and Interpretation
2. Aborting Commands and Deleting Arguments
3. Multiple Addition

C. Setting Up for Digitizing

1. Defining a Tablet Area
2. Calibration Commands

D. Adding Components

1. Lines
2. Arcs
3. Cells

E. Three-Dimensional Addition
F. Nonplanar Polyarc or Path Addition
G. Using Menus and Function Bottons

XII. Creating Components (Pictorial Library)

A. Flow Diagram for Creating a Library
B. Component Types
C. Designing a Component Library
D. Cells

1. The Edit Component Mode Drawing Cube
2. Cell Depth
3. Defining a Cell
4. Adding a Cell to a Drawing
5. Defining a New Cell from an Existing Cell
6. Defining a New Cell from Existing Components
7. Aborting Edit Component Mode

XIII. Display Distances, Angles, and Locations

A. Distance between Verticles
B. Coordinate Location in View Cube
C. Location of Identified Points and Vectors
D. Length of Lines
E. Angle Between Lines

XIV. Three-Dimensional Data base Concepts

A. Fundamental Graphic System Units
B. Natural Units (Inches-mm)

1. Setting Natural Units
2. Turning Natural Units Off and On

C. The View Cube

1. Three-Dimensional Zooming
2. View Cube Definition
3. Manipulating the Location and Size of the View Cube

a. Centering the View Cube
b. Moving the View Cube
c. Changing the Size of the View Cube
d. Viewing the Entire Drawing

D. Saving and Getting Views

E. Controlling the Number and Type of Views

1. Orthographic Principal Views
2. Isometric Views
3. Dimetric Views
4. Trimetric Views
5. Single Auxiliary Views
6. Multiple Auxiliary Views
7. Rotating the View Cube
8. Perspective Views

F. Grids

1. Working Grid
2. Secondary Grid
3. Flying Eye Grid (Auxiliary Views)
4. Angular and Radial Grids

G. Drawing Levels

1. Setting Level Status

a. Edit
b. Reference
c. Unedit

H. Using Components on a Level

XV. Creating Three-Dimensional Objects

A. Setting the Deep Plane
B. Bricking of Selected Shapes
C. Creating Edges Between Faces
D. Surfaces of Revolution
E. Ruled Surfaces
F. Warped Surfaces

XVI. Cutting Sections

A. Through Plane Faced Objects
B. Through Surfaces of Revolution
C. Through Ruled and Warped Surfaces
D. Cross-Hatching

XVII. Projecting Geometry to a Plane

1. Principle Surfaces
2. Inclined Surfaces
3. Oblique Surfaces

PART 3
CAM GUIDELINES AND SPECIFICATIONS

Robert J. Hofmann
Manufacturing Products
General Electric CAE International Inc.

Introduction

The United States manufacturing establishment faces disturbing trends in the early 1980s. As it strives for profitable growth needed to fund product development and basic research and to attract venture investment dollars, productivity is either declining or not keeping pace with the rate of improvements experienced by such major U.S. trading partners as Germany and Japan.

Reversing these downtrends is no easy task, as some of the causes for them go to the roots of our system of business measurement and taxation. It is a matter of record that our international competitors, Japan in particular, are highly motivated by the promise of future profits and by government to trade short-term profits for world dominance in such areas as electronics, shipbuilding, steel, and transportation equipment of all kinds—the historic bastions of U.S. trade dominance. This drive for dominance by foreign competition has led to a declining share of world markets for the U.S. economy.

The issues involved in such international competition are complex. Workers' expectations for a standard of living among differing cultures is one important issue. Cleverness in marketing and export savvy are other key issues. These issues will not be resolved by simply building better products at lower costs. But this is certainly a first and essential step, and the U.S. has made a good start in that area.

Computer-aided design (CAD) concepts have been embraced by major U.S. manufacturers. CAD has become a multi-billion dollar industry since its inception just ten years ago and is now making its way down to the small manufacturer and job shop level. The technology grows richer daily as hardware and software engineers continue to design more sophisticated and easier-to-use systems available at lower and lower cost.

While computer-aided manufacturing (CAM) concepts predate CAD by nearly twenty years, CAM technology has evolved more slowly. This slower evolution may be due to the conservatism of manufacturing management or to the lack of sizzle and glamour as compared to the color graphic and obvious visual impact of CAD terminal devices. CAM technology, however, is growing rapidly as manufacturing management is becoming aware of its significant leverage potential in reducing both direct and indirect manufacturing costs along with an inherent improvement in communication interfaces with other organizational components, such as design engineering, finance, and marketing.

The purpose of this section of the guidelines is to provide school administrators with an overview of CAM technology today, trends for the future, and skills required for successful implementation. Suggestions will be made for broad curriculum content, along with training skills needed and equipment required to train practitioners in CAM technology. The discussion also includes data on industry classifications where these skills will be most needed, along with geographic concentration of demand.

Computer-aided Manufacturing Defined

Computer-aided manufacturing is a body of technology that makes use of digital computers, manufacturing-specific software, operator input/output devices, and, in some cases, interdevice communications systems in both "real time" and "off-line" applications for the purpose of improving overall productivity of the manufacturing process.

CAM is comprised of four basic subdivisions:

- **Manufacturing Information Systems (MIS)**

  These systems are primarily "off-line" in nature. They generally include order service, manufacturing requirements planning, and materials requirements planning.

- **Manufacturing Engineering Systems (MES)**

  MES may be further divided into group classification/process planning, automated machinery programming, plant layout and investment analysis, and make/buy decision making.

- **Production Automation and Communication (PAC)**

  This subdivision includes machine, process, assembly, materials handling, and quality analysis control devices and communications systems that are used to coordinate an entire plant's activities with respect to a master production schedule.

- **Finished Inventory Warehousing and Shipping (IWS)**

  IWS provides a means for automated stock placement, retrieval, and shipping methods.

Historical Overview

The roots of CAM technology date back to the first numerical controls (NC) and NC programming systems, which were commercially introduced in the mid-1950s. The first major CAM programming language, Automatic Programmed Tool (APT), was a joint development of the United States Air Force and twenty-one aerospace and defense industry manufacturers between 1958 and 1960.

APT is a geometric and machine motion programming language used to control the motion of machinery with up to five axes of linear or angular degrees of freedom. Many of the fundamental aspects of the APT language provided a springboard for subsequent development of computer-aided design (CAD) technology. For this reason, significant potential exists for effective integration of the two technologies. This integration potential is of particular importance to vocational trainers, as various fundamental skills can therefore be applied to both CAD and CAM technologies.

Current Situation

The application of CAM has, in the past, been the province of large *Fortune* 1300 manufacturers. Recent advancements in computer technology and the incidental reduction in investment expense have brought some elements of CAM within reach of even the smallest job shop operation. For instance, computer-aided NC programming, order service, and shop scheduling systems may be readily acquired from several sources for as little as $30,000. These systems run on small but powerful professional computers, which typically sell for less than $5,000 in a basic configuration. A small but growing "cottage industry" of software writers are prolific in supplying software for application on these machines.

Industry forecasters predict that more than 65 percent of the discrete-part manufacturing establishments in the United States will be applying some form of CAM technology by 1986. As a result of competitive pressure, most firms not using these techniques by 1990 will be out of business. This represents a significant challenge to vocational schools and two-year colleges as the skill markets shift to meet industry needs over the next three to eight years.

Traditional tool maker and journeyworker machinist skills will be replaced by master computer programs, which can be implemented by clerks after weeks rather than months or years of training. Electronics technicians will be supplemented by diagnostic software and menu-driven systems that will lead the "technician" through each step of the fixing process, thus virtually eliminating the need for judgment and experience. NC programmers will be concerned with the development of "family-of-part" programming systems for use by clerical personnel rather than the development of specific programs for each part.

The student's ability and interest could lead to his or her becoming either a designer or a user of CAM programs. The role of vocational and two-year colleges will continue to be that of teaching basic analytical and communication skills but with a new emphasis on computer sciences, regardless of the field of study. In fact, the computer itself should play a major role in the training process.

Many administrators for schools that will successfully meet these needs have already begun formulating plans and implementing programs for this purpose.

Skills Required by CAM Users

General Skill Requirements

Specific skill requirements for CAM implementation will be similar to the traditional skill needs for a conventional manufacturing operation. A major difference, however, will be in the organizational level at which the skill is applied and the need at all levels for knowledge about what kind of impact a specific action has on others within the organization. For this reason, every manager or individual contributor should have the ability to analyze the objectives of the company along with how one individual's actions can affect other manufacturing elements. Schools will, therefore, need to expand and enrich microeconomic and financial courses over time. This will demonstrate the impact and sources of cost savings due to CAM and its subelements compared to conventional manufacturing practices and techniques.

A broad CAD/CAM survey course should be required for students seeking degrees in all applicable engineering disciplines. The objective of such a course would be to demonstrate that CAD/CAM technology tends to eliminate isolated functions within a product manufacturing organization and that each of the contributors in the organization adds a special level of expertise to a continuum of information. This infusion of expertise builds progressively from the product concept stage (which may be a solid model image developed and stored within the computer) to the production shop floor where every element of data necessary to produce the designer's concept is available to each specific work station via hardcopy printer or CRT terminal.

The paperless data flow is bidirectional, such that each contributor has the opportunity to provide suggestions and guidance on the feasibility and manufacturability of the product or its components. Thus time and expense are saved in the production process before significant commitment is made toward release of a product that has little chance of meeting manufacturing cost objectives.

This paperless data flow concept should be reinforced during the education process by use of similar equipment in the schools for classroom exercises, examinations, self-directed study, submission of homework assignments, and theoretical case analysis. This will further enhance the operating skills of the users in training through invaluable hands-on experience.

Specific Skill Requirements

The broad functional requirements for a CAM operation include the following elements:

- Programming
- Operations and operations supervision
- Maintenance
- Management
- Planning and analysis

The role of most postsecondary institutions will be in training persons for entry-level work in programming, operations, and maintenance. The following discussion concentrates on programming and operations, but it is important that the student also be provided with a broad business and total system overview.

The skills required by programmers and operations workers are essentially interchangeable. The differences are in the degree to which a particular discipline is applied in day-to-day work. The skills required may best be described by outlining, step-by-step, the *process* of developing a program for an NC machine and by listing under each task the specific skills needed. It must be understood that similar activities are required for programming other computer-controlled shop floor processes.

1. Analyzes part geometry, materials, finish, and precision required
   a. Mathematics, at least geometry and trigonometry
   b. Metallurgy
   c. Ability to read engineering drawings
2. Selects machine type(s) and tooling required
   a. Knowledge of machine types and capabilities
   b. Knowledge of cutting technology

3. Designs or selects part hold-down fixtures and jigs needed

    a. Fundamental mechanical design, drafting, and documentation

4. Uses a programming language to define finished part geometry and the geometry of the raw casting, bar stock, or other material from which the part is to be produced

    a. Knowledge of computer operating systems
    b. Knowledge of the use of the programming language

5. Defines tool path and chip removal technology (feed rates, spindle speed, and tool selection) for most efficient use of the machine tool and maximum chip removal rate for the tooling available

    a. Knowledge of machining processes
    b. Knowledge of machines and tooling

6. Verifies work against graphic representation on hard copy or CRT plotting devices

    a. Knowledge of computer operating system
    b. Knowledge of use of specific devices

7. Edits source program to correct errors or refine the process

    a. Knowledge of using system editor

8. Postprocesses standardized file output to obtain machine image code in either punched tape or direct NC data file format

    a. Knowledge of operating system

9. Tests program on machine tool in "dry run" mode (cuts air or styrofoam)

    a. Ability to operate the NC/CNC machine tool

10. Usually returns to step 7 one or more times depending on part complexity

    a. Ability to analyze results of dry run performance using total process knowledge

11. Machines prototype part on machine tool
    a. Ability to operate the NC/CNC machine tool

12. Tests results in metrology lab using gauging table or other measuring device

    a. Understanding of physical material properties.
    b. Ability to use metrology devices if required

13. Releases program for production or returns to step 7
    a. Good judgment and discipline

This work is performed by highly trained professionals today. Those professionals are now devising methods of extending their capabilities through family-of-part programs such that, in the future, steps 7 through 12 will be performed by entry-level or clerical personnel. Similar disciplines are required for programming and operations supervision of computer-aided plastic injection molding and quality analysis systems. Robotics technology is also moving rapidly toward similar off-line programming techniques.

Training Guidelines

An objective of most CAM product suppliers is to provide systems that are more powerful than traditional manufacturing methods and easier to learn and use. An experienced machinist or machine tool technician can acquire some proficiency in the use of traditional NC programming languages after forty hours of concentrated training. Full proficiency usually occurs after three to five months of continuous experience.

Both the concentrated training and in-practice training periods are being rapidly reduced through the use of menu selection and immediate response graphics systems. Similar concepts are being developed for computer-aided plastics engineering systems and will undoubtedly be used in other areas, such as robotics programming, process planning, and many other manufacturing engineering-related programs.

For this reason, a broad CAM or CAD/CAM survey course is likely to meet the needs of most students entering this field. This course should be followed up by an in-depth study of the theory behind the user interface. Such a course could cover two or three specific disciplines during a single course term. At least one course in computer science along with the underlying subject theory is a prerequisite.

Training Skills Acquisition

Training skills for CAM technology have in the past been acquired from vendors of the particular product or concept being taught. These vendors can no longer meet the demand for training. However, seminars and user training courses are available periodically from all major suppliers of CAM systems. These courses are almost always included in the purchase price of the system, and most suppliers will offer a free seat to educational institutions, allowing institution faculty to be trained and thus become able to train others.

Equipment and Facilities Needed

Obviously, the equipment and facilities required for instruction in CAM technology are dependent upon the depth of the subject to be covered. A complete CAM system would require access to a large mainframe computer installation. The majority of the manufacturing engineering system technology would, however, operate with multi-user capability on modern minisystems.

Research is required to determine the number of students that can be served per station. From industrial experience and some judgment, three to four students per terminal device would appear adequate for most training situations. Most computer companies will assist in configuring their product installations if rudimentary usage data can be supplied.

Basic Curriculum for CAM Instruction

The following subject areas are essential for a fundamental CAM program in postsecondary institutions:

I. Computer Sciences

A. A conventional overview of the digital computer, its applications, and how it is used
B. Specific training in programming languages, such as COBOL and FORTRAN

II. CAD/CAM Survey

A. Broad definitions and explanations of CAD/CAM functions and how they interrelate
B. Specific instructions in one or more CAM disciplines

III. CAM Economics and Finance

A. Comparisons with traditional manufacturing techniques
B. Specific sources of cost improvements and impact on business

IV. Process Technology

A. Metal and alloys
B. Metal cutting, forming, and fabrication
C. Tooling and fixture design
D. Plastic materials and molding technology
E. Modern shop practices

V. Physical Sciences

A. Physics
B. Chemistry
C. Electronics

VI. Mathematics

A. Geometry and trigonometry
B. Calculus and analytical geometry

Other elective courses could cover the following:

- Historical evolution of CAD/CAM technology
- CAD/CAM workshop—interrelating the disciplines in specific case studies

Industry Classifications

Three major industry groups currently share the highest interest in CAM technology. These industry groups, with their Standard Industrial Classification (SIC) codes, are as follows:

- Transportation equipment manufacturers (SIC 37)
- General machinery manufacturers (SIC 36)
- Electrical machinery manufacturers (SIC 36)

These industries represent a significant portion of the U.S. manufacturing gross national product and employed nearly 6.5 million workers in 1982. Productivity gains of just 1 percent result in an increase in gross income of more than five billion dollars to this group of manufacturers. Such data are evidence of CAM's direct importance to management at all levels.

These industries can be further subdivided into three groups according to their function within the context of product development and distribution. The first group is called the original equipment manufacturers or, more commonly, OEMs. The OEMs design, assemble, and distribute products to end user customers. They tend to be large companies with multi-location operations, and most of them will be found in *Fortune* magazine's listing of 1,300 top U.S. companies. Many of these firms have already embraced CAD/CAM concepts. Users are being trained by the CAD/CAM product vendors or by internal programs.

A second major industry grouping is supplier firms whose end product is a component or subassembly of the OEM product. Supplier firms are generally smaller than OEMs, but their manufacturing problems are equal in complexity. CAM and CAD systems are gaining in acceptance by the supplier industry, in part because of management's understanding of the benefits and because of OEMs' preference for buying from firms that have the best turnaround response from purchase order to shipment. CAD/CAM technology provides such a competitive edge. In addition, many OEMs are now providing suppliers with part drawings and cutter location listings for NC machines in machine-readable format. Suppliers with the ability to make direct use of this information enjoy a significant advantage over those without that ability.

Supplier establishments represent a second level of market development for CAD and CAM technology; however, they are the major portion of the total market and will be the primary source of employment for technicians trained by postsecondary institutions.

The third industry grouping is the job shop establishments. These establishments can produce short runs of components or finished products with minimal lead time and at relatively low cost. NC technology is becoming vital to survival for many of these firms. CAM vendors have developed single-user, limited capability products specifically for this market, which represents approximately eighty thousand establishments. These firms will also rely heavily on postsecondary institutions as a source for CAM expertise.

Demand for new skilled personnel can be analyzed in terms of new equipment installations. One NC programmer can typically handle work for three machines running on a two-shift basis. Two machine operators are needed for every three NC machines installed; but a typical NC machine performs the work of three to four conventional machine tools, so that, on a macro level, the actual number of operators needed will remain the same or decline.

Skilled support for maintenance and installation work requires an additional person for an average of every fifteen new installations. Thus every 15,000 new NC machines installed in 1983 will create demand for 5,000 new programmers, about 1,000 new installation and maintenance technicians and 10,000 operators, many of whom will simply shift to a new work station within the same firm. Some operators will also become machine programmers.

NC programmer salaries vary widely according to demand in any particular geographic area. The national average is estimated at about $25,000 in 1981. *NC Commline*, a trade journal published by Numeridex Corp., periodically provides statistics on salary and employment opportunities.

The CAM Market

A 1980 study by *Modern Machine Shop* magazine showed high correlations between NC machine installations and the use of both CAD and CAM technology at specific manufacturing sites. In other words, a firm using NC machines would be more likely to make use of CAM technology than one not using NC machines.

American Machinist magazine has, over the past sixty years, maintained a data base of the installed macnine inventory in the United States. The survey was last completed in 1978 and is scheduled to be updated in 1983. The coordination of these studies provides a fairly clear picture of the CAM market distribution in the United States. The percentage distribution is estimated as follows:

United States CAM Market

Region	Percent
Great Lakes	28
New England	20
Southern California	14
Ohio Valley	11
Atlantic Seaboard	10
Tulsa-Houston	8
All other	9
TOTAL	100%

SOURCE: American Machinist, Inventory of Machine Tools, 1978.

Long-Range Trends

Trends have been discussed throughout this guide. It is important to reemphasize, however, that manufacturers will strive, in the years ahead, to reduce direct and indirect labor costs in favor of investment in machines and facilities, which are more predictable in both cost and performance. CAM technology is an investment area that provides favorable cash flow. This is becoming more widely understood, and the technology is advancing rapidly to meet user expectations. Over the next five years, data management control systems will provide a data base hub from which all functions within a manufacturing establishment can access and enhance information. Parts of this data base will, in fact, be made available to the firm's suppliers for purposes ranging from design information to the establishment of prices and communication of shipping schedules. Isolated islands of functions that do not mesh or communicate with adjacent functions can no longer be afforded.

Postsecondary educational institutions can and will provide a major service in making the truly integrated manufacturing system a reality. The time to begin is now.

APPENDICES

APPENDIX A

SITES VISITED

Postsecondary Institutions

Dr. Russell Jerd, Dean of Engineering Technology
Professor James J. Houdeshell, Department Chairman, Industrial Packaging and Quality Control Technologies
Professor Nataraj S. Nataraj, Department Chairman, Mechanical Technologies, Electrical Repair and Transfer
Sinclair Community College
Dayton, OH

Professor Ed Konopka, Robotics Technology Program
Oakland Community College, Auburn Hills Campus
Auburn Heights, MI

Professor Jack Thompson, Director, CAD/CAM Programs
Macomb Community College
Warren, MI

National Conference on High Technology
Hocking Technical Institute
Nelsonville, OH

Robot Manufacture Users

Mr. Lloyd R. (Dick) Carrico, Applications Engineer
Industrial Robot Division
Cincinnati Milacron Company
Lebanon, OH

Mr. John B. Franklin, Manager
Advanced Technical Training
Chrysler Institute
Chrysler Corporation
Highland Park, MI

Mr. Dana Holmes, Technical Training Coordinator
GM Assembly Division Plant
General Motors Corporation
Lordstown, OH

CAD/CAM Users

Mr. Michael Baxter, CAD/CAM Application Manager
F. Joseph Lamb Company
Warren, MI

Mr. Bruce W. Dobras, Senior Engineering Associate
Monarch Marking
Pitney Bowes Company
Dayton, OH

Mr. Mike Kuntz, CAD/CAM Manager
Harris Corporation
Dayton, OH

Mr. David L. Michaels, Engineering Systems Manager
Monsanto Research Corporation
Miamisburg, OH

APPENDIX B

TURNKEY VENDORS OF CAD/CAM EQUIPMENT

A. M Bruning
(Division of AM International, Inc.)
1800 Bruning Drive West
Hasca, IL 60143
(312) 351-2900
Telex: 20-6596
Pres: Dieter E. A. Tannerbeg

Applicon, Inc.
32 Second Avenue
Burlington, MA 01803
(612) 272-7070
Pres: Donald W. Fedderson

Arrigoni Computer Graphics
231 O'Connor Drive
San Jose, CA 95128
(408) 286-2350
CEO: David M. Arrigon,

Auto-Trol Technology Corp.
12500 North Wadington Street
Denver, CO 80233
(303) 452-4919
Telex (TWX) 910-320-0772
Pres: Graham O. King

Avera Corp.
200 Technology Circle
Scotts Valley, CA 95066
(408) 438-1401
Pres: Michael Dickens

Aydin Corp.
401 Commerce Drive
Fort Washington, PA 19034
(215) 643-0600
(TWX) 510-661-0518
Pres: Ayhan Hakimoglu

Broomall Industries, Inc.
700 Abbott Drive
Broomall, PA 19008
(215) 328-1040
Telex: 83-4722
Pres: Andrew E. Trolio

California Computer Products, Inc. (Calcomp)
2411 West LaPalma Avenue
Anaheim, CA 92801
(714)821-2011
(TWX) 910-591-1154
Pres: M. J. Kosheff

Calma Company
5155 Old Ironsides Drive
Santa Clara, CA 95050
(408) 727-0121
(TWX) 910-338-2088
Pres: Robert Bendess

Computervision Corp.
201 Burlington Road
Bedford, MA 01730
(617) 275—1800
Telex: 92-3345
Pres: James Berrett

Computool Corp.
5600 Lincoln Drive
Minneapolis, MN 55436
(612) 935-8550
Pres: Frederick Zimmerman

Control Data Corp.
8100 34th Avenue, South
Bloomington' MN 55420
(612) 853-8100
Pres: R. M. Price

Data Technology Inc.
530 Atlantic Avenue
Boston, MA 02210
(617) 451-0430
Telex: 94-9476
Pres: Harry Margulius

Engineering Systems Corp.
2051 Silverside Drive, Suite 100
P.O. Box 80318
Baton Rouge, LA 70808
(504) 769-2226
Pres: D. David Vicknair

Gerber Scientfic Instrument Co., Inc.
83 Gerber Road, West
South Windsor Ct. 06074
(203) 644-1551
Telex: 99-290
Pres: Robert Maerz

Gerber Systems Technology, Inc.
40 Gerber Road, East
South Windsor, CT 06074
(203) 644-2581
Telex: 681-9200
TWX: 710-447-5300

Grafcon Corp.
5510 South Memorial
Tulsa, OK 74145
(918) 663-5291
Telex: 910-845-3009
Pres: Darrell B. Miskell

Graphics Technology Corp. (GRAFTEK)
1777 Conestoga Street
Boulder, CO 80301
(303) 444-8482
Telex: 450-250
Pres: James E. Starnes

Holguin & Associates Inc.
P.O. Box 12990
El Paso, TX 79912
(915) 581-1171
Pres: Hector Holguin

IBM
1133 Westchester Avenue
White Plains, NY 10604
(914) 696-1900
CEO: John R. Opel

Interactive Computer Systems Inc.
13541 Tiger Berd Road
Baton Rouge, LA 70816
(504) 292-7570
Telex: 65-6489
Pres: Kenneth W. Guillory

Information Displays Inc.
28 Kaysal Court
Armonk, NY 10504
914/273-5755
Pres: Bill Weksel

Intergraph Corp.
One Madison Industrial Park
Huntsville Alabama 35807
(205) 772-2000
(TWX) 10-726-2180
Pres: James W. Meadlock

Kauffel & Esser Co.
20 Whippang Road
Morristown, NJ 07960
(201) 285-5160
Telex: 13-6425
Pres: Thomas Nye

McDonnell Douglas Automation Co. (McAuto)
Brown Road at Lindbergh
P.O. Box 516
Saint Louis, MO 63166
314/232-6963
Pres: A. J. Quackenbush

Manufacturing and Consulting Services, Inc.
17942 Cowan Avenue
Irvin CA 92714
714/540-3921
(TWX) 910-595-2790

Manufacturing Data Systems Inc.
4251 Plymouth Road
Ann Arbor, MI 48106
313/995-6000
(TWX) 810-223-6039
General Manager: Seymour Rosen

Mentor Graphics Corp.
10200 S. W. Nimbus Ave, G7
Portland, OR 97223
503/620-9716
Pres: Thomas Bruggere

Perkin-Elmer
Data Systems Group
2 Crescent Place
Oceanport, NJ 07757
201/870-4500
(TWX) (710) 722-6532
Chairman of Board: Robert Sorenson

Phoenix Automation, Inc.
North Alfred Street
Woburn, MA 01801
617/938/1320

Prime Computer, Inc.
Prime Park
Natick, MA 01760
617/655-8000
Pres: Joe Henson

Racal-Redac Interactive Graphics, Inc.
1 Redac Way
Littleton, MA 01460
617/486-9231
Pres: Gene Marsh

Scientific Calculations, Inc.
7635 Main Street
Fisheris, NY 14453
716/924-9303
Telex 97-8316
TWX 510-254-8546
Pres: Paul Watkins

Sigma Design, Inc.
7306 South Alton Way
Englewood, CA 80112
303/-73-0666
Chairman of Board: Raun Rasmussen

Summagraphics Corp.
35 Brentwood Ave
P.O. Box 781
Fairfield, CT 06430
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APPENDIX C

A USER'S PERSPECTIVE

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We are in a period where productivity is a major concern of industry. Products must be manufactured efficiently to compete in the market place. We recognize that any successful product must begin with a good design; therefore, the designers require the best tools. Computer-Aided-Design (CAD) is the new productivity tool for the design staff.

Most major corporations recognize the importance of computer-aided design, and they are either using CAD or are in the process of acquiring CAD systems. This shift from drawing boards to computer terminals will impact the educational areas of drafting and design, and this number is expected to increase as computer design skills become a prerequisite for job placement and advancement.

Computer-Aided-Design has existed for nearly fifteen years. Yet only in the past few years have turnkey systems been available to meet the general industrial requirements. Prior to the turnkey systems, it was necessary for a firm to employ both hardware and software personnel to support the graphic operations. Only laboratories and large corporations, in particular the aerospace industry, could afford such a support staff.

With the advent of the turnkey systems, even the small firms could operate in an interactive graphic environment. The computer-aided design manufacturer supports both the graphic terminals connected to a graphic processor which translates the drawing data to the central processing unit which in turn controls the output devices such as plotters, tape punches and line printers.

The designer at the graphic work station communicates with the system; either via tablet strokes or keyboard entry. The designer utilizes the software and tablet symbol recognition to issue commands to the system. The userware software has applications in the major segments of project design and manufacturing and checking provide the typical software utilization with specific application in mechanical engineering, manufacturing, architectural engineering and electronics.

Productivity is the term most often associated with computer-aided design, and the area of greatest payoff is with the designers and drafters. During the process of creating a drawing, many changes are required, often on a short time scale.

Typically, the most time-consuming tasks were the many design changes which were required in the creation and development of a product. With the computer-aided design system, only the initial design is entered into the system. When changes are required, the designer makes the necessary changes to the computer data base for each update. The drawing changes and revised drawing hardcopy can be produced in a matter of minutes on a plotter. The initial entry of the design into the CAD system usually requires from 30 percent to 130 percent of the time required by traditional methods. The time varies depending on the complexity of the drawing. The CAD system frees the designer from the time-consuming manual drafting steps. Drawing changes require only a small fraction of the time. Therefore, in the overall design task, productivity is expected to increase from 25 percent to 50 percent for the experienced designer.

Computer-Aided-Manufacturing (CAM) also increases productivity. Computer-aided-design and the engineering drawing are means of communication between the designer and the engineer. The drawing information can thus be transferred from the drawing into a manufacturing omputer. The CAD system provides a common data base to be shared by the designer, drafter, engineer and machine programmer. With the common data base, changes can be quickly made and implemented. This will result in a significant improvement in the final part design, since a strong communication link will exist between the designer, engineer and machine programmer, all working closely together, linked by a computer. In addition, the machine programmer will be able to generate and edit machine-tool paths and commands on-line with the computer.

One of the major benefits of computer-aided design is the analysis capabilities of the computer. With geometric complex design, the designer spends much time defining surface intersections shapes and coordinate transformations. Because of basic limitations, three-dimensional drawings can be visualized by only a few highly skilled designers. With CAD, the analytical capabilities required by the engineers will be provided directly, using the same data base as the designers.

In addition, standardization of parts will be promoted by the CAD system through the use of a "library of standard parts" or group technology, automatic dimensioning and bill of materials. Components or assemblies which are used often in a variety of drawings can be drawn once and placed in a common data base. The CAD standardization should allow fewer errors in drawing interpretations and improved reliability.

The real productivity of the computer-aided design system is not necessarily the reduction of design time, but rather the ability to provide an analysis of the drawing in the time normally allotted to the design task itself.

APPENDIX D

COMPUTER-AIDED DESIGN SYSTEMS TRAINING CONSIDERATIONS

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I. Introduction

Computer-aided design systems have been gaining acceptance in many areas of mechanical engineering and design. Productivity improvement in basic drafting and detailing has been evident in many installations. There is even greater productivity when a versatile data base is created in the design process. This data base can then be used in a wide variety of applications such as numerical control of machinery and engineering analysis.

Training of in-house personnel to utilize this new technology is the usual method for filling the related CAD positions. However, many of the existing engineers and designers have little background and preparation in computer-aided design. "How much training?" and "How long will basic training be?" are frequently asked by potential users. This paper intends to analyze some of these relevant issues of training with the aim of an effective training program for mechanical engineering applications.

Some Relevant Issues

1. Varying Objectives of Users

In a computer-aided design system for mechanical applications, there will be design engineers, supervisors, support personnel, and so forth. These classes of people have varying objectives, backgrounds, and thus training needs. A closer look at individual training needs will be made in this paper.

2. System Developers vs. Users

Many system developers and users regard training as teaching the necessary commands only. This may be fine if users have a background similar to those who develop the systems. Most often, this is not the case. System developers and trainers should understand the users' application and background. Users, on the other hand, should understand the scope and limitations of a system and then plan accordingly.

3. CAD Subject Matter

The subject matter for CAD training will depend on how the system is to be used (e.g., drafting, design, numerical control and the back-grounds of users. With adequate preparation, learning to use these systems can become easy. We will attempt to list subject matter related to computer-aided design for mechanical engineers and designers. This list will help potential as well as current CAD users in determining their training needs and further education if necessary. By selecting topics from the list appropriate to a particular system application and personnel backgrounds, development of a suitable curriculum should help to reduce learning difficulties.

4. Human Factors

Computer-aided design systems are intended for human use. Worker-machine interaction and human factors considerations have to be looked into. Quantitative data on human factors of CAD training are difficult to obtain. However, we would like to discuss some of these issues and remind trainers as well as users of these related areas.

5. Training Program Development

Even though there are other factors (e.g., economics, scheduling) in determining a good training program, we would like to propose a sample training program development. It would still be beneficial to those who are planning such a program to tailor this example to their own needs.

In the coming years, computer graphics and computer-aided design systems will be used in increasingly diverse applications in industry. The complexity of such systems will also grow in order to utilize the design data base and computer graphics technology more effectively. In order to prepare engineers, designers, and related personnel, effective training programs are definitely needed.

II. Classification of Training Needs

As we concentrate on mechanical design applications, we would like to take a look at the mechanical design procedure as a first step. Figure 2 shows a simplified flowchart of the design process. All design activities begin with needs. After defining the problem, specifying constraints, and communicating with all parties involved, it moves onto concept generation. With many iterations in conceptual design and analysis, one of the many feasible designs will evolve. It is then prepared for production. We would like to identify the many classes of people who would be involved if a computer-aided system were used.

After receiving input for design, *supervisors*, *design engineers*, and *project engineers* will be involved in further defining the problem and looking for means to work out solutions. Design and project engineers will collect all necessary information for that design. Some information such as verbal information, photographs, and sketches will not be accepted by the computer. Some information such as previously designed similar parts and previously digitized designs will be retrieved. Systems *support personnel* will then be involved in getting the archived magnetic tapes, operating telecommunications, or writing special purpose programs for the initial design. With a computer-aided design system, additional decisions have to be made on ways to make a graphic system most productive for the design.

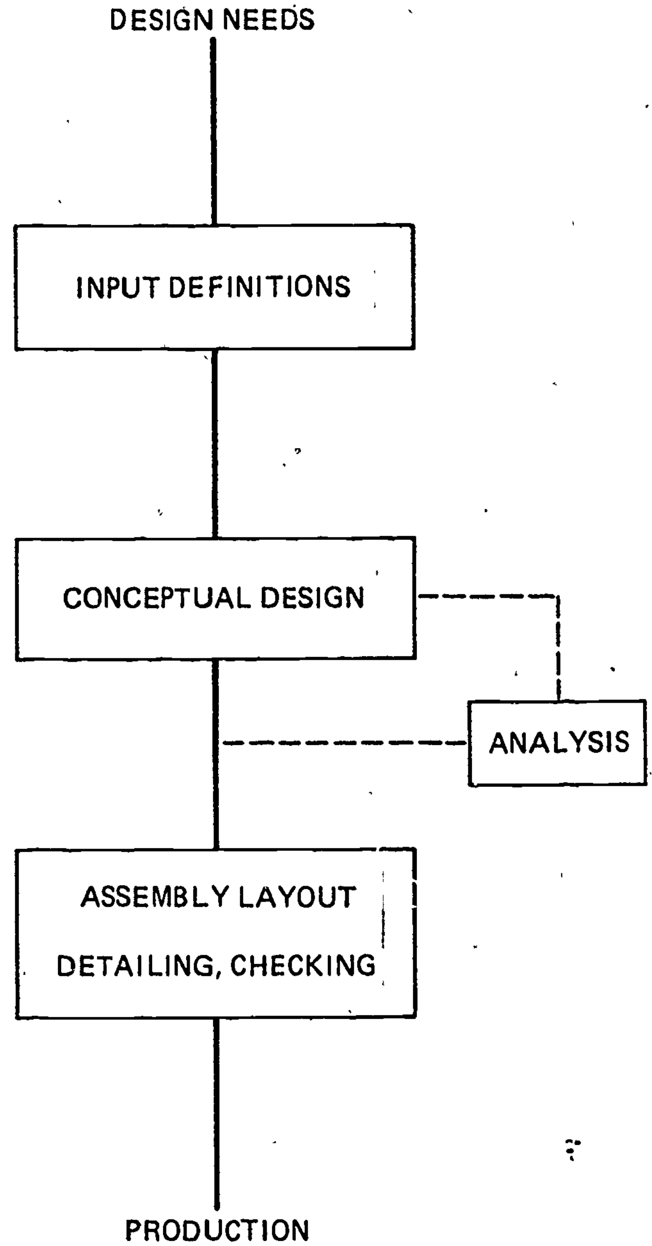

Figure 1.

Summarized Procedure of Mechanical Design Functions

In conceptual design, computer graphics offers advantages in sketching concepts and getting information on previously stored standard parts. Evaluation, analysis, and selection of the best concept will have to be made by designers and engineers. Some advantages of computer graphics will be evident if the analysis uses the data base of the graphic design for finite-element preprocessing and kinematic analysis. Specialized knowledge is required for such analysis, and *specialists* in these analysis areas will have to be involved.

After a design has been selected, the data base just created can be used effectively in related CAD operations. Layout, detailing, and dimensioning of drawings will yield high returns. Such drawings are used by machine shops, for documentation or for other purposes. Additionally, the design data base can be used to generate numerical control (NC) tapes, prepare data for an inspection machine, for testing, etc. Modifications of designs will also be easier once the design data have been created.

The example of the mechanical design process illustrates the major classes of people. Depending on the emphasis of an individual CAD installation, not all of these classes will be involved. If drawing production is of major concern, the emphasis will be on detailers rather than design and project engineers. If production of NC files is emphasized, NC programmers will be using the CAD system.

CAD systems include computers, and they do need care and maintenance to function properly. The amount of hardware and software support depends on the size of the installation and its intended use. Support personnel do become integral parts of the CAD system. They also need special training for smooth operation of the system.

III. System vs. Users

From the system developer's point of view, the system is always easy to use. Sometimes a few "tricks" may make the system work even better. From the user's point of view, the graphic system can never be a total replacement of drawing boards. Interactive devices are not like pencils, and CRT screens are always too small. Certain ways to blend curves and to fake lines are now allowed in computer graphics. For people who are used to the conventional method of design, there is indeed reluctance to give up what has been learned and used previously. As a result, there is a tendency among traditional design engineers to believe that graphic systems are not yet suitable for mechanical design.

Perhaps the truly easy-to-use and realistic CAD system will arrive in the future, but it is not available yet. The fact is that current CAD systems can be productive for many applications if new techniques are learned. Given what is available, users may opt to wait for the perfect system and lose potential benefits now or users will have to learn the new ways to make designs and increase productivity. At the current technology level, potential CAD users have no choice but to learn the rules that system developers lay out for them in design. Users have to think differently and to learn new things.

Very often, system developers emphasize productivity gains and skimp on issues of training. They may teach users how to use the systems in a limited time period. Then it is up to the users to proceed. There is a lack of structured and systematic approach in training. In fact, many users need training in multiple disciplines and in a number of steps in order to be productive. Neglecting training issues will only prolong the learning period unnecessarily.

System developers plan systems for productive use in the way they envision the applications. Imaginative and productive users will find ways to use systems in ways never thought of by system developers. A good training program will stimulate the imagination of the user.

IV. Subject Matter in CAD/CAM Education

In this section, we will attempt to identify the subject matter relevant to a CAD/CAM education. Not all of the topics are relevant to every installation and every user. We will make recommendations as to what type of training is useful to each type of user; but for a given installation these recommendations should be considered in the light of individual backgrounds and qualifications (see table 1).

This section is intended to help answer the questions new users often ask:

- How much mathematical background do we need?
- How much computer background do we need?
- How much graphics knowledge do we need?
- What is necessary to operate and manage a CAD system?
- How much other information do we need in order to assure smooth operation?

Based on the discussions in the previous sections, we have identified the following classes of people associated with computer-aided design systems for mechanical applications.

1. **Mechanical Designers**—who will be the primary users of most CAD systems and will be interacting with project engineers, analysis specialists, and others throughout the design process.

2. **Project Engineers**—who will coordinate the projects, provide the necessary input definition, specify design constraints, and have responsibility for the success of the projects.

3. **Specialists**—who will be involved in the analysis of design concepts (e.g. structural, kinematic, dynamic) and specialists who produce NC output.

4. **Supervisors**—who have responsibility for coordinating design jobs, management, and operation of the CAD facility.

5. **Detailers**—who are responsible for detail and special drawings.

6. **Casual Users**—who may use the CAD system for various other applications not normally intended for the CAD system, e.g., making organization charts, etc.).

7. **Trainers**—who will be teaching other new users.

8. **Support Personnel**—who will be involved with maintenance, repairs, and some daily operation of the system. They will also be interacting with vendor's support personnel.

In order to match these categories of personnel with training requirements, the subject matter of CAD training is broken into the following categories:

- Initial preparation
- Basic commands

- Advanced commands
- Mathematical preparation
- Computer preparation
- Graphics preparation
- Special subjects
- Special applications
- User programming language
- Systems support
- Management and operation

In each category we have suggested the type of information that should be covered.

Initial Preparation

Before a CAD/CAM system is selected and installed, a certain amount of background information is essential. This subject matter is classed as preparation. It applies equally as well to those individuals who are given the responsibility for evaluating and selecting CAD/CAM systems as to those people who are faced with the prospect of using a CAD/CAM system to perform their jobs. The subject matter to be considered in this category of training includes the following:

- Overview of computer graphics
- Overview of computer operation
- CAD/CAM terminology
- Basic programming concepts
- Types of CAD equipment

Basic Commands

Understanding basic operating commands is the minimum requirement for the users to communicate with the CAD system. Basic commands should be simple to learn in a short period, provide users with enough knowledge to generate simple drawings, and leave users with interest and excitement to proceed further. Different systems have different commands. The following items are intended to be general for all systems:

- Familiarization with interactive devices
- Basic principles of operation of all hardware
- Menu arrangement
- Grammar of commands
- Points—create, delete
- Lines—create, delete
- Arcs—create, delete
- Translation and rotations
- Basic windowing operations
- Basic display control
- Trimming operations

TABLE 1
LIST OF SUBJECT MATTER FOR CAD SYSTEM PERSONNEL

TRAINING	INITIAL PREP.	BASIC COMMANDS	ADV. COMMANDS	MATH PREP.	COMPUTER PREP.	GRAPHICS PREP.	SPECIAL SUBJECTS	SPECIAL APPL.	USER PR. LANG.	SYSTEMS SUPPORT	MANAGE & OP.
MECHANICAL DESIGNER	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
PROJECT ENGINEER	✓	✓						✓			✓
ANALYSIS SPECIALIST		✓✓	✓	✓	✓	✓		✓✓	✓		✓
SUPERVISOR	✓✓	✓✓	✓	✓	✓	✓	✓	✓		✓	✓✓
DESIGN DETAILER		✓✓	✓				✓				✓
CASUAL USER		✓✓	✓								✓
TRAINER	✓	✓✓	✓✓	✓	✓	✓	✓✓	✓	✓	✓	✓
HARDWARE PERSON		✓					✓				✓
SOFTWARE PERSON		✓✓	✓✓	✓	✓✓	✓	✓	✓	✓✓	✓✓	✓
OPERATOR							✓				✓

✓✓ absolutely essential

✓ essential

Advanced Commands

Basic commands lend themselves to memorization. Advanced commands require more understanding than remembering. Some users have difficulty in proceeding beyond learning the basic commands. This indicates that mere memorization of commands is not enough in CAD training. Most mechanical designers and engineers can relate to making points, lines, and arcs on a CAD system without any difficulty. Conceptual difference between system and users in the advanced commands can be problems. The following list suggests the scope of advanced commands:

- Editing commands—duplicate, move, mirror
- Use of temporary registers—to store a list of items, numbers or commands
- Coordinate systems and effective usage
- Flags associated with items—such as layers, levels, classes, names, etc.
- View ports and windows
- Surfaces
- Splines
- Masks for item selection
- Model manipulation

Mathematical Preparation

Understanding the mathematical representation of points, lines, arcs, surfaces, and their related operations will not only help in learning some advanced commands but also allow users to take advantage of the data base to do more productive work. Vector, matrix, and transformation operations will be used in order to provide additional output such as N/C tool paths and finite element models as well as special applications programmed by the user.

The following list suggests the scope of mathematical preparation:

- Vector algebra—cross, dot products
- Matrix algebra—addition, multiplication, determinant, transpose, inverse, orthogonality
- Coordinate systems—cartesian, cylindrical, spherical
- Representation of lines
- Representation of arcs
- Mathematics of conic sections
- Mathematics of polynomials and splines
- Transformations (3 x 3 matrix)—scaling, shearing, rotation, reflection
- Transformations (4 x 4 matrix)—perspective, translations
- Descriptive geometry

Computer Preparation

Any computer knowledge the users have prior to CAD training will help. This may reduce training effort and will enable users to perform productive work sooner. The following list suggests the scope of computer background preparation:

- Computer programming (e.g., BASIC, FORTRAN, or PL/I)
- Text editor usage
- Introduction to minicomputer and peripherals

- File and data structures
- Operating system concepts
- Coding schemes

Graphic Preparation

Certain concepts of graphic procedures will help users understand the "why's" of commands. Proper introduction of basic concepts will bring efficient use of CAD systems. The execution of some user commands may cause complete rebuilding of the files that manage the cathode ray tube (CRT) display while others that produce similar results are more efficient because this view file rebuild is not necessary. Computer graphics education can be quite novel and complex to mechanical designers and engineers who do not have previous background. Graphic preparation may be regarded as "advanced" to most users. The following is a list of some relevant topics for CAD systems:

- Design data base—graphic and nongraphic items
- Display file and processors
- Procedural transformations—windowing and clipping operations
- Limitations of graphic computation—searching, sorting, and transformations, etc.

Special Subjects

In addition to learning basic commands, users need to know one or more of the special features of a CAD system. Some of the special subject areas are aids to improve efficiency. Some are isolated topics that have to be learned in order to function. The following lists some of the subject areas. The choice may well depend on the particular application of the CAD system.

- Dimensioning and labeling
- Drawing preparation and plotting
- Merge and break drawing files
- Use of command editor
- Surface manipulations and how to use them effectively
- Computer Operation

Special Applications

The design data base can be used in a wide variety of applications. Some of the applications are supplied by system developers. Some of them are provided by other experienced users. These special applications yield high productivity from CAD systems. Both the number and complexity of special applications will grow in the future. Therefore, special training will be needed. Some examples of special applications of CAD are as follows:

- Group technology
- Kinematic synthesis and verification
- NC file generation and verification
- Finite element pre- and post-processing
- Frame analysis
- Gear train analysis

- Tolerance study
- Process planning

User Programming Language

The user programming language is a special, system-dependent language with both graphic and computational capabilities. On a small scale, it is an aid for efficient operations. Frequently used series of commands can be strung together as a "macro" and executed as a single command. On a large scale, it can allow development of special-purpose applications. If the use of a library of "standard" parts is contemplated, the user programming language is an excellent way of providing these without requiring large amounts of mass storage. Although these programs are usually installation-dependent, the flexibility and efficiency offered by the user programming language are very desirable features of a CAD system.

Systems Support

Mainframe CAD systems always have dedicated, full-time computer personnel maintaining the systems. In minicomputer-based CAD installations the requirements of such systems support may vary depending upon the size and the type of operation. For small installations, where no full-time systems analyst is available, the following areas may be considered as training for system support personnel:

- Operating systems of computer
- Macro programming
- System diagnostics
- System "bug" reporting
- Basic hardware maintenance

Management and Operation

Addition of computer-aided design systems to a mechanical design department means somewhat different operating procedures from the traditional methods. These procedures have to be developed and understood by all users in order to assure a smooth operation. The following is a list of some of the items to be considered for such operations.

- Daily records
- Library of drawing files
- Library of drawing symbols and programs
- Archiving procedure for tapes, plots
- Hardware maintenance
- Software maintenance
- Housekeeping and supply maintenance
- Emergency and fire procedures
- Job entry and selection procedure
- Scheduling
- Accounting
- Progress review

V. Human Factors Considerations

The most important element in a CAD system is the human operator. Operators are still responsible for making intelligent decisions and issuing control commands. In order to ensure efficient training and productive work, human factors must be considered. We would like to discuss human factors considerations in two sections: (1) initial preparations prior to training, (2) considerations during training. The emphasis is on the training of designers who are the primary users of CAD systems.

1. Initial Preparation

Prior to training of CAD users, a number of factors have to be considered. *Selection of trainees* is usually the first such consideration. Criteria of selection will vary in each individual installation. Very often, volunteers are requested as a means for selection. However, misunderstandings, rumors, and anxieties have to be cleared up in the department where CAD is about to be introduced.

It is important for potential users and related personnel to *understand what is done by the computer and what is done by the human operator*. Case studies of other installations will highlight the benefits of CAD systems. *Health considerations* in using new equipment, such as a CAD system, should be explained to designers and engineers. Vendors should be able to supply such information as radiation level, hazard statistics, and so forth.

Initial planning of training should also consider a potential *trainees' backgrounds* so that additional education can be added to better prepare them for CAD. In addition to the mathematical and computer preparation mentioned in section IV, some people may benefit from improving their *typing skill* prior to CAD training.

Motivation of potential trainees generally has direct correlation with successful learning and, eventually, productive use of systems. High motivation also relates to *positive incentives* for users to learn CAD and *minimize anxieties* users have towards CAD. In order to assure a high success rate of CAD training, it is important to discuss various issues with each trainee so that there is high motivation for learning.

2. During Training

Learning is a cumulative process. Different people learn at different rates through various means. Therefore, it is important for trainers to develop training programs with good human factors considerations. During training, it would be a mistake to dump a lot of commands and volumes of documents onto trainees without carefully *structuring the training sequence*. It is also important to emphasize the teaching of *concepts* rather than memorization of commands.

An effective training program will require the trainer to *understand trainees' needs and levels of background preparation* The trainer will then plan a curriculum combining *lectures, video tapes, on-line instructions, guided examples, and practice sessions* for a specific group of trainees. *Adequate help* should be available during practice sessions. Therefore, the ratio of trainees to trainers should not be too large. Two persons per terminal and four trainees per trainer seem reasonable for most practice sessions.

Most computer *documentation* is not easy to read for beginners and therefore not good training material. Training materials should be *concise and to the point* with *abundant illustrative examples*. These examples should be divided into gradual levels of difficulties with each emphasizing a *specific concept*. With copious examples, trainees can then pace their own progress during practice and will be able to come back to review these concepts at a later time.

Trainers should also understand that *learning rates of most people are limited*. If too many concepts and commands are introduced in too short a period, these new concepts become noise to the trainees. Not only will the noise not be learned, but it will also induce loss of other concepts due to confusion. Concepts not taught in the initial training class should be included as special subjects to be taught later.

Human factors of training should be considered by both users and system developers in order to make training successful.

VI. Training Program Development

Training programs will be different from installation to installation. They vary with applications, types of trainees, and many other factors. In this section we would like to discuss a training program development for CAD operations. Following the format of the section on "Subject Matter in CAD/CAM Education," this section will answer the following questions:

- How long will training take?
- How to develop an effective training program?

1. Preparation

This category is mainly for people who are assessing CAD/CAM technology and deciding whether it is applicable to their activities. Once applications become evident, they will be involved with evaluation, selection, and installation of CAD/CAM system for their activities. This education usually comes from seminars, system developers, consultants, other users, and papers such as this one. Depending on the individual background and the amount of effort, this preparation can take *from little time to many months*.

2. Basic Commands

Training of basic commands can be accomplished *within one to three days* depending on the extent. Most users should not have difficulties in using basic commands for simple sketches and drawings.

3. Advanced Commands

Learning advanced commands will take more time than learning basic commands. There are new concepts as well as new sequences of commands. The amount of learning effort also depends on how proficient users are with basic commands.

Depending on the extent of advanced commands, it will probably take a *week or two* for most users. Reinforcements on the concepts will be made from time to time. Videotapes and examples will also help in the reviews.

4. Mathematical Preparation

Mathematical preparation will help users to understand some of the special applications and to use graphics programming effectively (e.g., kinematic analysis, tool path editing). There are many ways to go about such preparation. Evening classes on matrix algebra and mathematics are available in many places. Such classes run from *ten to fifteen weeks* per term. For some engineers and designers, only a refresher course is needed. This refresher course can be taught by a qualified person in a few days.

5. **Computer Preparation**

Evening classes on computer programming can be found in high schools, community colleges, and a great many places. Knowing basic concepts about computers and programming will undoubtedly help most beginning CAD users to work with computers better. Computer programming can also be learned with a personal minicomputer. Many such personal computers are available with self-teaching instructions and BASIC programming. This can be a good alternative to prepare potential users in learning about computers. A typical programming course will take about *ten to fifteen weeks* (three hours lecture and six hours laboratory work per week).

6. **Graphics Preparation**

A formal course on computer graphics is usually not suitable for beginning CAD users. The relevant topics in graphics preparation are sometimes system-dependent and thus are better taught by system developers. These relevant topics can be blended in with training on advanced commands. The basic concepts in graphics preparation can be covered in about *one or two days*.

7. **Special Subjects**

Special subjects do not have to be taught to every trainee in the beginning of the training program. In section V.2, we have suggested that these subjects can be addressed at a later time after users have some time to practice basic and advanced commands fully. Special subjects can be taught in individual modules, e.g., making drawings and plots can be one module of *half a day*.

8. **Special Applications**

Learning special applications will require background in the application areas, mathematics, and programming. Depending on the application, training in each special application can be *two or three days*.

9. **User Programming Language**

User programming language should be taught after users become familiar with the particular CAD system. With experience in any programming language, user programming language of a CAD system can be learned in about *a week*.

10. **System Support**

Computer-system-related training is usually offered by computer manufacturers. Training on operating systems, accounting routines, diagnostic procedures, and so forth, can take *four to six weeks*.

11. **Management and Operation**

System developers usually aid in the initial operating procedures. To prepare CAD managers in initial operations, general procedures can be covered in *two to five days*. Later on, such procedures can be modified or redeveloped to suit the needs of a particular installation.

Figure 2 shows a bar chart of the order and span of training time for each of the categories described on the previous page.

Sample Program

The training program can be broken into four phases, based around the dates when a purchase order is issued and when the equipment is installed.

Phase I—Prior to Issuance of Purchase Order

During this phase the major activities are the selection of a particular vendor's system and the determination of how a CAD/CAM system will be applied to achieve the desired return on investment. The people involved with these activities should gain a thorough grounding in those topics listed in section IV.1, Initial Preparation. This will enable them to make intelligent business decisions as to the application of CAD/CAM for this installation. It will also assist in the evaluation of systems, a critical examination of vendor quotes and demonstrations, as well as performance on benchmarks.

Phase II—Between Purchase Order and Installation

Once the selection of a vendor has been made, specific decisions can be made about the details of the training program. The first step is to select the trainees. Given their background and experience it may be useful to start some training in the topics listed under "Mathematics and Computer Preparation." If the decision is made to have in-house computer operating system support and maintenance support personnel in house, such training should be considered for scheduling during this period so those persons can interface with vendor personnel during installation and system break-in. The procedures and management of the pre-CAD/CAM operation should be reviewed. Vendor input can reveal tools that will be helpful after installation, such as accounting procedures and file directories for recordkeeping. These new procedures must be documented and prepared for presentation during the initial training period.

Phase III—After Installation

Training of the initial users in the basic commands should be timed to the installation of the system. In some cases, the vendor will provide this on your new system. This is desirable. In any case, there should not be a time gap between the training on the basic commands and practice with them on your system. For the management, the casual user, and support personnel, this can be the extent of initial training. For the people that will begin to create the data base of designs, this training should be immediately followed by training in the Advanced Commands. At this point, the application of what has been learned can be put to use.

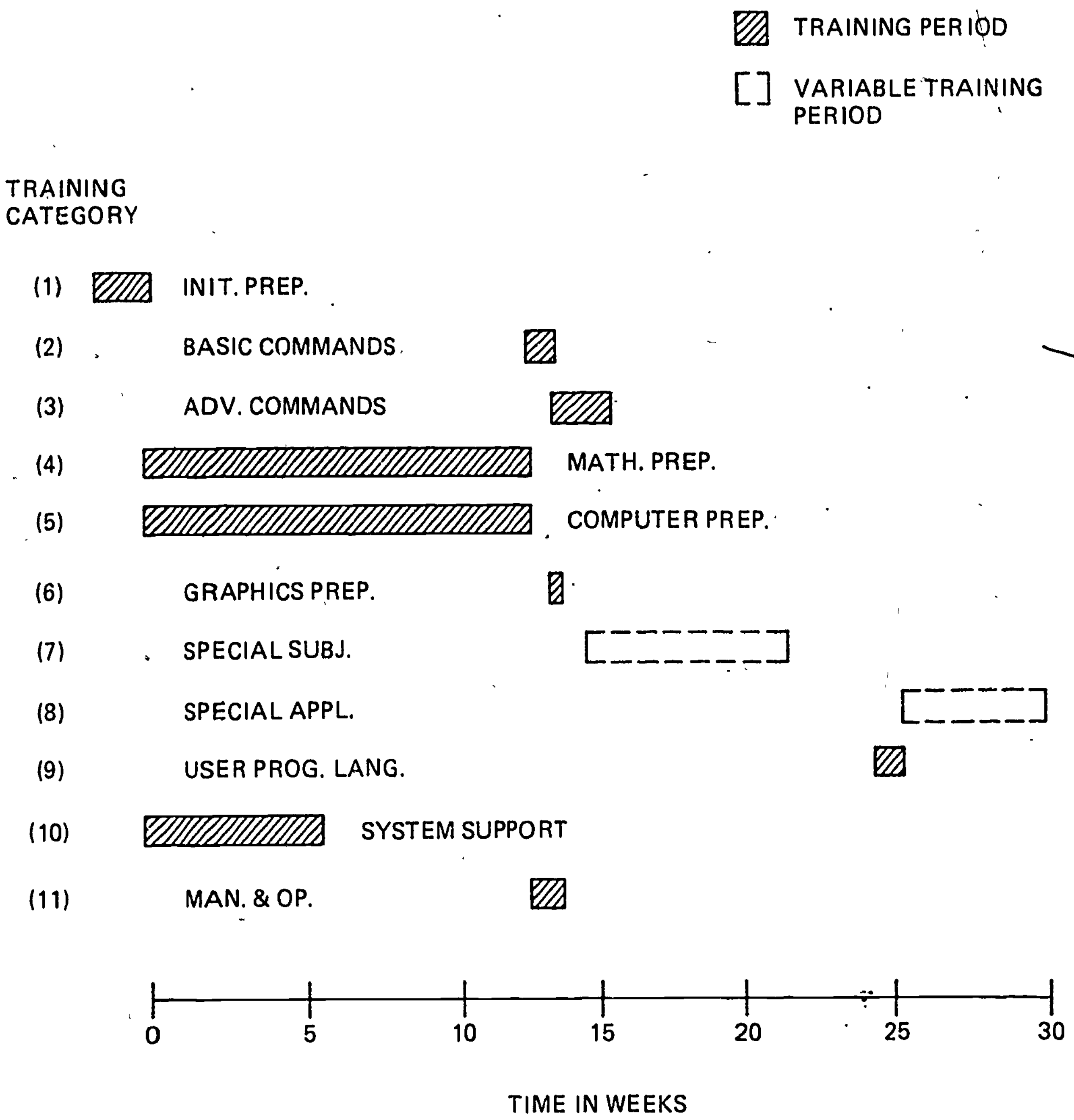

Figure 2. Time Table for a Sample Training Program

It is suggested that the training be immediately put to use on production work with a realization that only fractional productivity may be achieved. A weekly review with users of problems and difficulties is useful. During these reviews, some of the Special Subjects should be presented in seminar form to round out skills necessary for the installation application.

Phase IV—Three Months after Installation

Now is the time to schedule training in the user programming language and special applications. If the initial users are to become specialists, this training can follow directly; otherwise a repeat of advanced and basic commands are necessary. Care should be taken in the training of new users to insure that sufficient "tube" time will be available for the exercise of their newly obtained skills. It is for this reason that a delay of three to six months is recommended, since the timing will allow for the creation of a real data base to which the special applications can be applied.

Short-Cuts

Many short-cuts in training have been taken due to economic reasons or misunderstanding in the importance of training. Users' background preparation is very often neglected due to misconceptions about how easy the systems are to use. Although ease of use may be true of simple tasks of drawing lines and circles, it is not true of cases of using CAD systems for design and manufacturing.

Short-cuts have also been taken in vendor furnished training in preparing a suitable curriculum for trainees and in working out instructional techniques. Dumping concepts and commands on less-prepared users will not help learning. Handing out thick manuals does not help inexperienced CAD designers and engineers either.

Continuing education should not be neglected. Such education can be concept reinforcements, additional background preparation, and special subjects. There is a limit on the amount of training users can absorb during Phase III. The rest of them will have to come gradually in Phase IV.

One alternative training program that may speed up the training process is to train those who have sufficient background in mathematics, computer, and graphics knowledge. They will in turn help to train other in-house users. Recent graduates from many universities and technical institutes are quite well prepared in these areas. Such a method will become attractive in the near future.

Computer-assisted, on-line instruction has not yet been widely used in CAD/CAM training. It can be an effective training tool for many users in mechanical engineering and design. Such a development is yet to come.

CAD/CAM training, like training in engineering disciplines, will not be as effective if short-cuts are taken. What users and vendors should look for are *training aids* rather than short-cuts in order to assure successful training. It will take efforts both from users (in preparing background) and from system developers (in preparing better training techniques) to make training programs more successful.

VII. Conclusions

The length of training, or the amount of learning time to reach full productivity on a CAD/CAM system, is a concern of most users. From the scope of training considerations presented in this paper it should be clear that this question does not have a simple answer. The time required is a function of the following:

- **Background preparation** (e.g., education, experience in CAD-related subjects)
- **Human factors** (e.g., motivation, learning capability, etc.)
- **What the system is used for:**
  - 2-D
    schematics, hydraulic & electric
    plant layout
    mere duplication of manual drafting
    charts and diagrams
  - 3-D
    machines and tools
    dies and fixtures
  - Special applications
    NC
    engineering analysis
- **Effectiveness of training program** (e.g., instructional techniques, places, etc.)

Experience has shown that *six to twelve months* of training and learning are generally needed before real productivity gains become obvious. Productivity in many cases will continue to increase in the following twelve months. Finally, the *wisdom and support of management* in providing a good learning opportunity is essential. A good process is to encourage CAD/CAM designers to *practice methods learned on their regular assignments*, even though initial productivity will usually be well below the conventional method. While management normally wants to show productivity gains (return on the investment), patience is needed to avoid unnecessary stress on the users. The manager should have a realistic perspective on learning time required.

ACKNOWLEDGEMENTS

We would like to thank the management of General Motors Manufacturing Development for their cooperation, and, in particular, Mr. Richard Jackson for suggestions and review of this paper.

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APPENDIX E

OPERATOR CONCERNS SURVEY
UPDATED MAY 1982

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At the May 1979 Applicon CAD users group meeting the results of the first operator concerns survey was presented. The final tabulation of all responses to an update of this survey has been completeа and is contained herein.

I would like to take this opportunity to thank those individuals who participated in the survey. The data is new and should be beneficial to all Applicon CAD users group member organizations.

SURVEY RESULTS

A total of 96 sites responded to the survey. The questions and answers are as follows:

1. Where is your facility located?

   Figure 1 indicates that the bulk of the responses were received from the east coast and midwest.

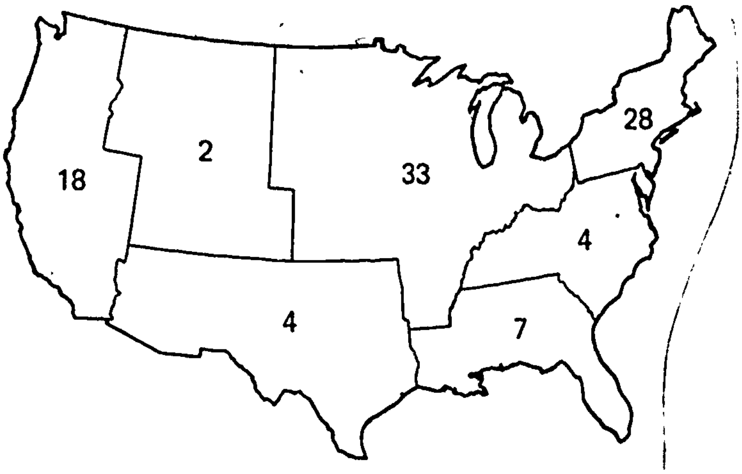

Figure 1

Regional Response

2. Are you using 860, 870, or 880 operating systems?

   Eight sites were only operating in 860, fifteen in 870, and thirty-two in 880. Thirty-eight sites were operating in both 870 and 880 while two locations were using all three operating systems.

3. What are your primary applications?

   Figure 2 indicates that 63 percent of the primary applications are in the fields of mechanical design and drafting, circuit boards and electrical documentation.

66

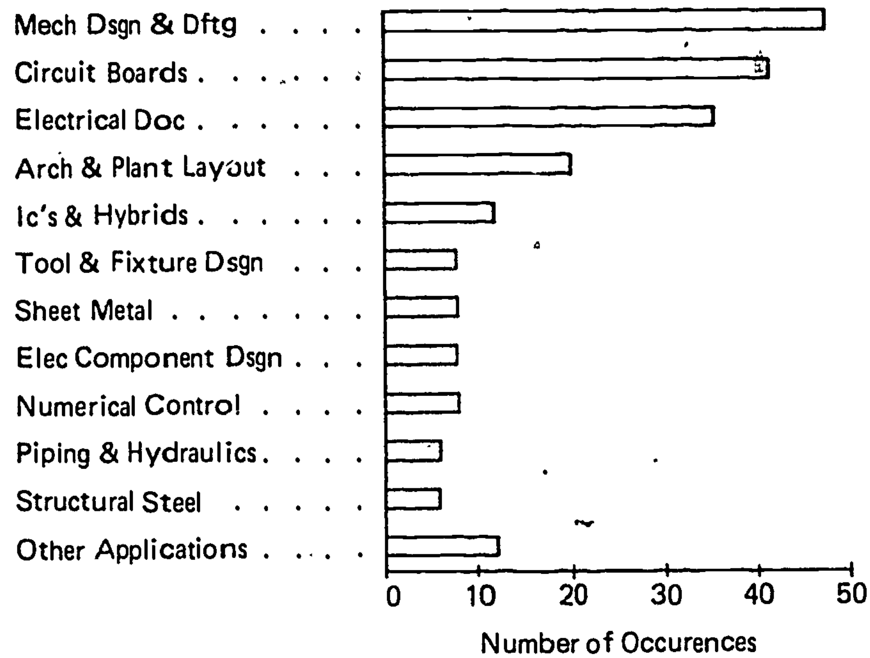

Figure 2
Applications

4. Do you operate on a split shift basis?

   Of the 88 responses, 68 indicated that they do not operate a split shift. The 20 respondees who do, have several different combinations of hours. The most popular were 5-1, 1-9, and 6-12, 12-6.

5. Do you operate a second shift?

   There were 45 yes and 43 no. Several of the facilities were operating 4-10 hour days on the second shift.

6. Do you operate a third shift?

   Only 20 percent (19) of the responses indicated a third shift operation.

7. Do you pay a shift premium?

   Two-thirds of the 77 sites responding to this question pay a premium for second or third shift operation. Figure 3 illustrates the second shift bonuses paid.

   There were two facilities that indicated that full pav for a shorter work period as the bonus.

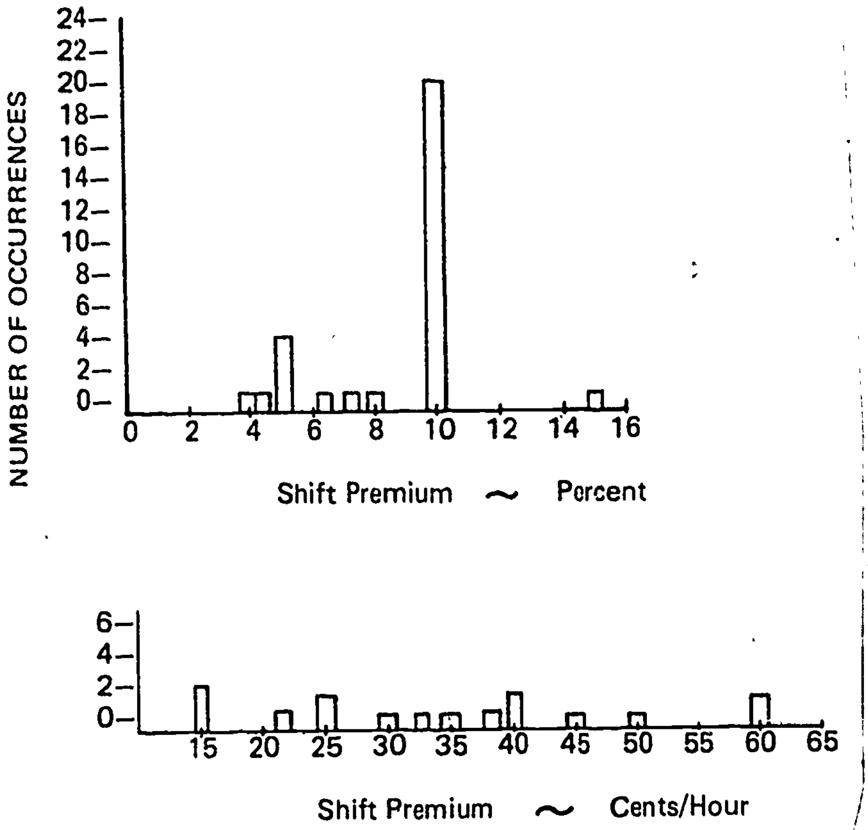

Figure 3
Second Shift Premium

Third shift premiums are shown in Figure 4.

By comparing Figures 3 and 4 you can see that a large percentage of the respondents pay a 10 percent premium for both second and third shift operation. However, if averages are computed you will find that the third shift bonus is slightly higher (9.7 percent vs. 8.6 percent).

Those sites which pay a straight hourly bonus averaged 0.36 cents/hour for second shift and 0.44 cents/hour for third shift.

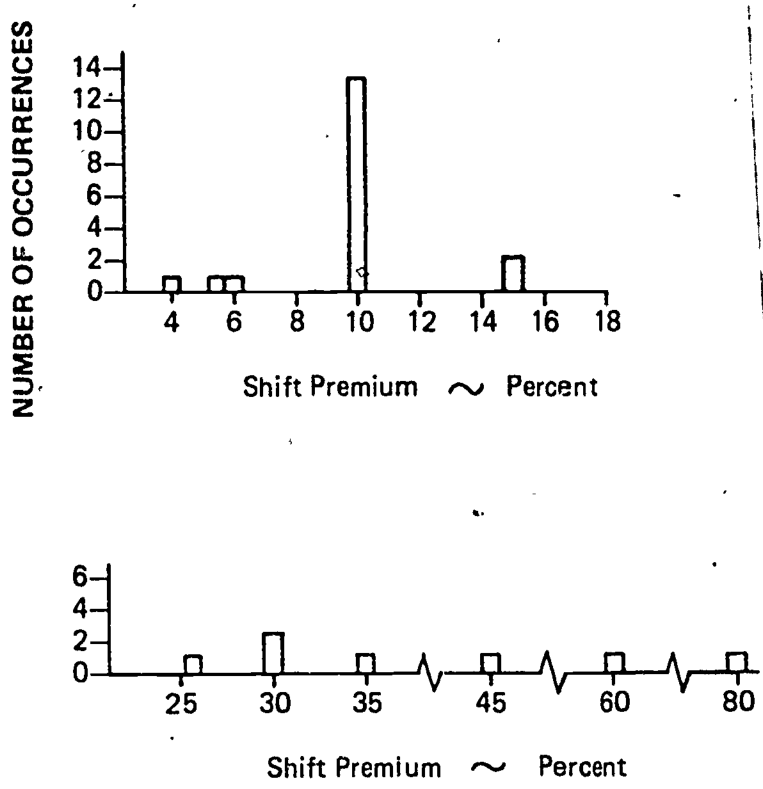

Figure 4

Third Shift Premium

8. Do you experience a difference in absenteeism due to illness between graphic system users and manual drafters?

   Over 87 percent of the respondents indicated that they saw no difference. Of the eleven sites that indicated they did experience a diffe ence all of them thought it was lower.

9. Do you use dedicated plotter operators?

   Approximately 73 percent (seventy) of the responses indicated they do not employ plotter operators. Twenty-six installations responded in the affirmative. Of the twenty-six, nineteen use plotter operators on the day shift only, and seven on two shifts.

   Figure 5 illustrates the salary ranges paid to plotter operators. The salary ranges are presented for both union and nonunion personnel. The numbers below the union and nonunion designations represent the total number of respondents providing salary data in each category.

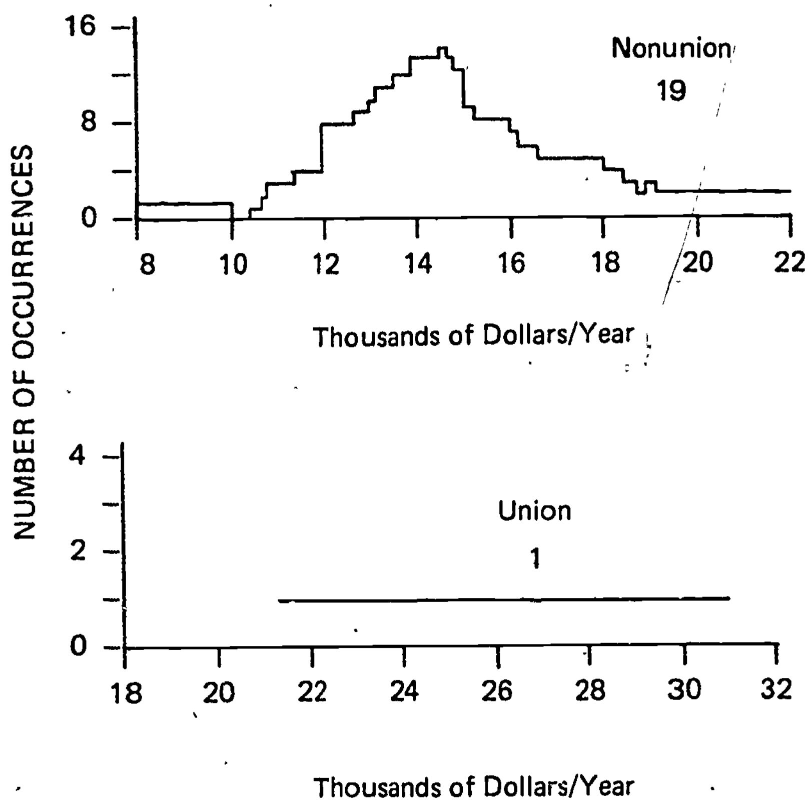

Figure 5

Plotter Operator Salaries

10. The following job description for a plotter operator was derived from a previous survey. Please indicate your desired changes.

The revised job description for a graphics plotter operator is as follows:

GRAPHICS PLOTTER OPERATOR

PRINCIPAL DUTIES AND RESPONSIBILITIES:

1. Operates plotters and/or photographic equipment.
2. Performs limited and/or preventive maintenance on plotters and photographic equipment.
3. Can perform limited assignments involving use of the graphic input stations, teletype terminals, magnetic tape units, and other associated equipment.
4. ◆ Maintain plotter supply inventory.
5. ◆ Performs data archival.
6. Confers with graphic service users.
7. Performs related tasks as assigned.

QUALIFICATIONS

1. High school graduate.
2. Possess mechanical aptitude.
3. ◆ Possess a positive attitude toward CAD/CAM.

NOTE: The " ◆ " denotes additions and/or changes to the job description.

The additional tasks that a graphic plotter operator might be assigned would include recording jobs in and out, operating blueprint machines, running special user commands, etc.

Additional qualifications could Include such things as dark room experience, good eye for quality and typing skills.

11. Are you plotting online or offline?

The majority of the respondents (69) are plotting online while only thirteen plot strictly offline. Nine installations were plotting both online and offline.

12a. Do you have drafting designers using the system and are they exempt or nonexempt?

Sixty-six (73 percent) of the responses indicate use of drafting designers on the system. Fifty-six percent use only nonexempt, 25 percent use only exempt and the remainder use both.

12b. Do you have engineering designers using the system and are they exempt or nonexempt?

Only fifty-one percent (39) use engineering designers on the system. A majority of which (78 percent) are exempt employees.

12c. Do you pay the designers using the system extra because of the added learning required?

Thirty-six facilities responded to this question while only four indicated a pay differential. The reasons stated included the fact that CAD operators move up the ladder faster and are the more experienced personnel. One indicated a pay differential as a result of the additional formal schooling.

13. Do you use dedicated operators?

Almost 75 percent (69) of the sites responding to this question use dedicated operators.

14. Are your operators unionized?

Only ten of seventy respondents ran a unionized facility.

15. Do your operators charge directly to a project or are they considered overhead?

A vast majority (52) of the respondents indicated that their operators charge directly to a project or purchase order. Only 15 sites were considered to be strictly overhead operations. Seven sites stated that their operators charge both directly and/or indirectly depending upon the application.

Figure 6 illustrates the charges/hour applied to the project. From this figure it appears that some sites only charge for labor, some only system time, while others charge for both.

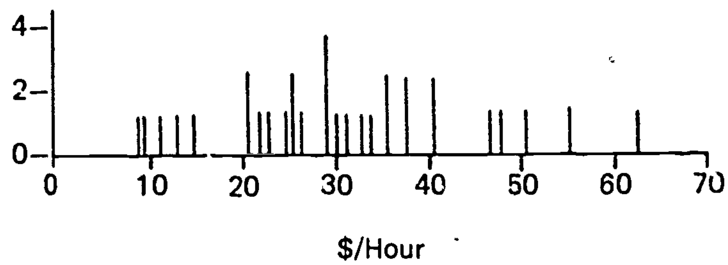

Figure 6

System Charges

It is apparent that before this data can become useful this question will have to be clarified the next time the survey is updated.

6. Do you use on premise contract personnel on your system and if yes what percentage?

Of the 76 respondents only ten use contract personnel. The ratio varied from all contract labor to only 5 percent.

17. In your opinion do tech school computer science certificate grads (two-year) make good operators?

Thirty respondents indicated yes, seven no, while thirty were lacking knowledge in this area. Six respondents stated they would prefer 2 year associate degrees in mechanical drafting.

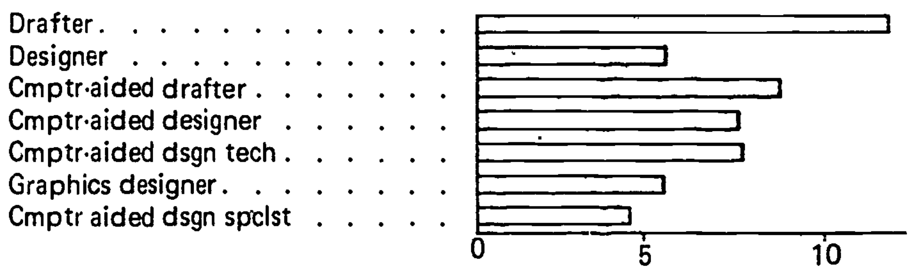

Figure 7

Alternative Titles

18. What other title can be used to classify a graphics operator other than operator?

Figure 7 indicates several alternative titles and the number of those responses. Other title suggestions include CAD/CAM Specialist, Interactive Graphics Specialist, and Computer Graphics Designer.

19. A previous survey indicated two classifications of operators. To distinguish between them they will be designated as "Graphics Operator" and "Senior Graphics Operator." Please indicate your desired changes.

The revised job description for a Graphics Operator is as follows:

GRAPHICS OPERATOR

PRINCIPAL DUTIES AND RESPONSIBILITIES:

1. Operates a computer graphics terminal to create, modify, delete, transfer and plot graphic files.
2. Prepares graphic files from sketches, prints or verbal instructions in accordance with established procedures and standards.
3. Can perform system start-up, system shut-down, disk swapping and magnetic tape operations.
4. Confers with graphic service users.
5. In addition, a Graphics Operator may be required to perform the duties of a Graphics Plotter Operator.

QUALIFICATIONS

1. High school graduate.
2. Two years engineering graphics experience or equivalent technical education.
3. ◆ Typing skills preferred.
4. Successfully complete on-the-job training program.

NOTE: The " ◆ " denotes additions and/or changes to the job description.

There were a number of responses that indicated that responsibility #3 and qualification #2 should be eliminated. Also three responses asked that an additional qualification should state "show a positive attitude towards CAD/CAD."

The revised job description for a Senior Graphics Operator is as follows:

SENIOR GRAPHICS OPERATOR

PRINCIPAL DUTIES AND RESPONSIBILITIES:

In addition to performing all of the functions of a Graphics Operator a Senior Graphics Operator is required to:

1. Have an understanding of fundamental drafting and/or illustrating practices and have the ability to scale, layout, and construct graphics output.

2. Have an understanding of system commands and be capable of editing symbols, writing macros, and creating menus.

3. Assist in adapting the graphics system to new applications and/or maintaining existing applications.

4. Assist in training operators.

5. May be required to take a lead position when on the second or third shift.

QUALIFICATIONS

1. Meet the qualifications for a Graphics Operator.

2. Perform satisfactorily as a Graphics Operator for a minimum of eighteen months or have a minimum of three years experience in engineering graphics or possess a two-year technical degree with one year of experience.

There were some who felt that responsibilities #3, #4, and #5 should be eliminated. Also the time of experience in qualification #2 should be changed in both directions.

20. Please indicate the salary range for the Graphics Operator and Senior Graphics Operator classifications.

A composite of the salary ranges, received in the responses, for Graphics Operators is shown in Figure 8. The data is presented for both union and nonunion operators. The numbers below the union and nonunion curve designations indicate the number of respondents.

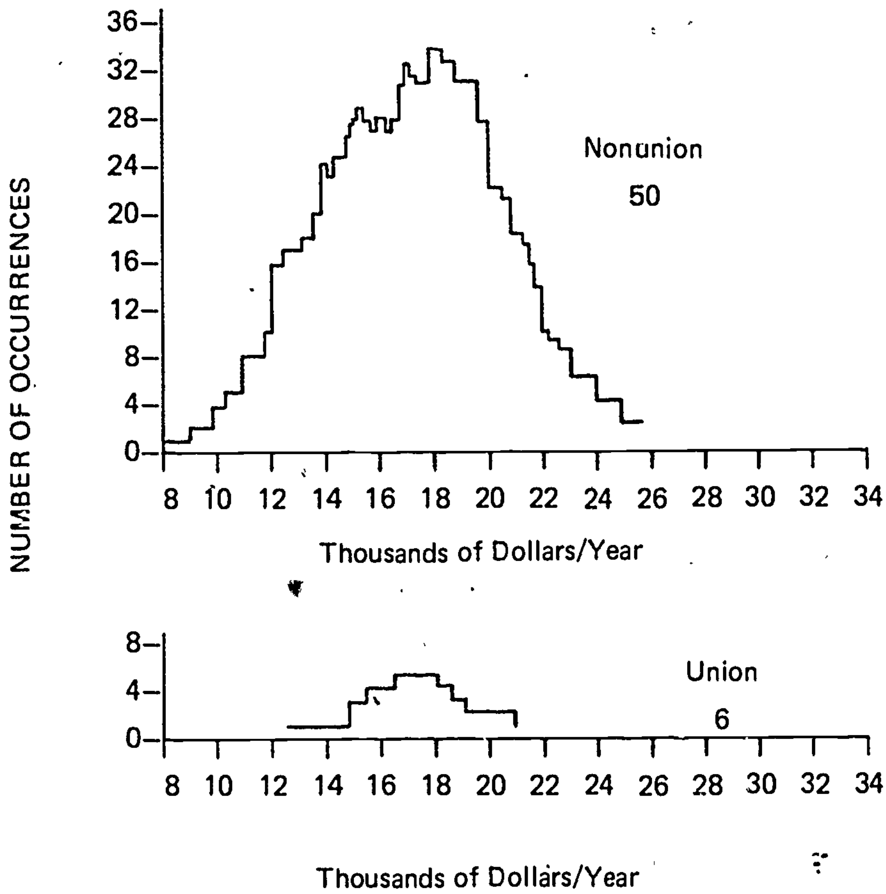

Figure 8

Graphics Operator Salaries

Figure 9 shows the composite of the salary for Senior Graphics Operators.

Note the different starting values on the salary axes for Figures 8 and 9.

The average salary from Figure 8 appears to occur at approximately $17K, however there are peaks at 15K and 18K. Figure 9 has a definite peak at approximately 24K but also has a disturbance around 18K. Assuming that the 15K and 18K peaks are the salary levels for the two operator classifications there has been a significant increase in salaries since the 1979 survey. The 1979 survey indicated that 11K and 13K were the national average salaries for the same operator classifications.

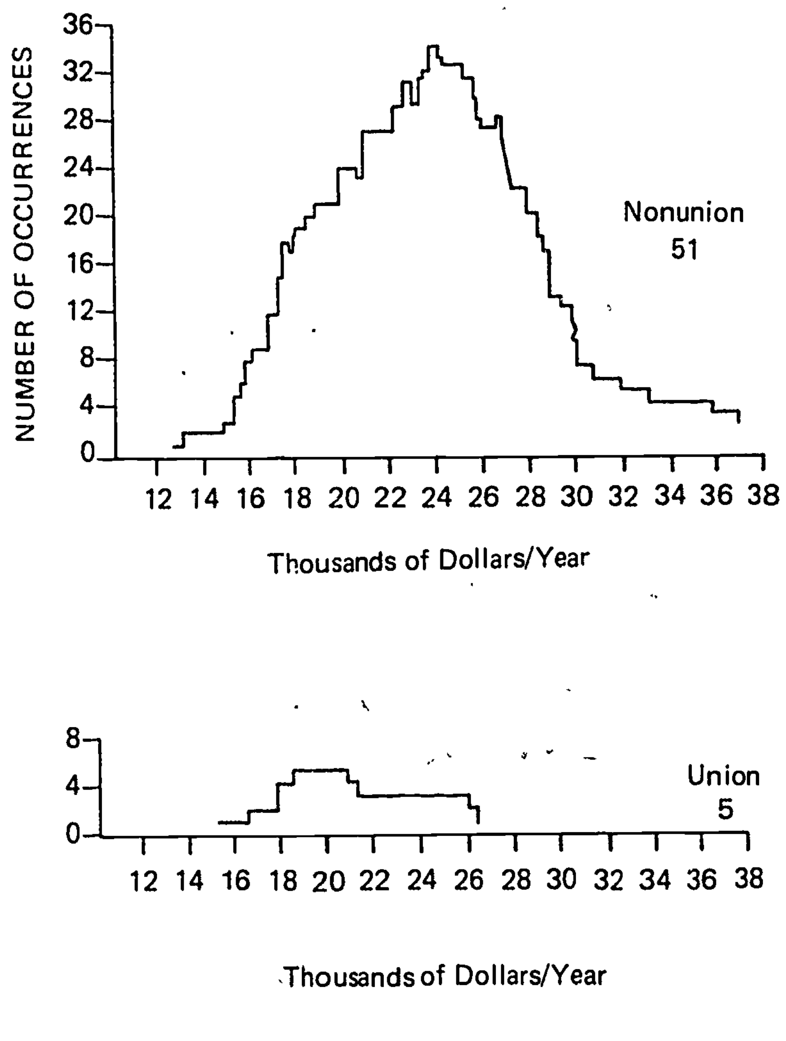

Figure 9

Senior Graphics Operator Salaries

21. Do you feel that the salary range is adequate for each classification?

A majority (52) indicated that the salaries they pay is adequate. However, four managers felt that the compensation was insufficient for the knowledge and ability required, especially for those operators who did not come from the drafting ranks.

22. Are the salary ranges higher, lower, or equal to an equivalent drafting position?

Fifty-one sites reported equal renumeration, fourteen higher and only one lower. The one that was lower stated that drafters have a well established position within the company compared to Graphic Systems Operators. Those that paid higher salaries felt it was justified because of the added learning required, additional mental and physical stress and short supply of qualified personnel.

23a. Do you feel that your operators are receiving proper recognition from your management?

Almost two thirds (56) of the respondents felt their operators receive proper recognition. However, it is quite significant that over one third (35) of the responses indicated a lack of understanding on management's part. In general those who gave a negative response felt that the extra skills required to become a productive graphic system user were underrated.

23b. Is there a solution to the management recognition problem?

A majority of that offered solutions felt that new job descriptions and education of management were the key answers. Another solution suggested was to deliver the goods on time.

24. Are your operators satisfied with their salaries?

Of the 85 responses received, 29 stated that their operators were not completely satisfied with their salaries. The reasons given include, not enough compensation for the added exposure, responsibility and training involved.

25. Do your operators enjoy what they are doing?

All responses stated that their operators were satisifed with their occupation.

26. Do you have lead personnel who establish procedures and/or prepare work for your operators?

Sixty-one of the sites that responded to the survey use lead operators while thirty-two do not. Of the 61 installations using lead operators, forty-eight use them on day shift only, and thirteen, two or more shifts.

27. A previous survey produced two classifications of lead personnel. For clarification purposes they shall be designated as "Graphics Designer" and "Senior Graphics Designer." Please indicate your desired changes.

The purpose of presenting the job descriptions is to provide a basis for the new user to develop their own customized job descriptions. The established user can use these job descriptions to provide a standardized format for communicating with other facilities concerning operator classifications.

There were several minor changes proposed to the Graphics Designer job description. The most prevalent concerned the experience factors stated in the qualifications section. There was a feeling that the number of years should be reduced by one in all cases and a four year technical degree could suffice for the required experience.

Some of the changes proposed for the Senior Graphics Designer included maintaining state-of-the-art technical skills, have supervisory training, reduce the experience factor by one year and add a four year technical degree as an alternate experience qualification.

The unchanged job description for a Graphics Designer is as follows:

GRAPHICS DESIGNER

PRINCIPAL DUTIES AND RESPONSIBILITIES:

1. Develop, maintain and document application procedures.
2. Establish communication formats for transfer of information between the autographics facility and users.
3. Train and provide guidance to assigned personnel in the operation of equipment and application procedures.
4. Schedule work for assigned personnel and maintain a work history file.
5. Responsible for maintaining data in accordance with standard procedures for their assigned applications.
6. Assure the accuracy and quality of all graphics produced by assigned personnel.
7. Review incoming jobs for clarity of interpretation and conformation to established standards.
8. Determine tasks which can be automated via user commands.
9. Perform the duties of a Senior Graphics Operator when required.

QUALIFICATIONS:

1. Meet the qualifications for a Senior Graphics Operator.
2. Perform satisfactorily as a Senior Graphics Operator for a minimum of eighteen months or have a minimum of five years' experience in engineering graphics or possess a two year technical degree with three years of experience.

The unchanged job description for a Senior Graphics Designer is as follows:

SENIOR GRAPHICS DESIGNER

PRINCIPAL DUTIES AND RESPONSIBILITIES:

1. Be capable of performing system functions such as loading system software, adding software patches, generating system software tapes, formating disks, and performing failure diagnostics.

2. Establish accounting privileges for the operators and casual users.

3. Maintain equipment downtime problem/solution logs.

4. Utilize new and existing knowledge of software, hardware and procedures to develop new applications, techniques and methods.

5. Provide troubleshooting and technical assitance to operators, casual users and associates.

6. Resolve complex arrangement of graphic symbols to facilitate entry into the system.

7. Evaluate the potential for interface with other CAD/CAM activities.

8. Perform the duties of a Graphics Designer.

QUALIFICATIONS:

1. Meet the qualifications for a Graphics Designer.

2. Perform satisfactorily as a Graphics Designer for a minimum of eighteen months or have a minimum of seven years' experience in engineering graphics or possess a two-year technical degree with five years of experience.

28. Please indicate the salary range for the Graphic Designer and Senior Graphic Designer classifications.

The salary range for Graphic Designers is shown in Figure 10. The data is presented for both union and nonunion personnel. The numbers below the union and nonunion curve designations indicate the number of respondents.

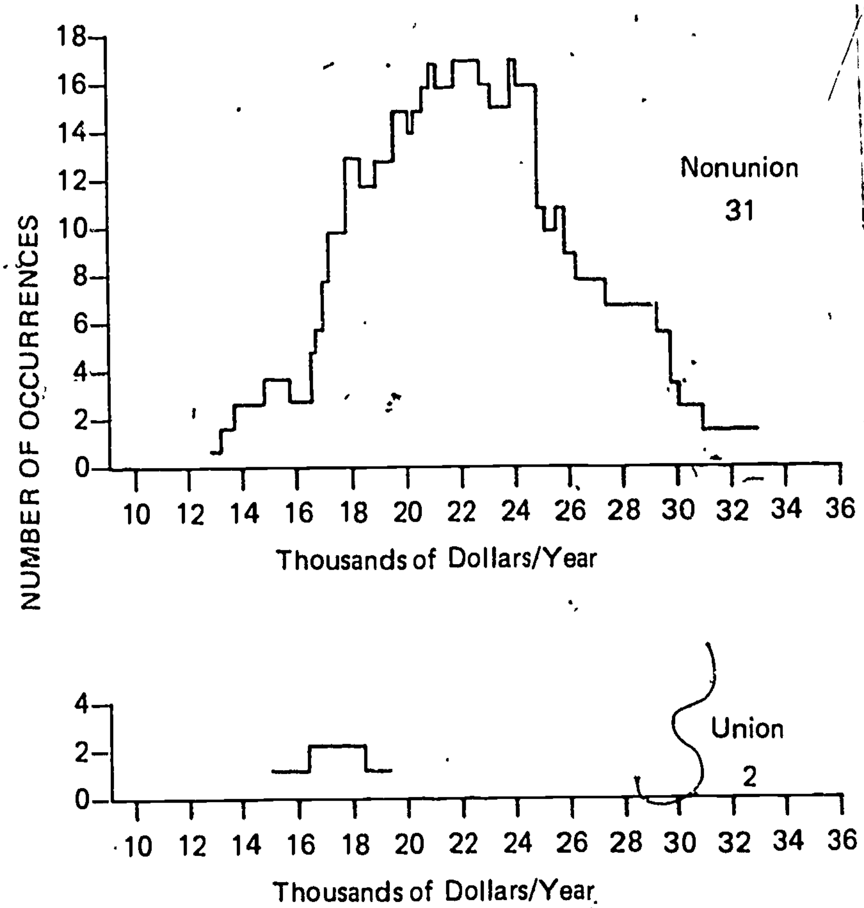

Figure 10

Graphic Designer Salaries

The salary range for Senior Graphic Designers is shown in Figure 11.

Figures 9 and 10 are similar to the salary curves for the Graphics Operator classifications shown in Figures 8 and 9. They each show multiple peaks. In fact the correlation in peaks between curves further justifies the conclusions reached concerning the operator salary levels.

From Figure 10 and 11 it can be assumed that the Graphics Designer and Senior Graphics Designer salaries average approximately $23K/year and $30K/year respectively.

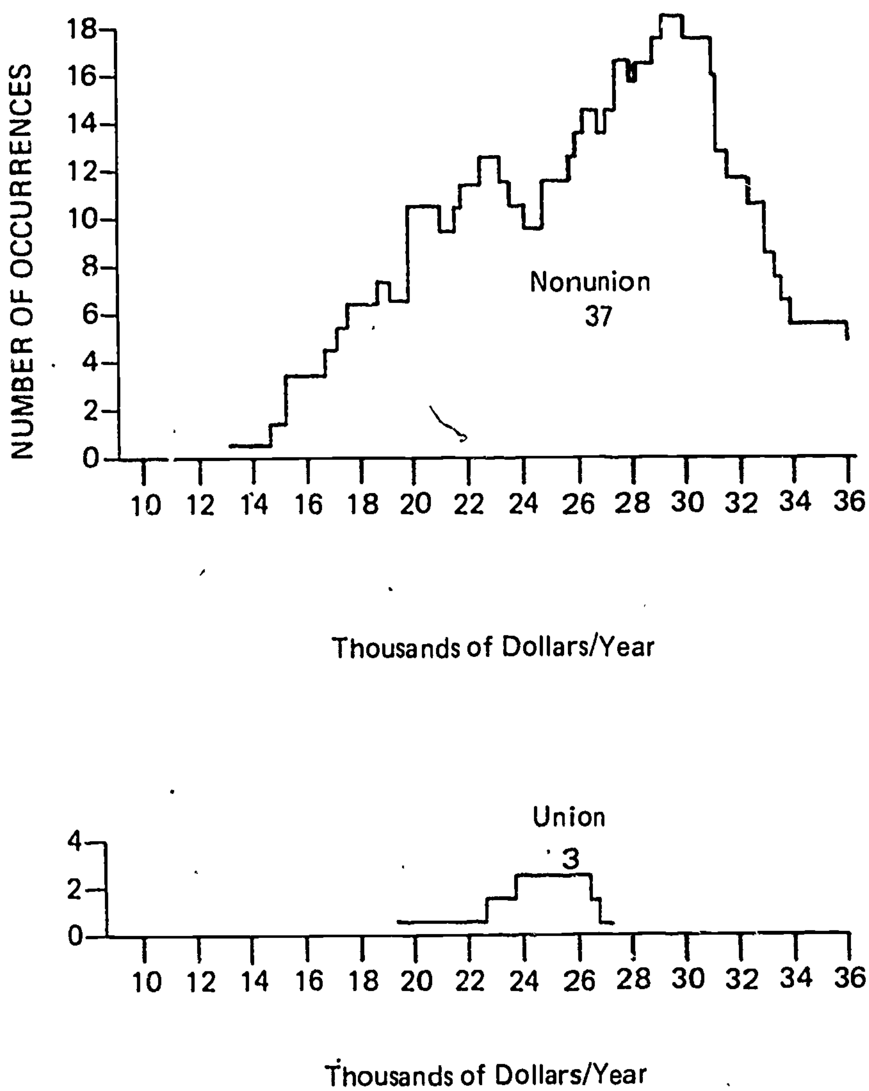

Figure 11

Senior Graphic Designer Salaries

29. What is the background of your system manager?

Eighty-one responses were received. They indicated that one-half (41) of the managers were from a design-drafting background, one-third (29) had an engineering background, while the remaining came from various disciplines such as computer operators, programmers, etc.

30. What do you consider the ideal organization? Please provide a sketch.

There were fifty-four organization charts submitted as being the ideal solution to managing a computer graphics facility. From this input there appears to be two schools of thought as to how the organization should appear. Approximately one-third of the respondents felt that the organization should include a programming staff while two-thirds omitted this function. A like number felt that a plotter operator was not necessary.

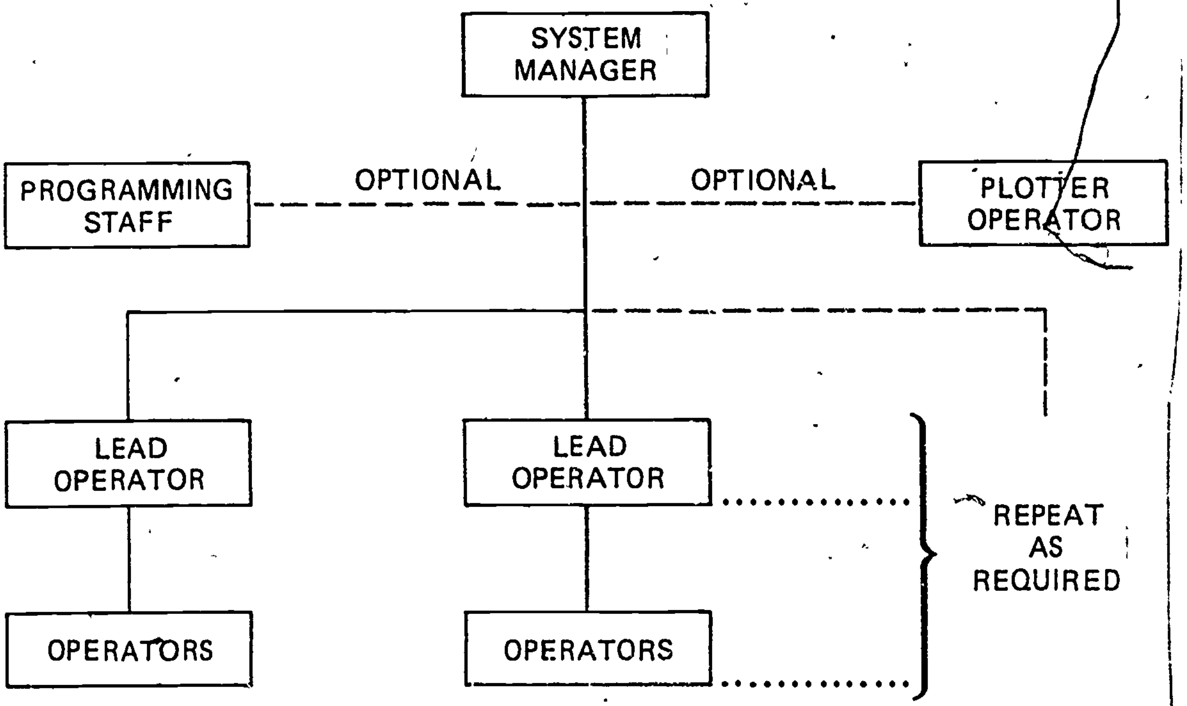

Figure 12
Ideal Organization Chart

31. Does this describe your organization?

Sixty-one sites answered this question. Only 24 of the responses felt that their organization was ideal for their application while 37 indicated a need for change.

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