1989

Analysis of CAD/CAM systems :

Stephen K. Deutsch
Lehigh University

Analysis Of CAD/CAM Systems:

Planning, Implementation, and Evaluation

by

STEPHEN K. DEUTSCH

A Thesis

Presented to the Graduate Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Manufacturing Systems Engineering

Lehigh University

1988

This thesis is accepted in partial fulfillment of the requirements for the degree of Master of Science.

December 9, 1988

(date)

Professor in Charge

Project Director

M U Thomas

Chairman of Department

Acknowledgements

1 Acknowledgements

The following individuals and/or companies have been very helpful in participating in the CAD/CAM users survey in this report.

- Mr. Paul Pepin, GM - Delco Automotive Components
- Messrs. Bill Lusby and Art Darr, General Dynamics Fort Worth Division
- Mr. Dan VandenBossche, Chrysler Motors
- Mr. Harold Schweitzer, Doehler Jarvis Company
- Mr. William Widmer, General Dynamics Electronics Division
- Messrs. Dwight Blaser and Calvin Mitcham, General Motors Research Laboratories
- W. F. Wagner, E.I. Du Pont De Nemours & Company
- Mr. Tom Gill, Bell and Howell
- Mr. James Hayes, Boeing Helicopters
- Mr. Bruce E. Hausser, Grumman Aircraft Systems
- Jacob Pattern Works, Pottstown, Pa
- R. Biekert, Garrett Engine Division of Allied-Signal Aerospace
- Mr. Manohar Prabhu, IBM Essex Junction, Vermont
- Madison-Kipp Corporation, Wisconsin
- Westhoff Tool and Die
- Mr. Davis Fleming, Webster Manufacturing, Canada
- Ingersoll-Rand Corporation, Process Machinery Division
- Mr. Wayne Divoky, Caterpillar Tractor Company
- Bally Engineered Structures, Inc.
- Mr. Richard Ernest, Penn Mfg. Company

The following have contributed to the quality issue in terms of CAD/CAM system vendors:

Suzanne Shouman, Hewlett Packard Electronic Design Division

Bridget Shycoff, CADAM Inc.

A special thanks to Dr. Keith Gardiner, Director of Lehigh University's Manufacturing Systems Engineering Program for his valuable direction, advice, and information for this thesis, Mr. Ronald VanNostrand of Simmonds Precision Corporation, Mr. Derek Cocks of the American Die-Casting Institute, Mr. Neiland Pennington of *Modern Metals Magazine*, the Die-Casting Development Council, and American Society for Quality Control.

Thanks also to Dr. Ben Litt of Lehigh University for his "Systems Thinking" help, and the Lehigh University Manufacturing Systems Engineering Program faculty for their dedication to modern manufacturing methodologies and principles.

Table of Contents

List of Figures

List of Tables

Abstract

CAD/CAM systems play a vital role in modern manufacturing. The justification and implementation issues reach beyond technical boundaries and involve financial aspects, human perspectives, systems thinking, and organizational change. The issue of quality is addressed in terms of the CAD/CAM system and the end product.

There have been many successful CAD/CAM system implementations, but there also are many that have not been properly planned. This thesis describes and discusses the results of a CAD/CAM Usage/Performance Survey undertaken across a range of companies with both negative and positive experiences.

A hypothetical CAD/CAM implementation plan for a die-casting company is developed.

Chapter 1
Introduction

Computer-Aided Design and Manufacturing (CAD/CAM) is a very vital part of modern manufacturing. This thesis covers a brief background of the evolution of CAD/CAM and what the future holds for this technology and its next phase. There are very many textbooks written on the subject of CAD/CAM system implementation and justification issues, but with a very "cookbook" type approach. The intention of this report is not to follow this type of structure, but to focus on issues which are relevant to today's CAD/CAM manager, user, and interested customer.

As a result of a literature search undertaken involving historical data, as well as current periodicals, a CAD/CAM usage/performance survey was developed that was sent to 63 companies across the U.S, and Canada, to gain an appreciation for the current and anticipated conditions facing these companies in regard to CAD/CAM. 22 of the 63 responded to the survey which is detailed in chapter 5. This thesis also presents implementation and justification issues in CAD/CAM systems, details a case study of a successful CAD/CAM system implementation, discusses the human, organizational, and technical issues of technology implementation, devotes a chapter to the issue of quality from a CAD/CAM "Systems" perspective, and finally develops a theoretical CAD/CAM implementation procedure for a die-casting firm.

In addition to covering basic topics on how to install, select, and manage a CAD/CAM system, this thesis raises issues that have either been noticeable, but not really focused upon. It addresses emerging sensitivities to the technology transfer issue that U.S. companies are facing due to increased global competition.

1.1 CAD/CAM: Where We Have Been And Where We Are Headed

1.1.1 A Brief History Of CAD/CAM

CAD/CAM - Computer-Aided Design / Computer-Aided Manufacturing can be considered a relatively new technology, dating back to the late 1960's. However, it's growth rate is notable and increasing at a healthy pace. It was pioneered and developed in the United States and now is an international byword in the complex manufacturing society of the 1980's. Boeing Aircraft Company defines CAD/CAM in the following way:

- **CAD** - The application of computer technology to the design of a product. This includes layouts, detail design, analysis, drafting, and formal release of design data.
- **CAM** - The application of computer technology to the fabrication, assembly, and verification of a product that does not depend on an cannot productively use CAD data.
- **CAD/CAM** - The application of computer technology to the fabrication, assembly, and verification of a product that directly depends on using specific CAD data.
- **Integrated CAD/CAM** - Although somewhat redundant, this term is used to define a purposeful working relationship between manufacturing and engineering that results in specific CAD activity to meet specific CAM requirements.

The first digital computer was operating around forty years ago in a military application, with minimal impact on outside industry. The development of CAD/CAM began in the computer graphics arena. MIT was involved in the 1950's with work on multi-access computing activities and in the 1960's in aerospace applications. The development of the aerospace and computing activities concurrently led to the first workable Numerically Controlled machine tool at Landis Tool Division of Litton Industries.

Early NC applications were a direct result of the pioneering work of John

T. Parsons who developed an automatic machine tool controller to allow interpolation of curved surfaces on a milling machine. The aviation industry took advantage of this technology and the early advent of computer systems and computer-aided manufacturing techniques was born. However, the early processes were not without bugs and glitches. There was no standardization for NC tapes and each manufacturer bold enough to attempt computer-aided NC developed his own recipe. Figure 1-1 shows an early business plan graphic for a CAD system.

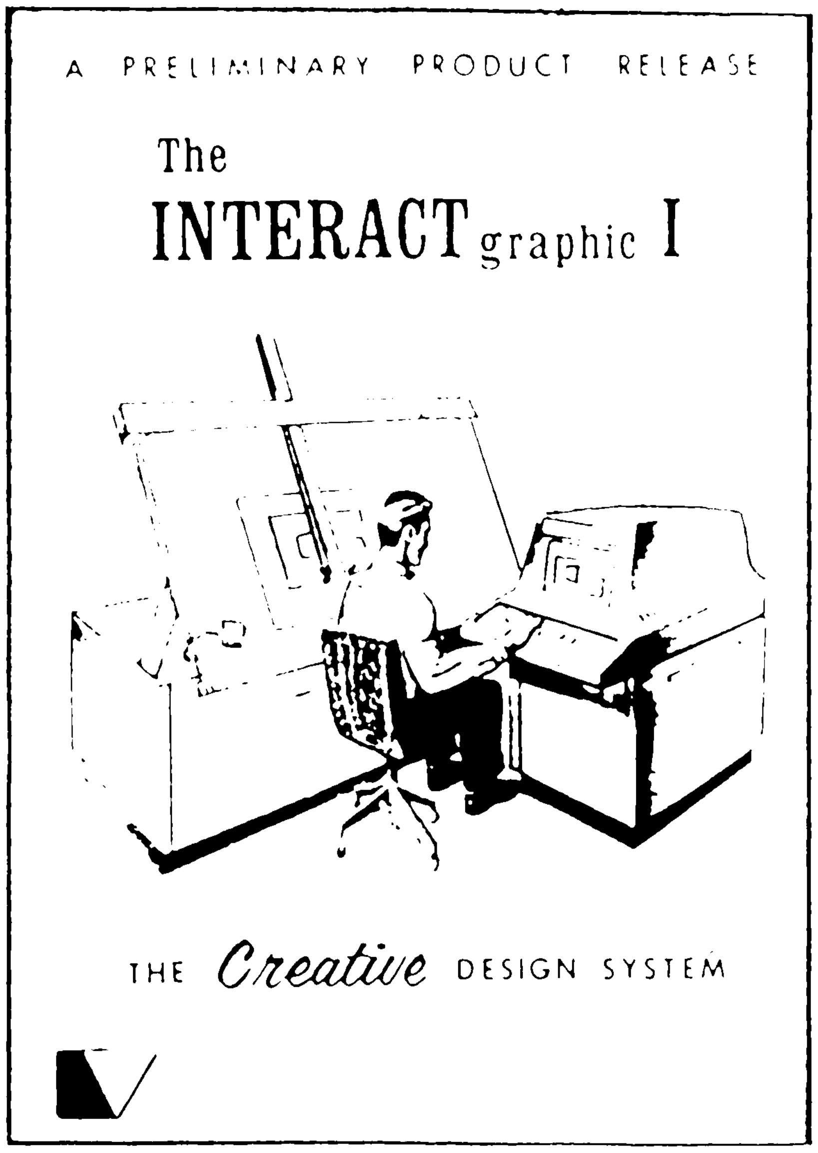

Figure 1-1: An Early CAD System Business Plan.*(Courtesy of Computervision)*

The advent of the programming language APT (Automatically Programmed Tools) developed by Illinois Institute of Technology, based upon initial work at MIT, aided the beginning of more standardized toolpath generation for cutting tools. The initial parts were simple 2-dimensional lines and curves, but the term NC was firmly recognized in manufacturing by the mid 1960's. By 1965, more advanced (compared to the early 1960's) NC hardware and control systems were developing. The APT language began to evolve to other applications such as creating drawings.

Later in the 1960's APT was able to do complex mathematical calculations and saved programmers valuable time. In 1973 Boeing engineers adapted APT to create a variation of the language to produce drawings. These technical prospectors began to build a database of APT programs that became the future method of building drawing libraries. APT enhancements to create lofted surfaces was a great benefit to the Boeing operation [26] [7].

The transfer of data between designers and manufacturers was a major issue at that time, even with the advent of better computing capabilities. In 1972, an organization called CAM-I (Computer-Aided Manufacturing International) was formed to pool the knowledge base in this burgeoning field. Companies were beginning to form CAD/CAM groups and the need for standardization issue was being addressed.

1.2 Interactive Computer Graphics Emerges

The development of interactive computer graphics began in the research labs of GM, GE, and McDonnell Douglas in the late 1960's, but did not emerge to the "shop floor" until around 1974. Early work on the theoretical basis for Computer graphics occurred in the 1960's by MIT's Dr. Ivan Sutherland and Steve Coons. In the mid 1960's, commercial CRT graphics terminals were offered by such companies as Control Data, Digital Equipment, IBM, and others. The link to develop interactive systems was on the horizon. The Offutt Air Force base in Nebraska was also involved with the development of a batch and interactive system during this time. Through the 1970's this system successfully linked computational, storage, and data management with an intelligent graphics device. Early terms such as "electronic displays" or "computer-controlled" became recognized as computer graphics.

The emergence of computer graphics began in the design area and allowed designers to communicate with the computer and realize the results of their work immediately. The CAM side of CAD/CAM was not a distinguishable feature in the early computer graphics systems, but the gradual union occurred throughout the 1970's as companies such as Computervision and Applicon grew. Numerical Control also emerged in other environments and spawned CNC (Computer Numerical Control) and DNC (Direct Numerical Control). Its application grew to a variety of drilling, milling, inserting, inspection, and other applications. The entire concept of CAD/CAM was a logical union of the computer graphics development, NC evolution, and the interactive design capabilities of the systems at that time. Figure 1-2 presents a mapping of events which led to computer graphics.

1.3 CAD/CAM As We Currently See It

The CAD/CAM world has experienced growing pains due to its emergence as a necessary technology. The rapid memory expansion of computer chips throughout the late 1970's and 1980's has caused the nature of systems to change. CAD/CAM systems were originally centered around a host computer which was a major capital outlay for a company. The computing speed of early systems was better than manual methods for creating designs and manufacturing the parts on NC machines. Figure 1-3 illustrates a typical aerospace design environment in the 1960's. Figure 1-4 represents the design environment of the 1980's.

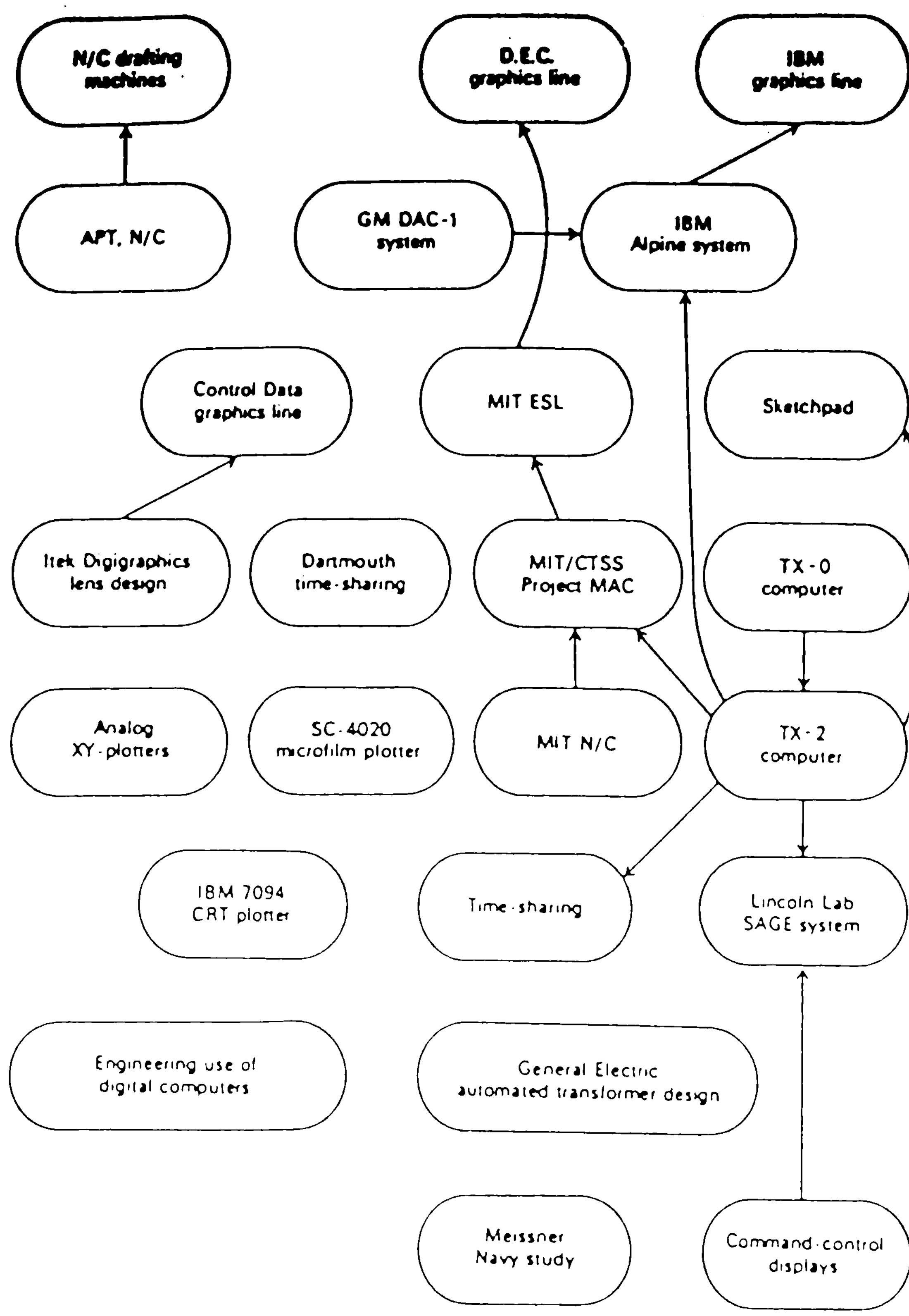

Figure 1-2: **Technological Milestones Leading To Computer Graphics.** *(Courtesy of Addison-Wesley Publishing Company)*

The increased capabilities of silicon chip technology began to overwhelm the processing speeds which had been identified. This boom began to reduce computing costs significantly. Downsizing of CPU's became evident in the late 1970's and the advent of powerful mini-computers, personal computers and super-mini and microcomputers through the 1980's eroded the central host computer stranglehold. "Faster, better, cheaper" was and is a constant expectation for the computer industry and CAD/CAM systems suppliers. The day of the

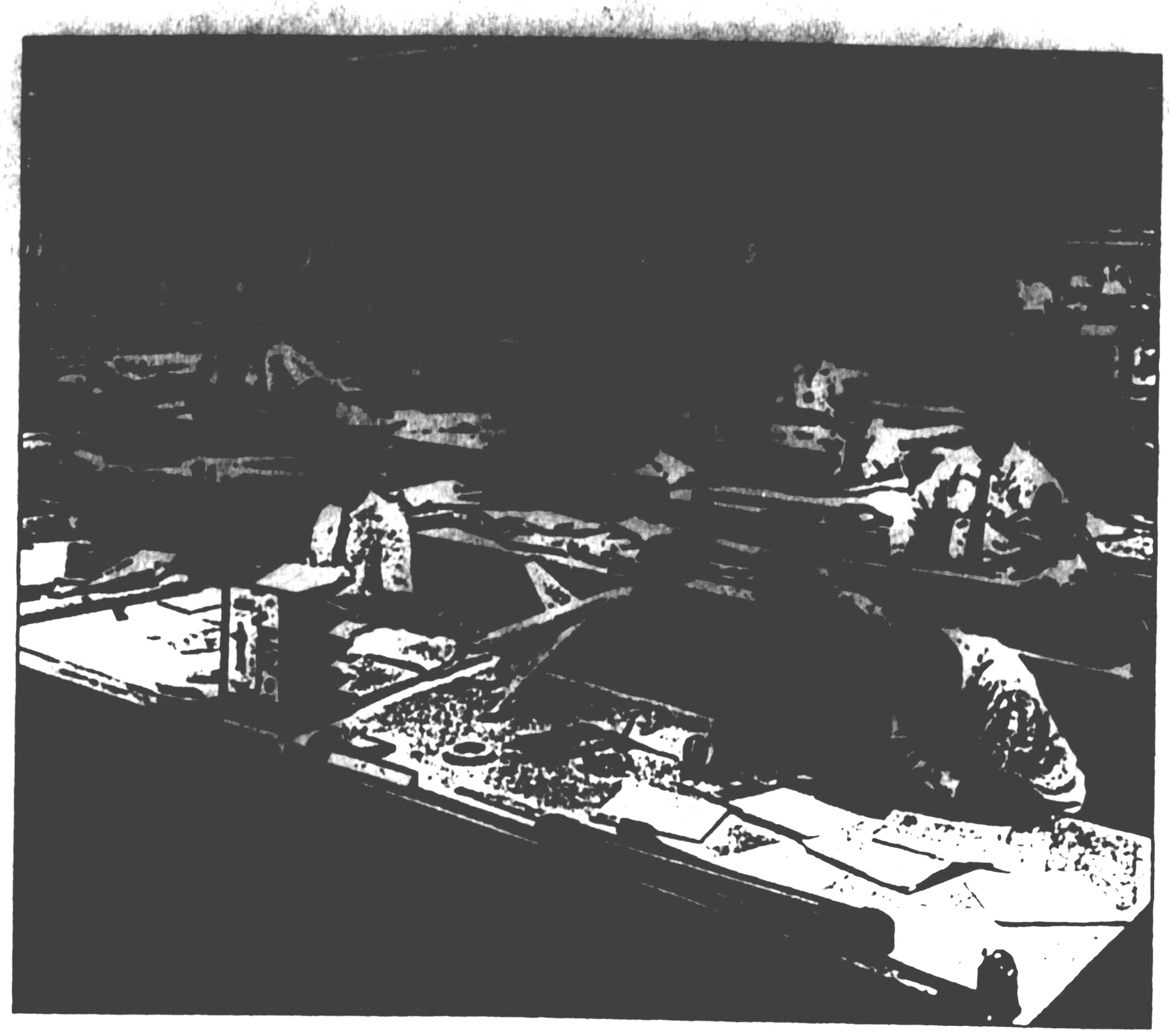

Figure 1-3: Design environment of the 1960's.*(Courtesy of Boeing)*

multi-megabyte silicon chip is here and computing speeds are increasing at a phenomenal rate.

The early CAD/CAM systems with refresh CRT's and relatively slow response time is antiquated when compared to today's CAD/CAM systems that offer color CRT's with local processing capabilities, solids modelling and finite element analysis packages. PC-based platforms are now a necessity to offload the design task from the host central computer and place it at the designer's desktop computer. This distributed environment is growing in acceptance at many companies that utilize CAD/CAM and will eventually be the standard. An article in "CAD/CIM Alert" noted that only one new company has entered the turnkey systems business, signalling the end of this market segment [3]. Most of the major turnkey vendors now offer their proprietary systems for PC or workstation platforms.

Figure 1-4: Design environment of the 1980's.*(Courtesy of Boeing)*

1.3.1 Integrated CAD/CAM Must Be More Than A Concept

The concept of integration must be accepted and practiced in order for CAD and CAM to exist as one single entity. There is still a large gap between the design and manufacturing data bases in terms of how they are related and utilized in many companies. Design information must be accessible and relevant to manufacturing in order for a smooth exchange of function to exist. CAD data which is developed independently of CAM functions is basically using a new technology to automate old practices of design it, turn it over to manufacturing and let them build it. Automating old problems makes them more complex, and does not solve them. Figure 1-5 illustrates the integrated CAD/CAM concept.

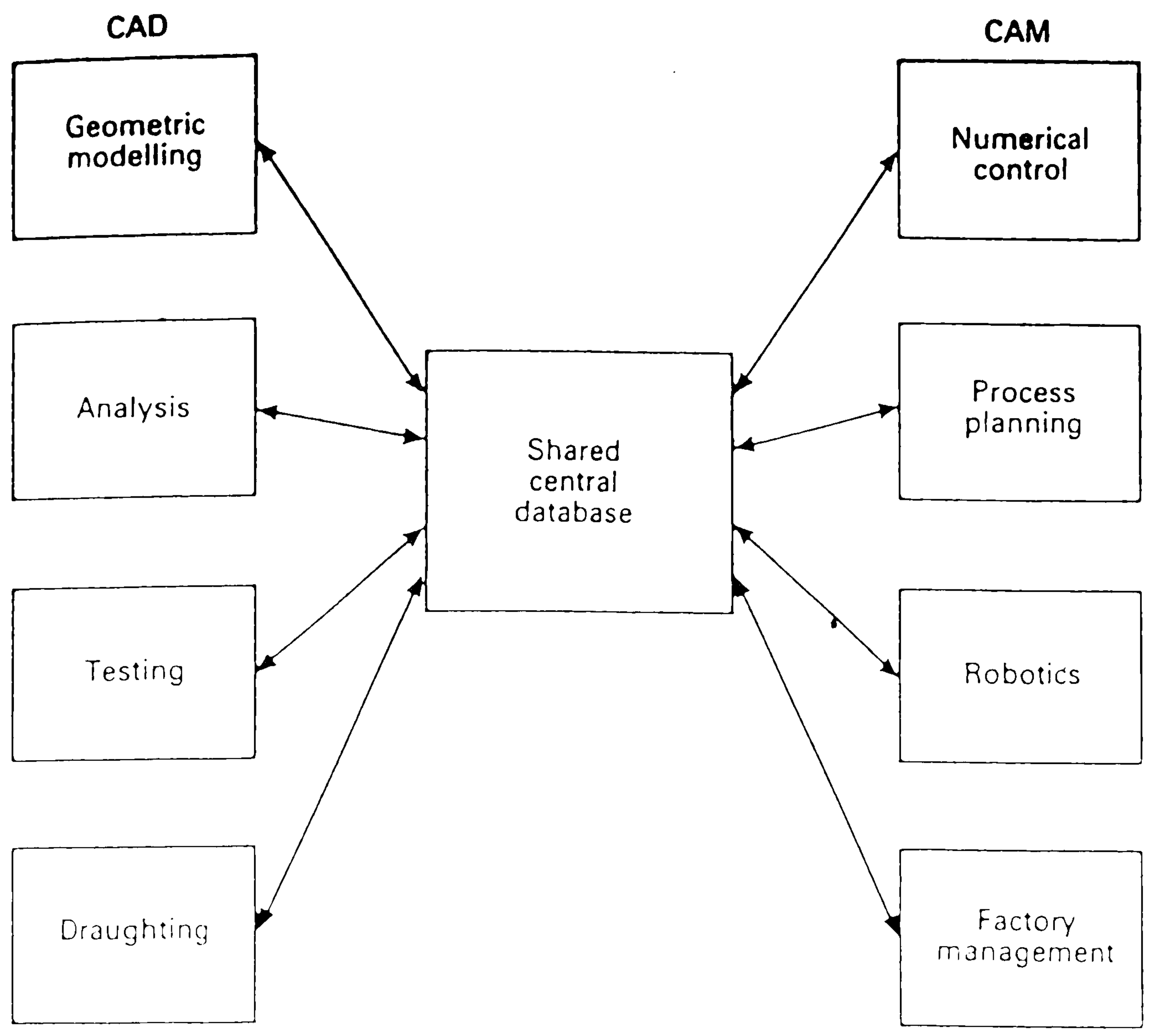

Figure 1-5: Integrated Computer-Aided Design And Manufacturing Concept [7].

1.3.2 Results of CAD/CAM, CAE Users Survey

The staff of *Computer Aided Design Report* conducted a survey of 815 users of CAD/CAM, CAE systems in manufacturing companies [31]. This report was released in early 1988 and some findings are noteworthy. The report mainly focused on which CAD/CAM applications are most widely used in these firms, and which vendors of systems and software are the most popular. Lastly the survey indicates the level of user satisfaction with each application and whether they plan to buy more software. A pie-chart summary of 4 main applications for CAD/CAM systems in shown in figures 1-6 thru 1-9.

In all applications, nearly two/thirds of the CAD/CAM users are unlikely to switch vendors. Those that do plan to switch cite poor performance as the

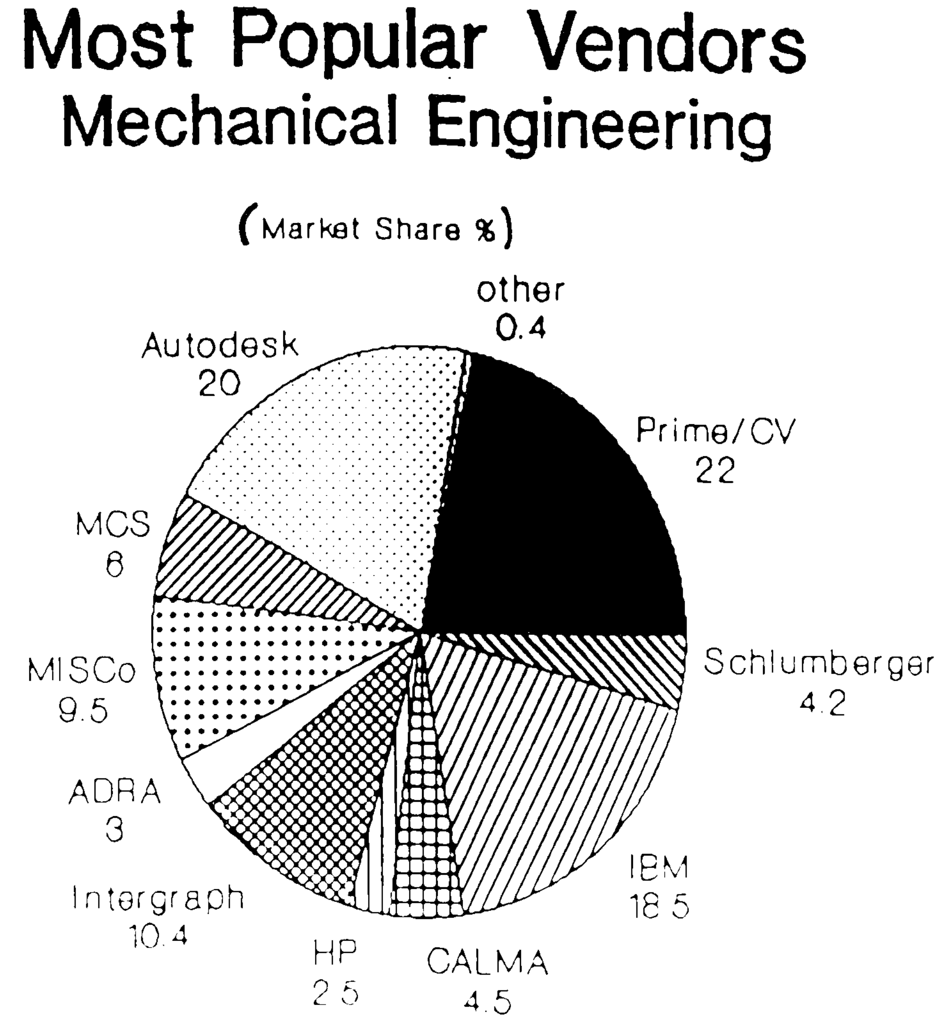

Figure 1-6: CAD/CAM In Mechanical Engineering [31].

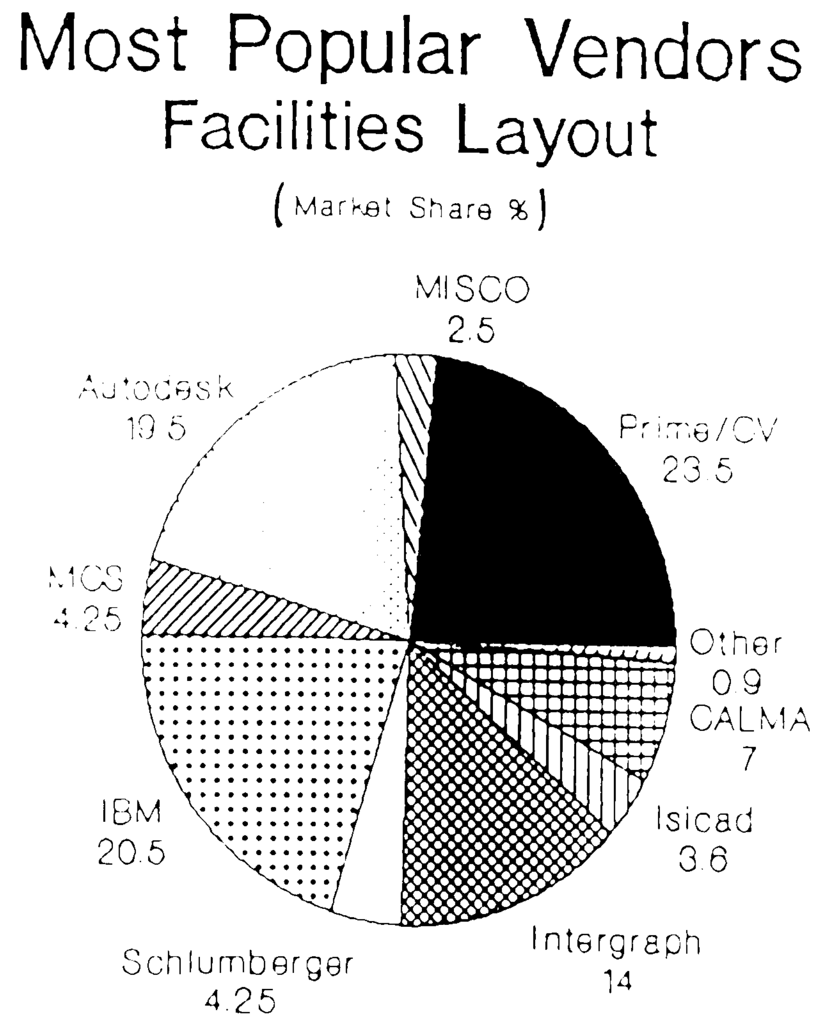

Figure 1-7: CAD/CAM In Facilities Layout [31].

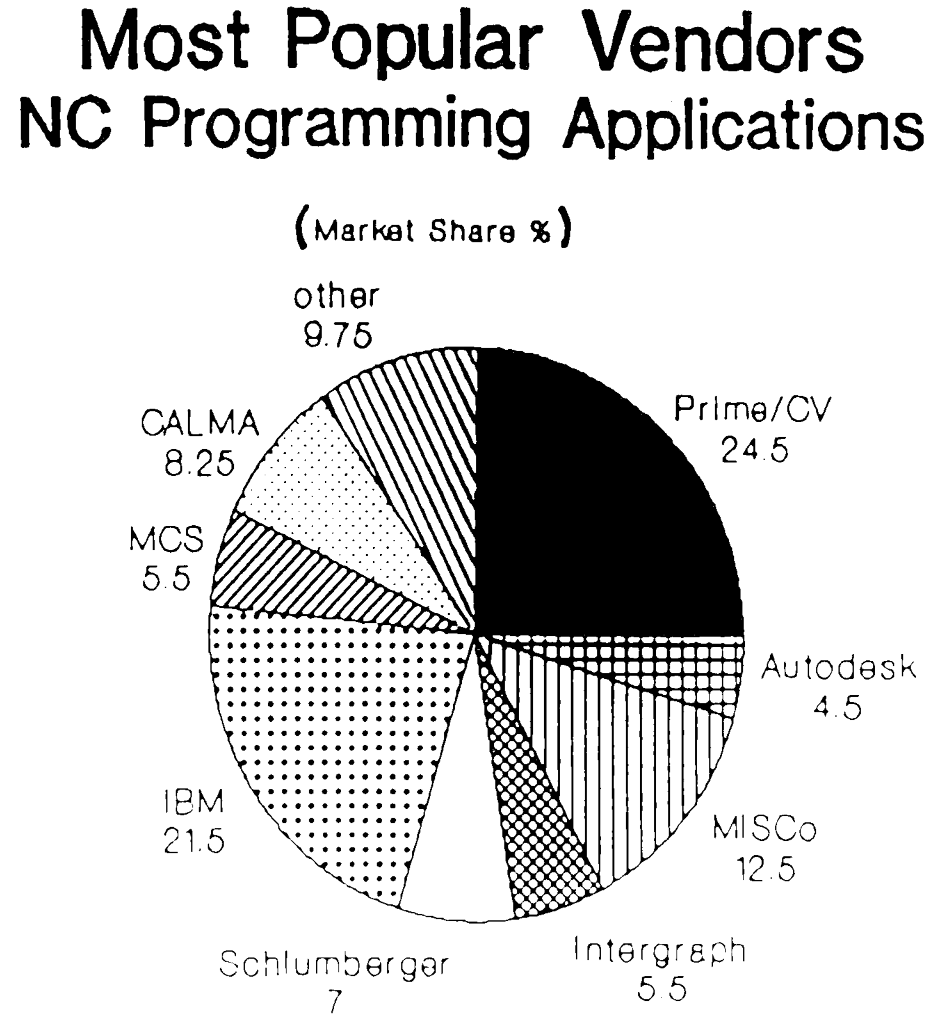

Figure 1-8: CAD/CAM In NC Programming [31].

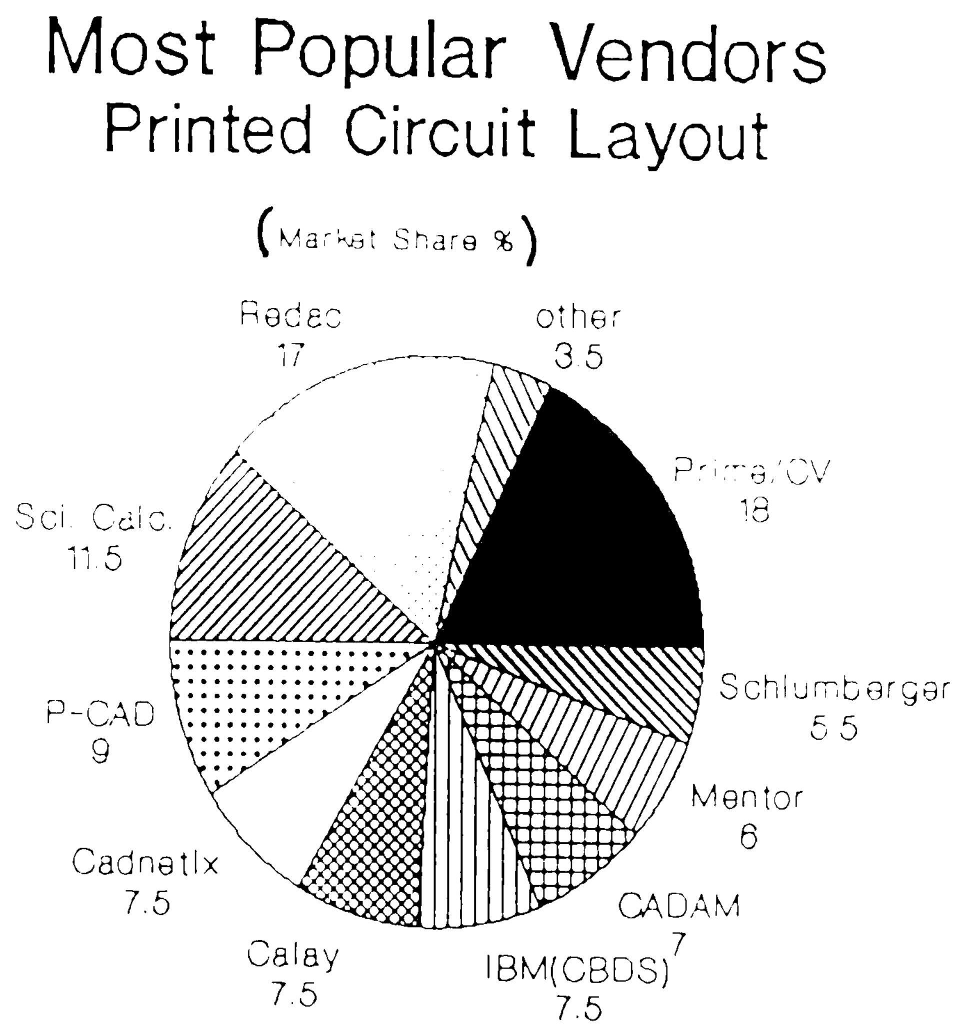

Figure 1-9: CAD/CAM In Printed Circuit Layout [31].

main reason, while software bugs, poor service and support, high maintenance costs, and standardizing computer brands within the company are secondary reasons. Over half of the companies plan to expand their systems through more workstations and software packages with mechanical applications the most robust of this group.

1.3.3 Current Aids And System Configurations

There are varieties of software and hardware on the market that are considered part of the CAD/CAM systems technology. For example, simulation packages, pre-engineering conceptualization software packages, expert systems, process planning programs, and a host of others are expanding the concept of CAD/CAM from a design/drafting/part cutting tool to a system embracing the entire design and manufacturing cycle. Some of these packages are stand-alone CAD systems which can run on a PC and cost less than $1000. There are also various low-priced software packages which are able to do some of the design and analysis tasks which previously required mainframe time and effort. This is a rapidly-growing and valuable segment of the industry that allows entry level users to get CAD/CAM into their organizations at an acceptable cost.

Many experts argue that the linking of the various manufacturing, and engineering systems (such as CAD/CAM) with business systems falls under the CIM (Computer-Integrated Manufacturing) umbrella. CAD/CAM is a separate entity in such a system and it has evolved from its rudimentary stage to a powerful tool that allows the design and manufacturing functions to co-exist. The CAD/CAM system market was developed in the U.S. and continues to be dominated by American vendors to the tune of $1.3 billion in annual worldwide sales with annual growth rates up to 35% in European markets. The future marketplace will involve more foreign ventures in this field and the possibility

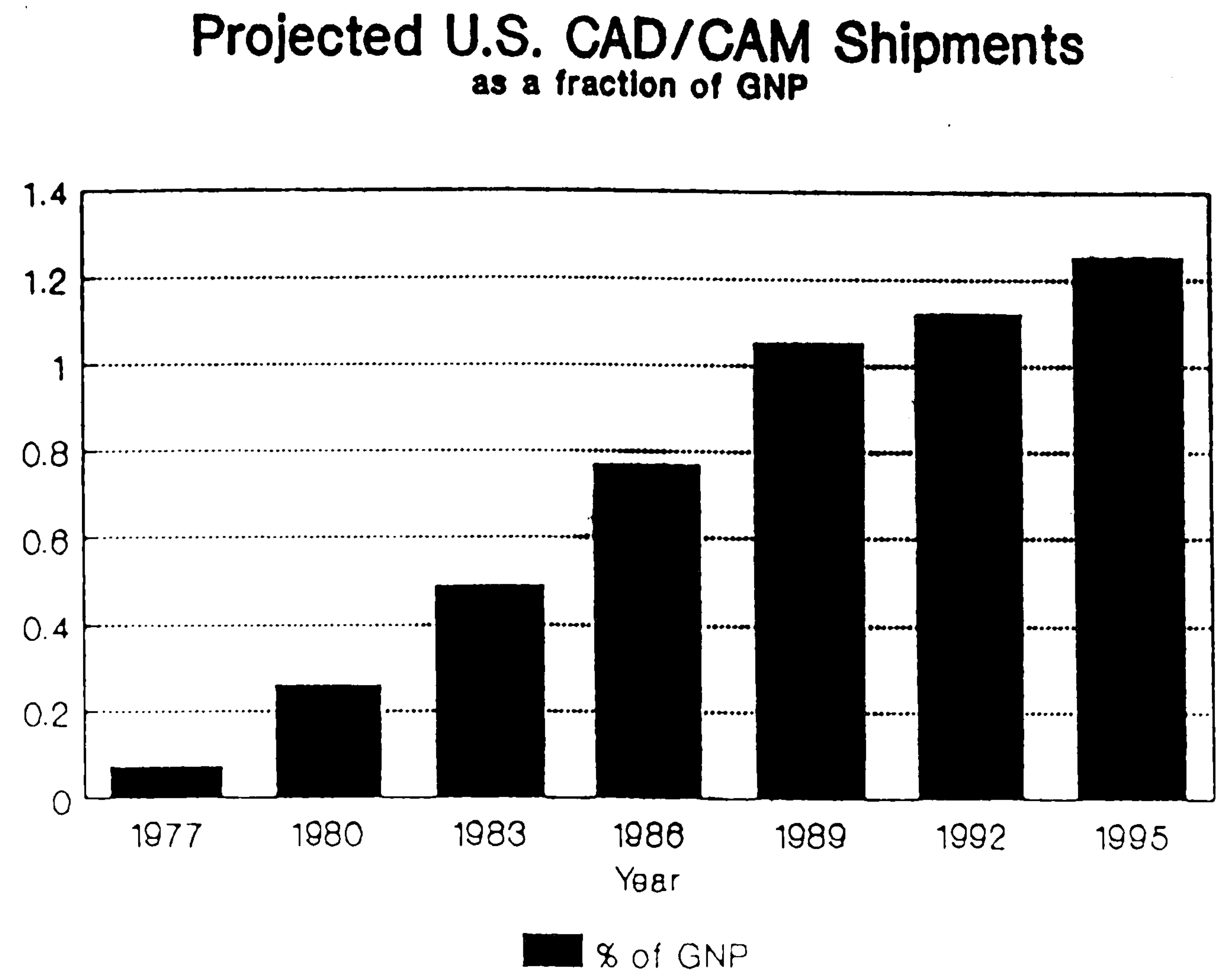

Figure 1-10: The Outlook For The CAD/CAM Systems Market Is Positive [11].

of a European Common Market by the mid-1990's will stiffen the competition.

Historically, CAD/CAM systems were based on the mainframe host computer. The CAD/CAM system was therefore a very expensive tool in terms of initial capital outlay and computing expense. The trend in the last 5 years has been to port the CAD/CAM system software onto a PC or workstation environment. In fact, this is the fastest growing segment of the CAD/CAM systems installation base. Figure 1-11 shows how the workstation segment of the market has advanced to 1987.

Feature/Performance	1982	1987
Product Features		
Lowest Entry Price	$20,000	$4,490
Average System Price	$60,000	$22,000
Primary Oper. Syst.	Aegis, UNIX	UNIX, Aegis, VMS
Windowing/UI Environ.	Proprietary	X Window System, NEWS, Prop.
Network	Token Ring	Ethernet
Display Resolution	1024 x 800	1024 x 1024
MB Main Memory	1-3 MB	2-16 MB
No. Applications	300	1,500
Performance Specs		
Integer Perform. (MIPS)	0.5-1	1-10
Float. Pt. (dp KFLOPS)	40-100	to 1,100
High-end 3-d Graphics (3-d transforms/sec.)	< 20,000	to 140,000

Figure 1-11: Past and present characteristics of CAD/CAM workstations [4].

1.4 The Future Outlook For CAD/CAM Systems

Back in the late 1960's numerically controlled milling was considered a classroom adventure. Since then Computer Numerical Control (CNC) evolved and Distributed Numerical Control (DNC) is on the horizon. Computer-Aided Design has evolved to include Computer-Aided Manufacturing and the trend is toward Computer-Aided Engineering (CAE) and advanced design and manufacturing technology (which is often referred to as the "catch all" buzzword CIM). Robots, automated assembly and material handling systems, and CAD/CAM systems linked through information and communications software and hardware produce Flexible Manufacturing Systems (FMS's) and are making the factory of the future an obtainable goal. The realization of the technology is

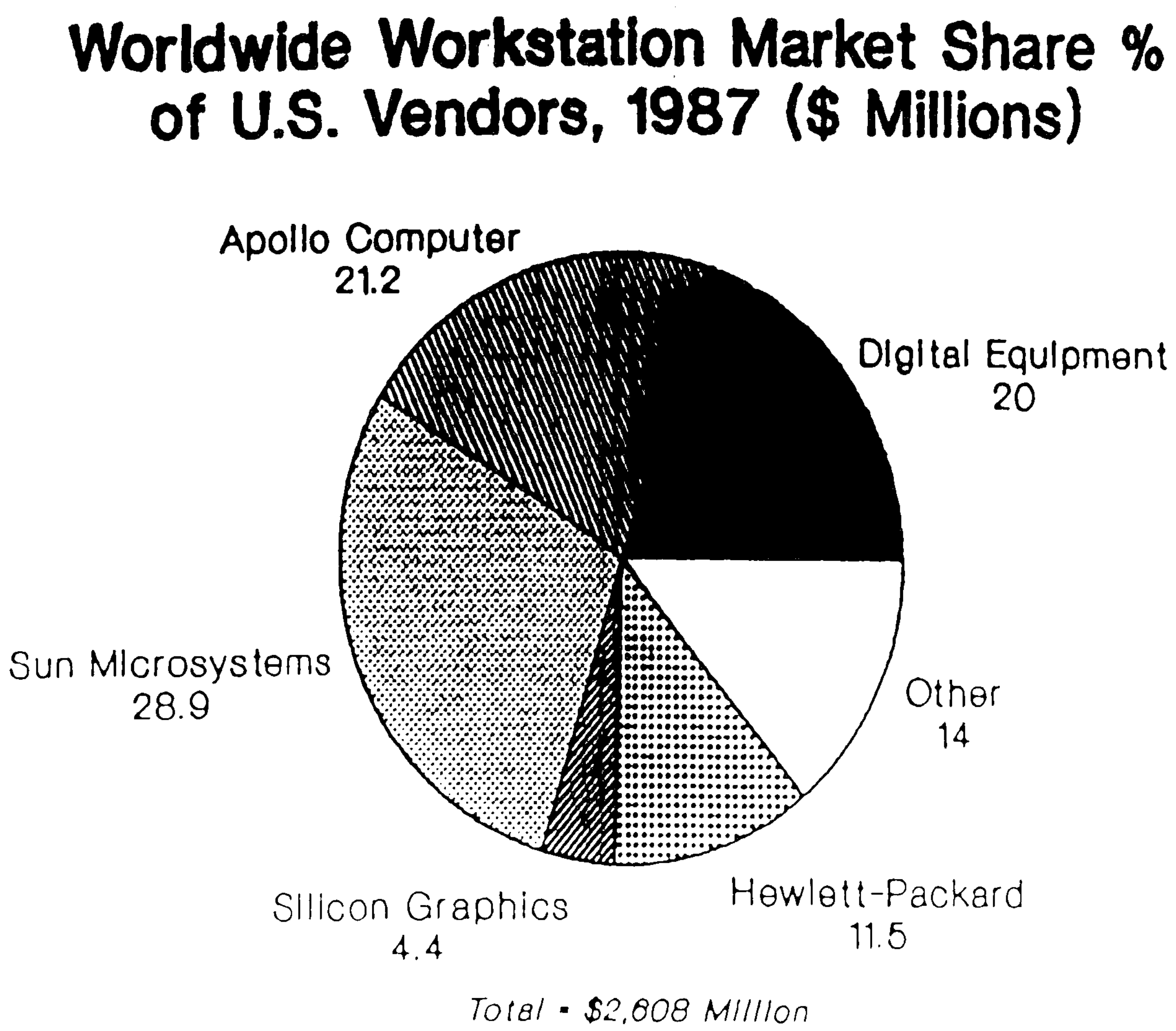

Figure 1-12: CAD/CAM Workstations Are Increasing In Worldwide Use. [4].

very definite, but the terminology still rests in the mind of the beholder. CAD/CAM is still a principal building block for advanced design and manufacturing technology.

1.4.1 An Automated Design And Manufacturing Technology Perspective

General Dynamics' former CEO David Lewis said "Our aim is to get the right parts, the right tools, the right skills, and the right data to the manufacturing process at the right time" [3]. Although most major and many smaller companies are agreeing that advanced integrated technological strategies are necessary to compete in the 21st century, currently less than 30% are implementing such strategies [1]. The advanced technology systems goal for most companies is not well-defined and strategically planned.

Large sums of money are being invested in advanced design and manufac-

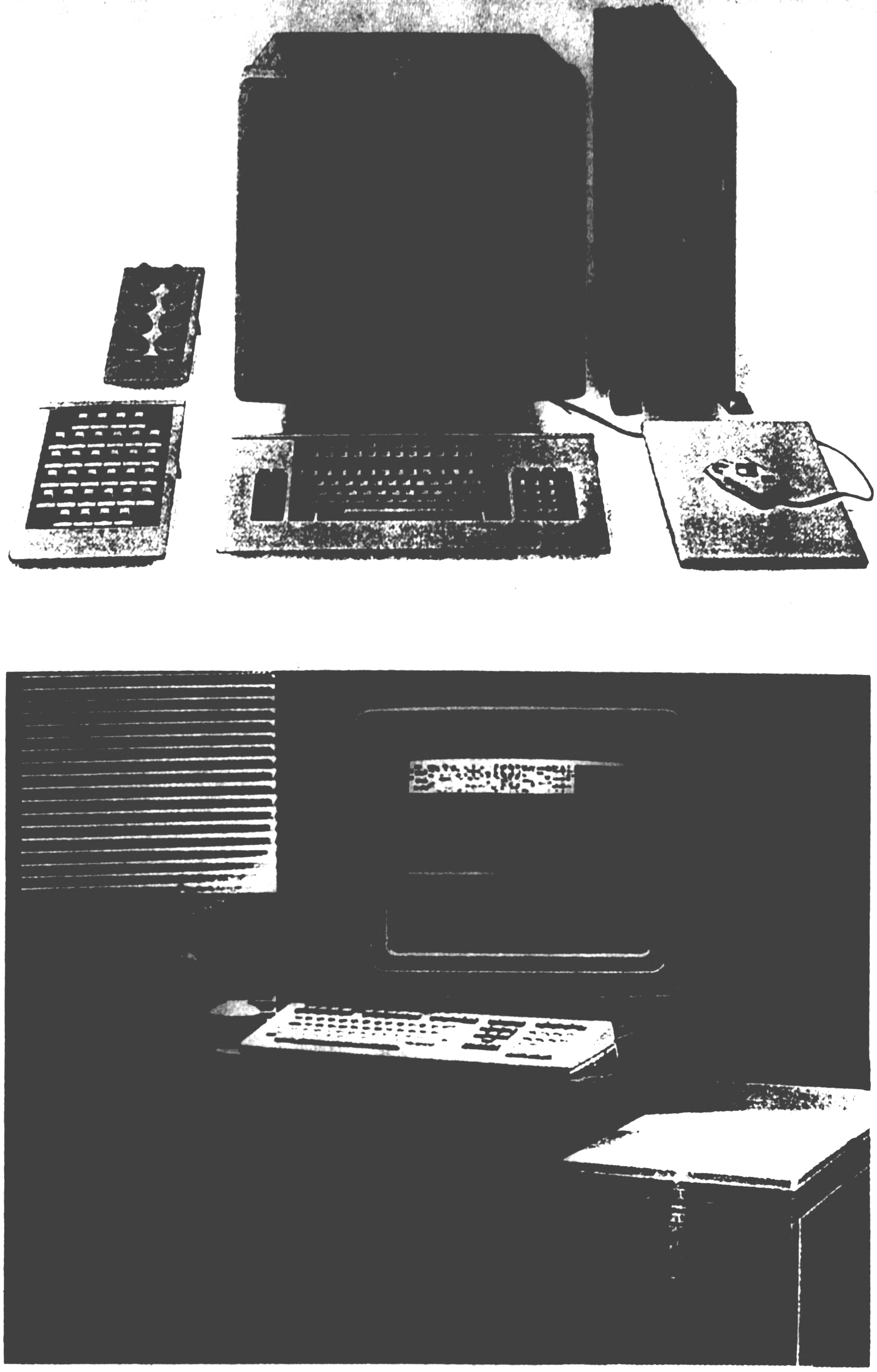

Figure 1-13: The Changing Face Of CAD/CAM Systems Through Workstations.

turing technologies. For example, over $17.2 billion was spent in 1987 worldwide and that figure is expected to reach $36 billion by 1992 [19]. Advanced design and manufacturing concepts are recognized as a major part of helping American industry regain its position as a world leader in manufacturing and technology.

IBM has committed 1500 engineers and programmers to advanced projects in engineering design, production planning, and plant floor products - representing the largest development group in a single industry sector within IBM. According to Mr. Robert Williams, vice president of IBM's Applications Systems Division, there are two absolute truths about advanced design and manufacturing concepts. First, don't automate your existing processes, because doing that places all your existing problems under automation. Second, implement the technologies under some master plan so that it will all fit together.

Islands of automation should not be the focus, but eliminating the islands of authority should be the objective. A team approach driven by a strategic vision is a key to the success or failure of more advanced and integrated design and manufacturing technologies. CAD is well accepted and used in industry, integrated CAD/CAM is still in development, CAE is still in the laboratory, and further advanced design and manufacturing technologies face great challenges in implementation. Although computing environments have changed rapidly in scope and power since 1985, the industrial acceptance of CAD/CAM and realization of CAE and advanced design and manufacturing concepts continue on a gradual path. It is very possible that the current global market competition will stimulate quicker industrial adaptation towards these technologies, but only time will tell.

1.4.2 Integration And Information Flow Is The Key

Integration of systems is the binding mortar in how well advanced design and manufacturing technology (and CAD/CAM) evolve in American industry. However, according to a study conducted by Hewlett Packard, integration is not a fact of life for most of the participants in the study. In fact, less than 1 percent of the companies interviewed responded that their manufacturing, engineering, financial, and management functions were fully integrated. This may seem surprising, but it is realistic. Integration also means proper exchange of information flow throughout the entire organization on its way to an advanced design and manufacturing environment. Integration of technology cannot occur without solid information systems as part of the strategic planning phase. The equipment is available, but the massive organizational change required is the greatest obstacle facing it's implementation, acceptance, and evolution.

Some key concepts to understand are:

- Integrated design and manufacturing systems technology is first and foremost an organizational, not a technical process.
- Integrated design and manufacturing systems technology is planned top down, implemented bottom-up.
- Payback is on a continuum, short term and long term, all focused on long-term improvement [13].

Coopers & Lybrand believe several key questions must surface within the company when planning such strategies:

- What are we good at?
- What can we be good at?
- What should we not be doing?
- What is our competition good at?
- What is our competition doing / what will they be doing?
- What impact will technology have on: Product? Process? Service [13]?

A proper advanced manufacturing technology strategy cannot fix a bad product, but it can make a good product and operation better. The measure of success in applying advanced manufacturing technology will differ in various companies because of the varying environment in which it must operate. Some important questions to ask include:

1. **What will a firm's competitive position be after successful implementation of an advanced design and/or manufacturing technology program?**
2. How long are manufacturing lead times versus customer response times? Could advanced manufacturing technology allow making to order?
3. How long are product and process life cycles? Is it reasonable top expect to fully amortize advanced design and manufacturing technology investments over one or many product generations?
4. Does the chosen solution improve the value of a product in the end user's eyes in terms of cost, delivery time/reliability or quality?

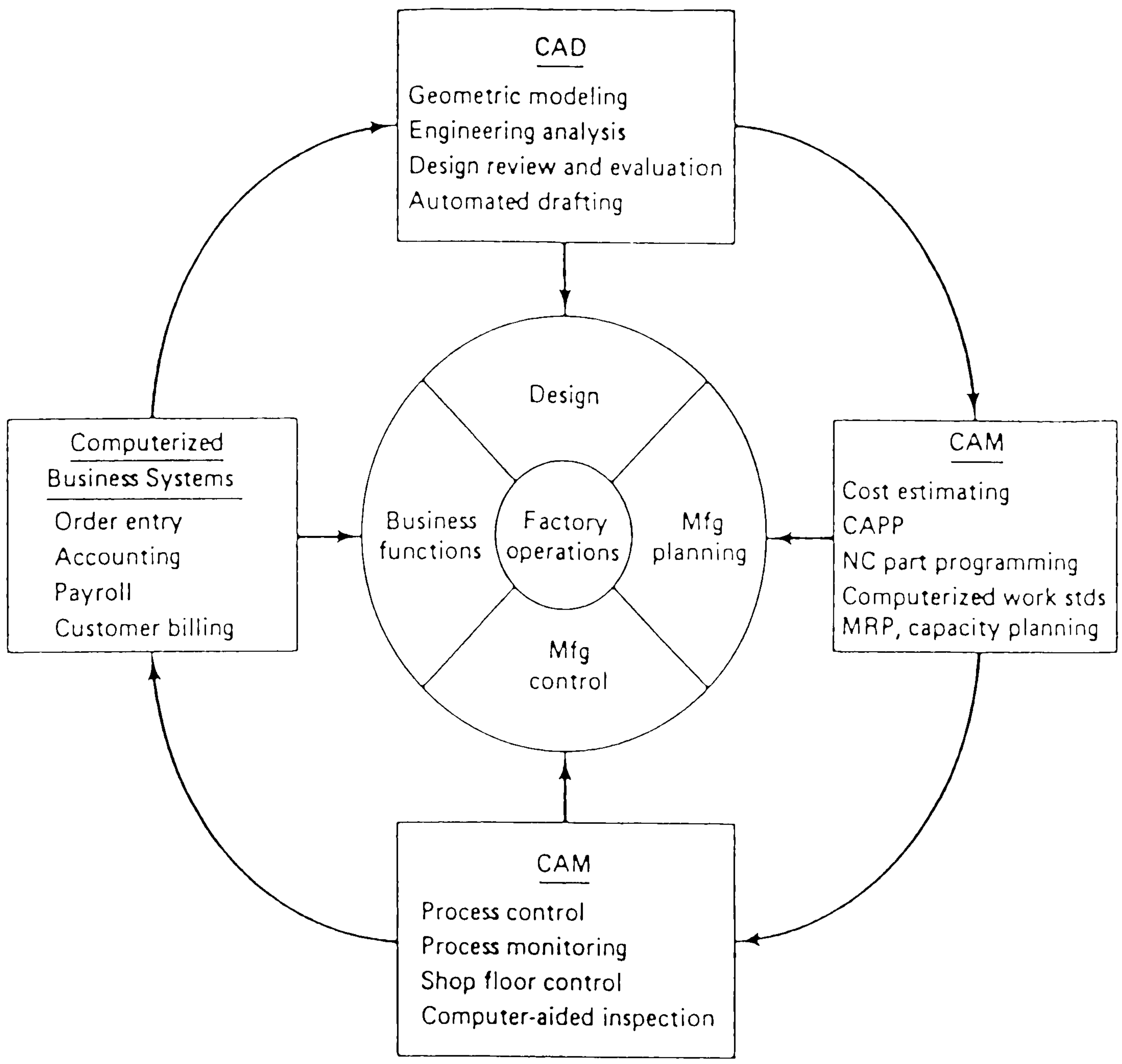

Figure 1-14: One of many frameworks for Automated Design And Manufacturing Technology [16].

These similar lines of questions can be asked of a CAD/CAM strategic plan or another type of technological implementation plan.

As a final note on the future of CAD/CAM systems and their evolution, the Wall Street Journal (Sept 1, 1988) printed an excerpt that the trend in industry is to focus on "getting back to the basics". The emphasis is heading away from high technology machines and developing better training programs for existing systems. TRW's Arden Bement was quoted in the article as saying "We have so much technology available that it is choking us". The paperless "factory of the future" vision is now being modified in many industries to reflect a sober attitude toward the technology invasion. The key point to remember is that proper planning is the key to the proper progression of technology within companies. TRW's experience is quite different from IBM or a local shoe manufacturer, but they all must realize that they can only digest so much technology at one time before they choke on it.

Chapter 2
Justification And Implementation Issues For CAD/CAM Systems

2.1 Recognition Of A Need and Beginning An Implementation

There are many valid reasons companies have for initiating CAD/CAM. There are also many companies that contradict their need for implementing CAD/CAM by not developing a total strategy which incorporates this "tool" with their business objectives. This section of the report deals with key issues to proper justification, implementation and management of CAD/CAM systems, but also addresses a key issue often overlooked by companies and strategists: **communication.**

The first step in bringing new technology into a company involves recognition of a need. With the realization that American companies are in a global marketplace full of competition, CAD/CAM has become, for many companies, a necessity to compete at this international level. This seems to be a sufficient need for many firms to justify CAD/CAM as an investment for their future. However, there must also be a concurrent strategic plan for smoothing the transition to change which CAD/CAM initiates. Management must be willing to lead the initial planning effort once the need for CAD/CAM has been recognized. Some checks that can be used to verify that the true need exists include:

- Recognizing productivity problems.
- Antiquated design practices.
- Inability to compete with others using current technology.
- Lack of creativity and spontaneous idea generation.
- Bottlenecks in design and manufacturing.

Of course, recognizing that the need exists for considering CAD/CAM, there may still be other corporate habits that may doom its eventual success. These include:

- **Management unwilling to change and become involved.**
- **Over 50% of parts designed externally.**
- Lack of piece part drawings.
- No real integrated system appreciation.
- Minimal numerical controlled tool requirements.
- No present analysis of current systems.
- Not recognizing the various CAD/CAM system choices:

    1. Bespoke, or newly developed systems for a single company.
    2. Turnkey Systems, designed, installed and maintained by the supplier i.e. Computervision Corp. or CADAM Inc.
    3. Existing systems tailored for the specific needs of the company, recognized as usually the best choice for small to medium size companies [12].

A needs analysis can focus on the specific costs associated with doing business without CAD/CAM and the anticipated costs associated with CAD/CAM. The following points are crucial system considerations if the implementation of a CAD/CAM system is to be a success:

- Financial justification
- Specifications
- Evaluation and selection
- Support services
- Future expansion
- Corporate expectations

The road to successful implementation does not hinge upon the "biggest is best" philosophy. The management which is willing to accept the changes in organizational climate that CAD/CAM brings can target many areas for benefit.

These targets must be reached in a logical and reasonable manner as so not to overwhelm the system capabilities. By system we must include the people, computer hardware, software, and the company objectives.

2.2 Heading In The Right Direction When The Go-Ahead Is Given

After it is determined to implement CAD/CAM, the formation of a selection team should take place. This should represent all the company interests from sales and marketing to engineering and manufacturing. They can be listed (in random order) as:

- Engineering
- Information services
- Technical publications/illustrations
- Facilities planning
- Manufacturing
- Sales/Marketing
- Upper management
- Union (if applicable)
- Team facilitator or leader

The team inherits the task of CAD/CAM system selection which is sometimes overwhelming in today's world of rapidly advancing computing capabilities. A basic chart to compare vendors is useful in gaining an understanding of how well the system will fit in with the company's needs. Many are published and key features are listed here:

- Delivery Schedule
- Vendor concern for client
- Vendor Support
- Future offerings/upgrades

- Lease commitment
- Operating system
- Communication between devices
- Data base associativity
- Applications packages
- Software development capabilities
- Upward compatibility
- System reliability
- Obsolescense
- Ergonomics
- Report card from users
- System cost
- PC capabilities/link
- Justification assistance

In a survey conducted by Mr. Lee Schlenker of *Design Graphics World*, it was reported that less than 10% of European manufacturing firms have a CAD/CAM plan/solution even though many of them are considering CAD/CAM system purchases [28]. In these companies management offers classical reasons for seeking CAD/CAM such as productivity, rapidity (of product turnover), and peer pressure. This European figure compares less favorably than in the U.S., but the majority of U.S. firms that are interested in CAD/CAM implementation also do not have a specific CAD/CAM strategy. This is a glaring fact that needs to be addressed for any company considering a CAD/CAM purchase.

The investment in a CAD/CAM system is no simple matter considering that the expected life cycle of such a system is 5 to 7 years [10]. Because this signals a dynamic nature of the business, many companies purchase new systems from different vendors when this life cycle ends, thus beginning the cycle again. CAD/CAM system vendors need to address this important fact. Figure

2-1 illustrates this lifecycle.

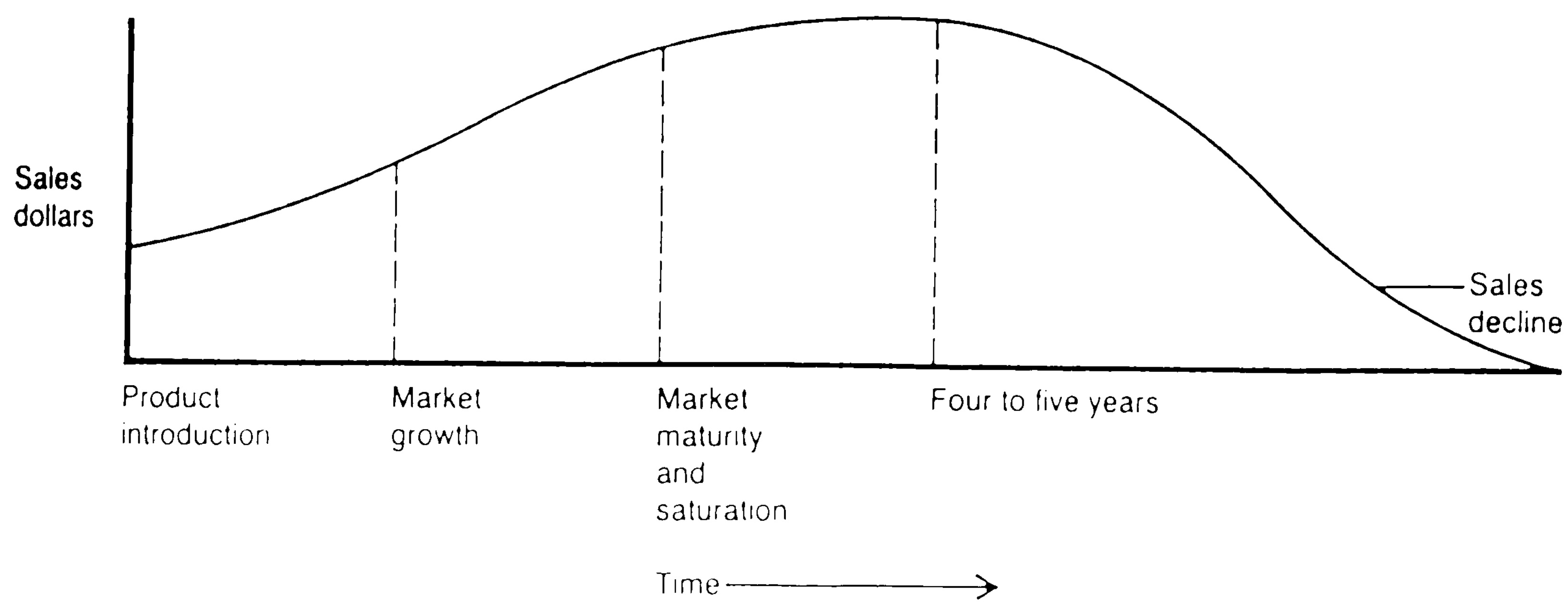

Figure 2-1: The Life Cycle Of A CAD/CAM System.

Later in this report (chapter 5) the CAD/CAM usage/performance survey is detailed and a major item to note from that chapter is that initial system cost is not the highest concern for many companies. Most major CAD/CAM vendors will be willing to determine what your company requires in terms of system needs to fit your business objectives. The list of CAD/CAM vendors is lengthy (see Appendix A), but the committee should narrow the field to 3 choices and let the benchmarking and bidding begin. Meanwhile, the team representatives should be addressing the possible implications CAD/CAM may have on their area.

2.3 Why Some Companies Fail

Many companies who fail in implementing CAD/CAM do so because they researched it minimally and expected it to be a panacea to their economic woes. This type of attitude often results in hurried decisions on system purchase before examining alternate choices such as leasing or service bureau. Another very inexpensive method for researching justification of CAD/CAM and specific vendors is through user communities. The experience gained by other companies in making the transition to CAD/CAM is an invaluable aid which can help clear confusion and speed a logical decision. A broad base of users is needed in various user communities to assess the true pulse of the CAD/CAM marketplace from a user's perspective.

A thorough investigation into the company needs and impact CAD/CAM has on those needs can be accomplished in time spans varying from as little as 3 months to as much as 1 year. It is heavily dependent on the corporate society and its acceptance to change.

According to Lockheed company approximately 30% of all companies who attempt CAD/CAM implementation fail due to poor planning [26]. Also, the lack of a true "Systems Thinking" philosophy can be a factor in the failures. CAD/CAM is not a system that can stand alone on its merits. It is part of the overall corporate system which includes the business system, the manufacturing system, and the engineering system. It's impact is felt in all these areas and all must be interdependent in order to continue smoothly on a progressive path to success.

2.3.1 The Misunderstood Productivity Issue

For many companies, the real need for and justification of CAD/CAM comes in the productivity area. The CAD/CAM implementation team usually has to deal with justification of the CAD/CAM system on three fronts: financial, technical and social.

The financial issue usually deals with the productivity myth. Many companies believe that the increased output of their designers and manufacturing engineers is the main gain from CAD/CAM systems. More drawings or designs do not constitute productivity. The actual benefits may be unforseeable initially

2-1 illustrates this lifecycle.

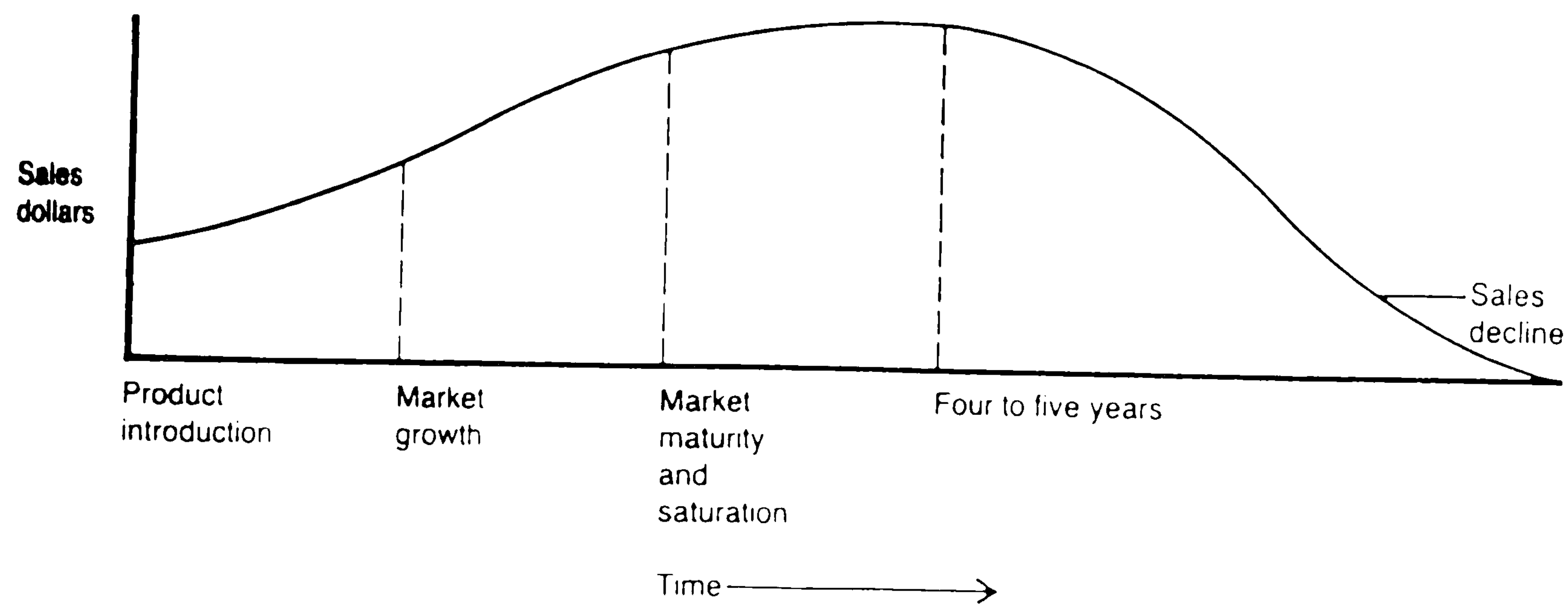

Figure 2-1: The Life Cycle Of A CAD/CAM System.

Later in this report (chapter 5) the CAD/CAM usage/performance survey is detailed and a major item to note from that chapter is that initial system cost is not the highest concern for many companies. Most major CAD/CAM vendors will be willing to determine what your company requires in terms of system needs to fit your business objectives. The list of CAD/CAM vendors is lengthy (see Appendix A), but the committee should narrow the field to 3 choices and let the benchmarking and bidding begin. Meanwhile, the team representatives should be addressing the possible implications CAD/CAM may have on their area.

2.3 Why Some Companies Fail

Many companies who fail in implementing CAD/CAM do so because they researched it minimally and expected it to be a panacea to their economic woes. This type of attitude often results in hurried decisions on system purchase before examining alternate choices such as leasing or service bureau. Another very inexpensive method for researching justification of CAD/CAM and specific vendors is through user communities. The experience gained by other companies in making the transition to CAD/CAM is an invaluable aid which can help clear confusion and speed a logical decision. A broad base of users is needed in various user communities to assess the true pulse of the CAD/CAM marketplace from a user's perspective.

A thorough investigation into the company needs and impact CAD/CAM has on those needs can be accomplished in time spans varying from as little as 3 months to as much as 1 year. It is heavily dependent on the corporate society and its acceptance to change.

According to Lockheed company approximately 30% of all companies who attempt CAD/CAM implementation fail due to poor planning [26]. Also, the lack of a true "Systems Thinking" philosophy can be a factor in the failures. CAD/CAM is not a system that can stand alone on its merits. It is part of the overall corporate system which includes the business system, the manufacturing system, and the engineering system. It's impact is felt in all these areas and all must be interdependent in order to continue smoothly on a progressive path to success.

2.3.1 The Misunderstood Productivity Issue

For many companies, the real need for and justification of CAD/CAM comes in the productivity area. The CAD/CAM implementation team usually has to deal with justification of the CAD/CAM system on three fronts: financial, technical and social.

The financial issue usually deals with the productivity myth. Many companies believe that the increased output of their designers and manufacturing engineers is the main gain from CAD/CAM systems. More drawings or designs do not constitute productivity. The actual benefits may be unforseeable initially

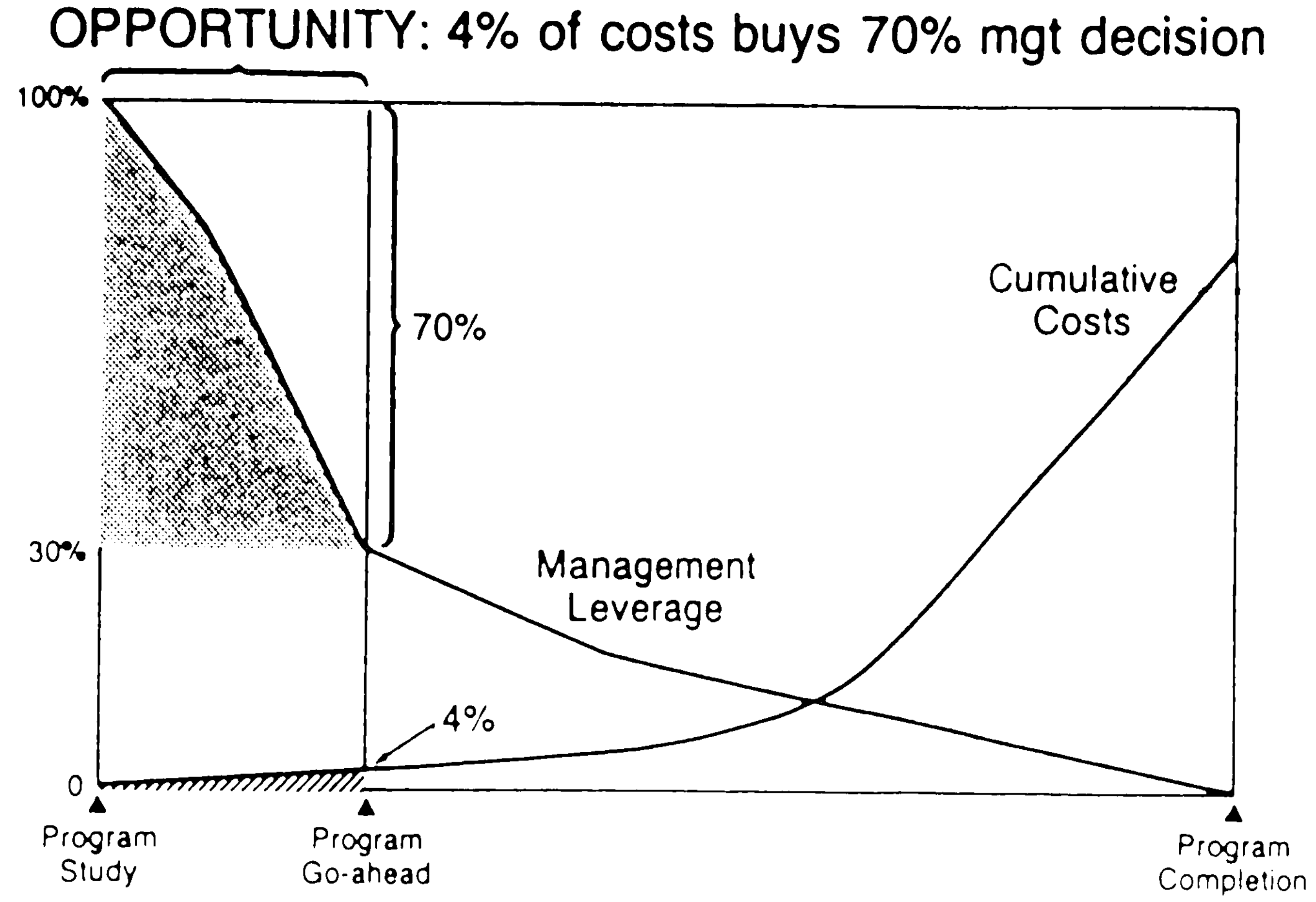

Figure 2-2: Benefits Of Planning A System. *(Courtesy of Boeing)*

and are not quantifiable. For example, the standardization of part classification and drawings may actually reduce the number of drawings. The ability of a system to analyze particular design features and components may reduce the number of components of a particular product. Or machining applications in 3-dimensions may now be a possibility thus enabling the manufacturing team to participate in more challenging tasks. Benefits such as quicker mathematical calculations for design and manufacturing tasks, analysis of toolpaths at the CAD/CAM station before actual machining and other time saving benefits are not usually expected initially.

Productivity issues are more deserving when discussed in terms of consistency and availability of information, reduction of waste, analysis of information, ability to do things that could not be done before, and standardization. The productivity issue is definitely measurable, but its scope must be correctly realized. The components of productivity are in the following figure:

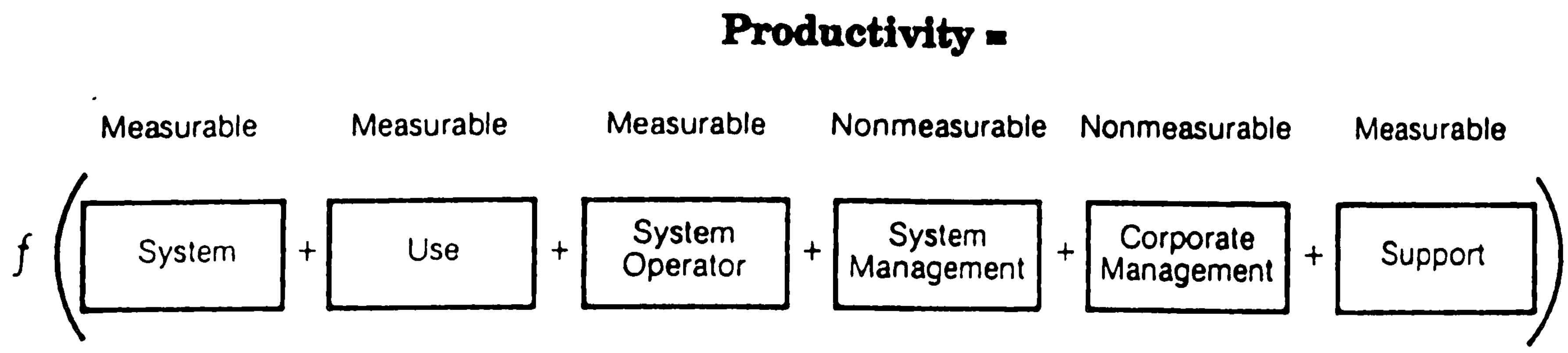

Figure 2-3: The Components of Productivity [26].

A typical productivity report contains the following sections:

- Overview of the CAD/CAM organization.
- Organization of the CAD/CAM department or function.
- Personnel:
    - Observations and recommendations of system by management.
    - CAD/CAM supervisory observations and recommendations.
    - CAD/CAM users observations and recommendations.
- Standards for specific disciplines affected in the CAD/CAM cycle.
- Training observations and recommendations.
- Current equipment listing.
- Work environment - observations and recommendations.

In terms of value-added measure per employee resulting from CAD/CAM system implementation the following formula applies:

$$\text{Revenue} = \frac{\text{Direct material costs} - \text{Value added/employee}}{\text{Number of employees}}$$

In order to analyze the CAD/CAM operation, it is necessary to divide the operation into components of the system: The system itself, the system utilization, and the system operators. The system can be analyzed according to hardware, software, application packages, revision levels, interfaces to translators, etc. The tangible attributes of the system may include mean time between failures, downtime, response time, ease of use, ergonomics, and many others. The system utilization may be measure in terms of number of terminals, number of shifts, type of work (R&D, production), or the included accounting packages with the system.

System operator components include: Experience, motivation, proficiency, attitude, quality of work life, career path, and others. The training level is very important and is discussed in later sections of this report. The Sha and Yan equation for measuring efficiency for an operator is:

$$E = (I_i * S_i) / Sm_i$$

Where: Sm = Average labor hours to manually produce a category i drawing including i revisions

Ss = Average labor-hours utilizing CAD/CAM to produce a category i drawing i

E = Efficiency with which the user operates the system

The methodology used here incorporates:

1. Select a typical cross-section of engineering/design work by application and categorize.
2. Establish manual drawing creation times (based on previous initial studies or historical data).
3. Establish automated drawing creation times by time monitoring the engineering work by an experienced user.
4. Develop productivity ratios for each category by dividing the automatic create time by the manual create time.
5. Apply the Sha and Yan equation to develop efficiency factors for each category of engineering/design work [26].

Of course there are other ways to measure system productivity. Each company may have different needs for their system and need to apply variations of these key areas. Remember that individual operators will have varying learning curves in terms of the system operation. Figure 2-4 illustrates this point.

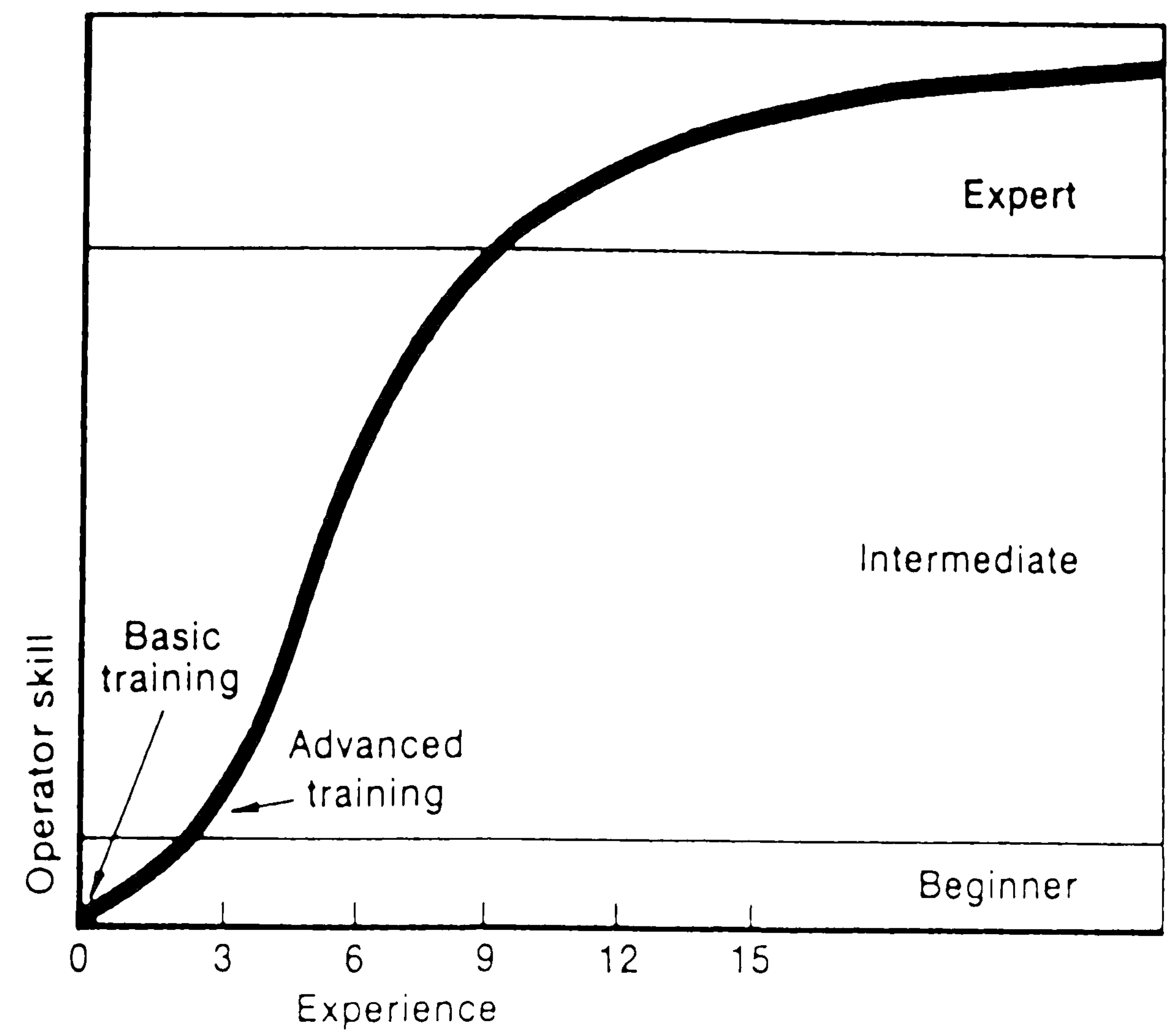

Figure 2-4: A Typical CAD/CAM Operator Learning Curve. *(Source: Machine Design)*

2.4 Justifying Capital Investments Using Discounted Cash Flow Methods

CAD/CAM systems may be a very necessary tool for aiding in the company's future competitiveness and long term financial health, but most capital projects are doomed if they are uneconomical. Exactly how they are economically justified can be the difference between acceptance and rejection of a CAD/CAM proposal. Considering that Japan is investing nearly 30% of its output dollars in capital investments compared to a dismal 15% in the United States with productivity increases for Japan vs. U.S. at 6 to 1, our methods of justifying capital investments are a serious problem.

Traditional cost accounting is a major barrier to implementing Computer-

Aided Design and Manufacturing [8]. **Accounting systems were well established before CAD/CAM systems became a production factor. The traditional accounting systems did not anticipate such systems and , consequently, treated them as traditional investments. There are basically four methods used in industry to justify capital expenditures in high technology** [32] . They are:

1. Payback (Return On Investment)
2. Internal Rate of Return (IRR)
3. Accountant Rate of Return (ARR)
4. Net Present Value (NPV)

2.4.1 Payback Method (ROI)

The Payback method is the most widely used method to financially evaluate projects. This method defines the time required to cover the initial investment. It is a weak method because it does not take into account the time value of money (discounting).

Example: Company ABC is considering two projects, a new packaging machine (A) and a CAD/CAM system (B) . Cash flows for each are:

Year	**Cash Flow** Project A	Project B
0	($200,000)	($250,000)
1	$70,000	$50,000
2	$80,000	$75,000
3	$80,000	$85,000
4	$60,000	$90,000
5	$60,000	$90,000
6	$50,000	$80,000
7	$70,000	$80,000
Total:	$250,000	$300,000

Although project B would be more profitable, project A would be chosen because the payback period is 3 years, whereas B is 4 years payback period. This me :od does not recognize long term strategy and should be avoided.

2.4.2 ARR Method

This method also does not utilize discounting and is also referred to as Simple Rate of Return. It is used less widely than the ROI method but that is also unfortunate. This method provides a measure of the attractiveness of the potential investment. The consideration of depreciation in the calculation of the ARR provides a return on investment in terms of accounting income, which is concerned with P & L (profit and loss).

The variation in approaches illustrates the variation in outcomes : 6.86% vs. 12.7%. The concept of expressing return as a function of accounting income is beyond the scope many technical managers are willing to address. Although this method is easy to use, easy to post audit, and sell to management, it does not take into account the time value of money, varies in calculation results, and results are in terms of accounting income. This method is not recommended for high technology investments such as CAD/CAM systems. Before discussing the DCF methods, the difference between compounding and discounting is necessary. The concept of future value in engineering economics is referred to as compounding in business terms. Compounding is the method of calculating interest accruing on an investment over a period of time.

$$S = P(1 + i)^n$$

Where:

S = total received by investing a principle amount P, at an interest rate i, for n periods of time.

In contrast discounting is the accounting terminology for present value. It can be defined as the reciprocal of compounding.

Example:

A company is considering purchasing a CAD/CAM system that is estimated to save $70,000 per year before depreciation and taxes. Equipment cost is $250,000 and the expected life is 7 years with salvage value = $20,000. Straight line depreciation is used and is taxed at 50%.

```
Annual benefits                                = $70,000
Annual depreciation     ($250,000/7)           = $35,715
                                                ---------
                             Net Benefit       = $34,285

Taxes    ($34,285 * 0.5)                       = $17,142

                             Net Income        = $17,142

Average of first year's investment:

   (1/2(Initial investment + Investment at year-end)

   = 1/2($250,000 + $232,858)                  = $241,429

                                $17,142
     Rate of Return          = --------        = 7.10%
                               $241,429
   ----------------------------------------------------
                                $17,142
     Rate of Return          = --------        = 6.86%
       (initial)               $250,000
   ----------------------------------------------------

Average Benefits, Average Investment:

     Avg. Investment = 1/2(Initial Investment + Salvage)

                     = 1/2 ($250,000 + $20,000)

                     = $135,000

                        $17,142
   Rate of Return    = --------        = 12.7%
                       $135,000
```

$$P = \frac{S}{(1 + i)^n}$$

Where: S, P, i and n are same as previous method.

2.4.3 Net Present Value

This method is gaining rapid acceptance in industry and is touted in various recent technical and financial journals [6] [8]. NPV compares the cash flows of a project, discounted at a determined rate, to the initial investment. If the NPV of the project is greater than the investment then it is considered economically acceptable. The computation of a project's NPV is relatively simple. The future cash inflows and outflows are converted to present value amounts and compared to the initial investment.

Example:

Again we will use the simplified CAD/CAM system model. The after tax saving and investment are summarized below. The company uses a discount rate of 12% in evaluating technical projects. Note: the savings take into account depreciation and tax benefits plus scrap reduction, time savings, inventory cost savings and utility savings to simplify the model.

Year	Savings	Investment
0	$50,000	$250,000
1	$75,000	--
2	$85,000	--
3	$90,000	--
4	$90,000	--
5	$80,000	--
6	$80,000	--

The net cash flows are calculated and converted to present values. I used the text by Horngren for the present value conversion factors [18].

Year	Net Cash Flow	PV Factor(12%)	Present Value
0	($250,000)	1.0	($250,000)
1	$50,000	0.893	$44,650
2	$75,000	0.797	$59,775
3	$85,000	0.712	$60,520
4	$90,000	0.636	$57,240
5	$90,000	0.567	$51,030
6	$80,000	0.507	$40,560
7	$80,000	0.452	$36,160
		Total NPV	$99,935

This method does not have varying values such as the ARR and IRR methods due to a fixed discount rate. This is best when used with evaluating projects with irregular cash flows and projects with different life cycles. The advantages of this method include the realization of the time value of money, using cash flow instead of accounting income, easy to calculate, and it measures the profitability of the project, and it produces a precise measure of the worth of a high technology investment. Its disadvantages are the need to predetermine cost of capital, results are expressed in units of dollars and not in ROI terms, and choosing the proper discounting rate is critical.

2.4.4 Internal Rate Of Return

This method is also referred to as Discounted Cash Flow Rate of Return (DCFR), Yield Method, Discounted Return Method, Investors Method, and Adjusted Rate of Return Method. The Internal Rate of Return is the more used of the two discounting techniques in practice today. This method defines the discount rate that equates the present value of an anticipated cash flow to the initial investment. This method is more accepted in business because management is more familiar with the unit rate of return than to a dollar Net Present

Value. The most common method of solving investment evaluations with this method is trial and error. Accuracies of +.5% are acceptable.

Example: Using the same CAD/CAM system examined previously, a company requires a 12% return on investment. The after tax savings are similar to previous examples. Again, the NPV factors are taken from the Horngren text [18].

Year	Net Cash Flow	PV Factor(12%)	Present Value
1	$50,000	0.893	$44,650
2	$75,000	0.797	$59,775
3	$85,000	0.712	$60,520
4	$90,000	0.636	$57,240
5	$90,000	0.567	$51,030
6	$80,000	0.507	$40,560
7	$80,000	0.452	$36,160
		Total NPV	$349,935

Since Total NPV is greater than the initial investment, discounted at 12%, the return is above the company's minimum requirement. To stress the difference in trial and error, assume that a discount rate of 22% is used.

Year	Net Cash Flow	PV Factor(22%)	Present Value
1	$50,000	0.820	$41,000
2	$75,000	0.672	$50,400
3	$85,000	0.551	$46,835
4	$90,000	0.451	$40,590
5	$90,000	0.370	$33,300
6	$80,000	0.303	$24,240
7	$80,000	0.249	$19,920
		Total NPV	$256,285

Although the project is still feasible, it's profitability is greatly decreased using the higher discount rate. This project would not be feasible at a rate higher than 22%. The disadvantage with this method is that cash flow estimates with unconventional metrics (ie. negative years) will usually have multiple answers. Also the analysis of projects with different life spans is not suitable for this method. In all of these methodologies the issue of risk is involved.

There is no such thing as a risk-free investment. CAD/CAM systems require large outlays of capital and are not guaranteed to be financial successes. Analysis of the effects of risk in a project should be undertaken according to the size of the investment. If this investment represents more than half of capital outlays for the fiscal year, detailed sensitivity and risk analysis. The objective of this report is not to detail such methods. Further detail is available in the article by Swindle [32].

2.5 Develop A Control System To Monitor Performance

There are several useful ways to assess the actual performance of the CAD/CAM system at a particular operation including system generated usage figures, feedback from users, feedback from customers, and general attitude changes that occur in the company after the system has settled into its surroundings. One technique borrowed from accounting practices to monitor the system success is a Control System for monitoring the first year of the CAD/CAM implementation program.

The basic function of the control system is to catalogue or formally rank CAD/CAM system goals and how effectively they have been implemented, and to include recommendations for improvements or problem solutions. For simple demonstration purposes, a partial Control System is shown in table 2-1.

This kind of control chart can expand to include dozens or even hundreds of listings. The control chart setup by an individual company will vary in many

Objectives	Desired vs. Actual	Corrective Strategy
1. Improve drafting productivity	4 to 1 vs. 2.2 to 1	Learning curve
2. Reduce product cycle time	45% vs. 20%	Learning curve
3. More complex NC Tasks	2 new bids vs. 3 new bids	Continue to plan
4. Improve end-product quality measured by rejects	20% vs. 29%	Continue to plan
5. Place workstations in key departments	4 depts. vs. 2 depts	Study plan better
6. Increased quote/ capture rate	3 of 10 vs. 3.5 of 10	Continue to plan
7. Train users for specific time amount	3 weeks per 6 months vs. 1 week per 6 months	Budget more time for training
8. Predict time of user learning curve	6 months vs. 10 months	More training and focus on problem.
9. Reduced drafting room area	50% vs. 60%	Better than expected
10. Reduction of ECO's	40% vs. 15%	Evaluate nature of current ECO reporting

Table 2-1: Control Chart To Monitor CAD/CAM System Performance.

areas, but be similar in others. It is recommended that such a chart be developed by the expected user community in a company prior to CAD/CAM implementation and serve as a measure for gauging how well the system was planned. It should also be done in 6-month increments for the first 2 years of operation, and then become an annual document until the CAD/CAM system life cycle begins again due to a system upgrade or new purchase. As an alternative to a control chart, a departmental survey is appropriate (see Chapter 7).

2.6 Integrated CAD/CAM Must Be An Implementation Goal

When all of the decisions to implement CAD/CAM into the working environment have been accomplished, the convergence of administrative control, production, and design technologies toward the firm's technological goal must be realized and accounted for. The linking of CAD with CAM can be expressed in terms of a progression of systems integration:

1. Downloading of data directly from the CAD database to the manufacturing environment.
2. Inclusion in the CAD database of manufacturability design rules, criteria, and models so as to assure the reliability of the downloaded data.
3. Inclusion in the CAD database of automatic manufacturing process planning, and broadening the ability of designers to incorporate manufacturing concerns.
4. Error recovery capabilities such that contingencies in manufacturing can be automatically identified, diagnosed, and rectified or rechanneled.

Very few manufacturing organizations have been successful with stages 1 and 2, and most have not proceeded past stage 3. Many critical organizational issues remain in making certain that these stages can be achievable. If CAD/CAM acts as a building block for an advanced design and manufacturing strategy within a company, how well it is integrated usually will spell how well it achieves its goals.

Chapter 3
Classic Example Of A Successful CAD/CAM Installation

3.1 The Simmonds Precision Company CAD/CAM Implementation

Mr. Ron Van Nostrand authored a CAD/CAM Justification and Follow-up case study at Simmonds Precision, in Vermont [29]. The company designs, develops and manufactures measurement, control, and display systems for industrial and aerospace applications. This case study typifies some of the previous information in this report, but also can be judged as more relative to electronic installations. The company follows a historically conservative stance of basing financial decisions on quarter-to-quarter earnings growth. Their capital equipment justification policies reflect this conservativism:

- Savings statements are developed using only direct costs + variable burden.
- Resultant savings are halved for payback calculation to reflect after-tax savings.
- Payback period, return on investment, and net present values are determined.
- Payback of 2 YEARS OR LESS is required for approval at the division level.

Simmonds first CAD/CAM analyses were based on available source data published or presented by turnkey CAD/CAM vendors or from major CAD/CAM users with mature operations. These operations reported glowing successes of 10, 20 , or even 40 to 1 productivity ratios. Simmonds team investigated these claims and found inconsistencies and misleading figures. They came to the conclusion that they needed to develop criteria for evaluating whether CAD/CAM was feasible. These actions included:

- **Developing cost/utility applications profiles for candidate systems.**
- **Develop an independent index for small to medium size users including their applications and productivity assessments. Investigate various approaches to capital equipment procurement.**

Simmonds team assembled a roster of small to mid-size companies with applications similar to theirs. They followed up this investigation with communicating with the CAD/CAM functions in these various companies and found that 2-year financial justification is extremely difficult to obtain. The 3 major application areas they identified for CAD/CAM are : engineering, manufacturing, and graphics.

The engineering area targeted the printed circuit (PC) design as its chief CAD/CAM promise for productivity gains. They had excellent historical data to judge the vendor benchmarking on, but chose to use productivity gains based on 5 similar companies using CAD/CAM for this application due to the lack of benchmark conductor expertise, small sample size, and inability to factor variable into the test.

	Manual (actual)	Computer-Aided Drafting (actual)	CAD/CAM (estimated)
Schematics	22	22	16
Feasiblity Analysis	5	5	1
Design and Layout	40	40	20
Fabrication Drawing	6	6	2
Assembly Drawing	32	6	2
Artwork	40	10	0
Checking	30	30	11
Total	175	119	52

Table 3-1: PC Design Elements: Labor Hour Requirements.

Simmonds believed that the CAD/CAM system could save them approximately $145,000 per year in PC design.

In the mechanical design area, Simmonds team felt that there was little historical data to develop a model to calculate projected savings. They found that sizeable investment in up-front training, custom programming, and data base development costs would offset any sizeable gains in the first year of system operation. They projected a savings of $42,000 per year based on a proprietary mechanical design practice in a highly specialized area.

The manufacturing personnel team approached cost savings projections in a conservative manner. They based the $18,000 per year savings solely on numerical control programming efficiencies for NC lathes and machining centers.

The projected savings in technical presentation graphics and technical reports and manuals was estimated to be $35,000 per year. Overall the total CAD/CAM savings for the first year of operation was projected as $240,000. However, subsequent financial investigation revealed that a 40-month period of transition would be necessary to achieve this target, instead of the company edicted 24 month justification period.

As mentioned earlier in this segment of the report, intangible benefits arise from a CAD/CAM installation such as doing work which could not be done before and standardization. A study by Lockheed Corporation showed that design efforts using computer graphics resulted in more ideas and 15% fewer design changes. For Simmonds, the standardization issue was very important in order to reduce the number of parts in some of the complex assemblies Figure 3.1 shows how CAD/CAM standards reduced the number of parts for a product at Simmonds.

Simmonds chose not to include the intangible benefits resulting from

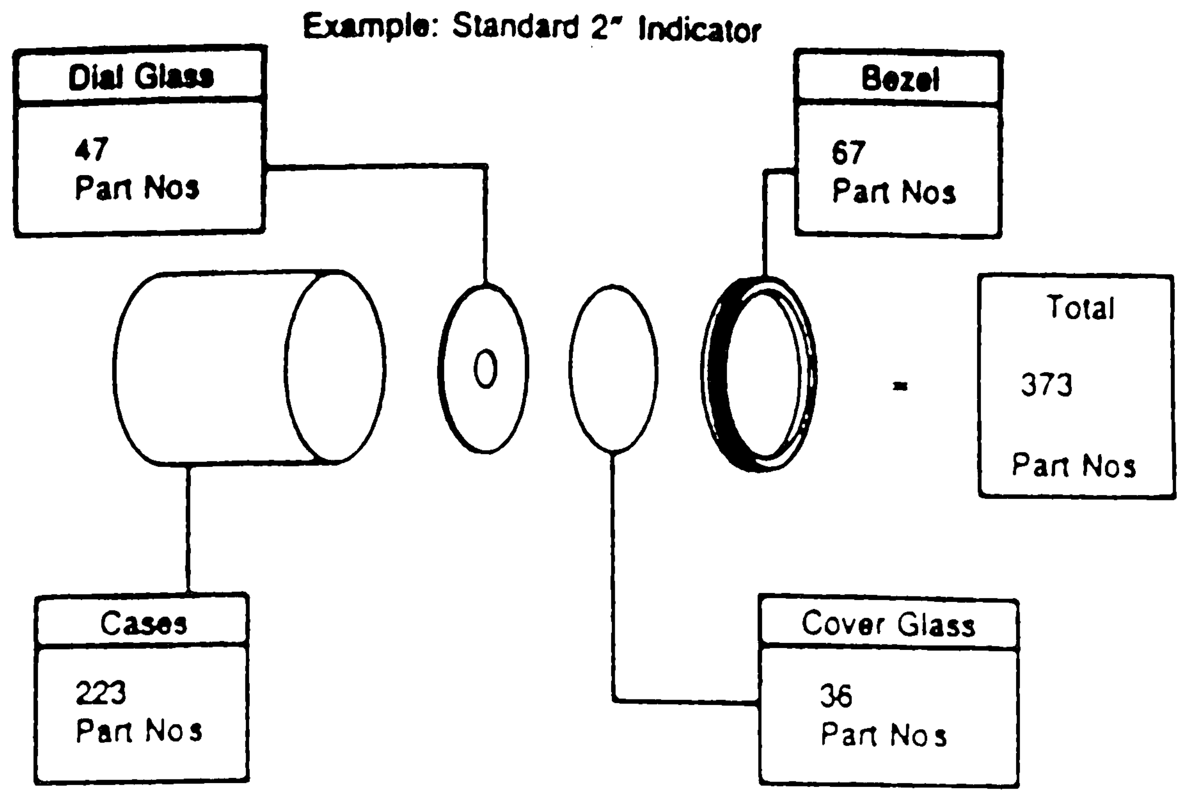

Figure 3-1: Part Number Proliferation Before CAD/CAM Imposed Standards.

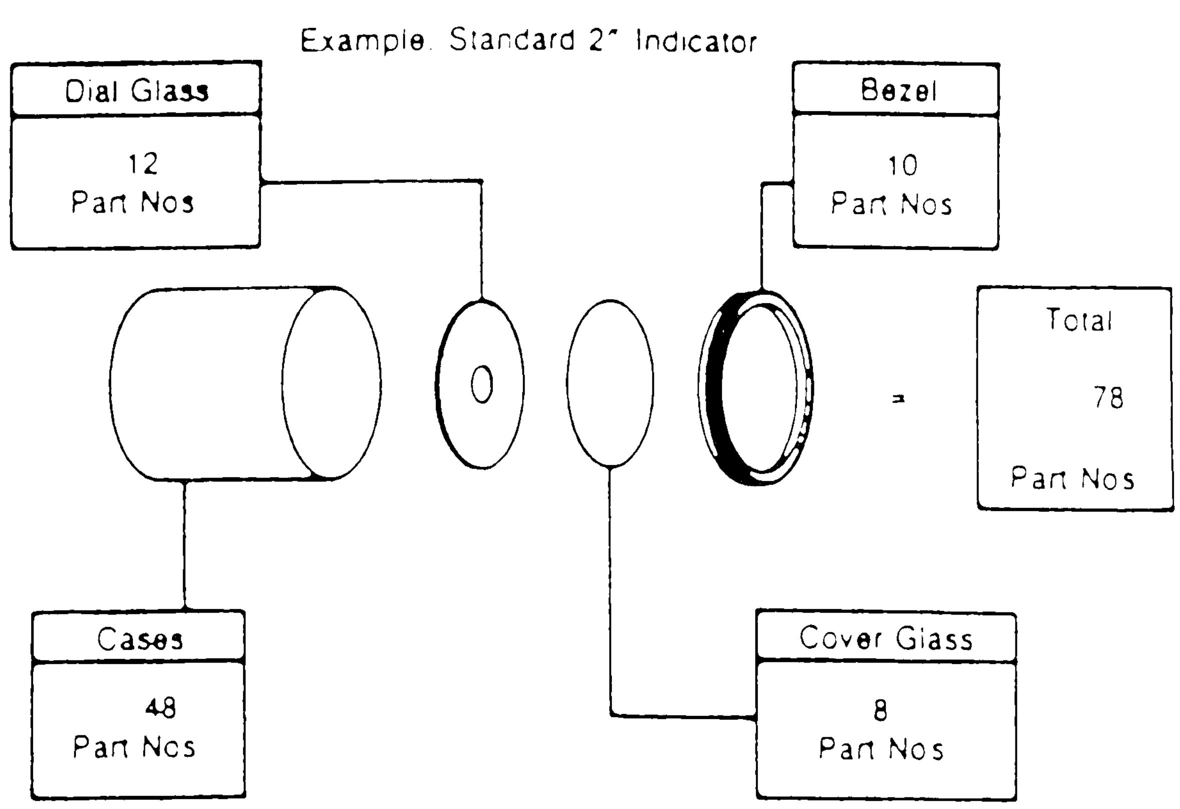

Figure 3-2: Part Number Proliferation After CAD/CAM Standards.

CAD/CAM because they were only realizable in the long run. The strategic benefits of CAD/CAM according to Simmonds are:

- CAD/CAM is the basis for developing systems and methods to strengthen an organization's position in the marketplace.
- CAD/CAM enables the design and production of higher quality products at lower cost with fewer errors.

- **CAD/CAM enables faster turnaround of high quality proposals.**
- **CAD/CAM generates a higher level of customer confidence.**
- **CAD/CAM helps integrate engineering and manufacturing.**

Because the Simmonds team was perplexed by the 2-year justification envelope, the top management intervened. This is an example of a management team convinced that a change was necessary. They issued two statements that basically stated Simmonds must establish priorities for critical new investments and incorporate a strategy of long-term competitiveness.

Simmonds hired a CAD/CAM consultant to examine the CAD/CAM system proposal and the consultant stressed three key issues:

1. The company might not realize any net savings in the first 18 months.
2. At the end of the first 24 months, the savings would not be directly attributed to a specific function.
3. A significant reduction in design and documentation errors could not be measurable.

The result of the consultant's study yielded management's approval to approve the capital request for purchasing the CAD/CAM system. Mr. Van Nostrand included several considerations in this report on implementation factors and tactics that influenced that actual payback. They are:

- A balanced approach to training and work assignment was taken.
- A well-managed, full-time, centralized design group was established.
- The company was made aware of its limitations.
- A well-structured series of do-able, successful projects was undertaken while avoiding the "all in one bite" approach.
- In order to avoid guinea pig projects, Simmonds provided a cash reserve budget to guarantee rebates covering any overruns. 110 hours were rebated while thousands of hours were saved overall.
- The care in system facility planning and installation netted a virtual 100% reliability rating.

The post audit results of the project were recorded and only included areas where sufficient historical comparison of pre-CAD/CAM and post-CAD/CAM existed. For the first year, PC design time was reduced from 119 hours to 50. This data was collected by a computerized tracking system for engineering functions. The savings amounted to $154,000.

In the second year the volume of PC work exceeded any previous period similar by 220 percent (See figure 3-3). These projects also reflected the changing nature of PC technology in the unprecedented technical requirements. All projects were delivered on time and at or below bid, suggesting the importance CAD/CAM played in meeting customer requirements. Intangibles such as reduction of drawing size, ability to have photoplotted masters developed overnight, and paper reduction among others surfaced. The PC design productivity ratio was now 3.4 to 1 versus conventional methods.

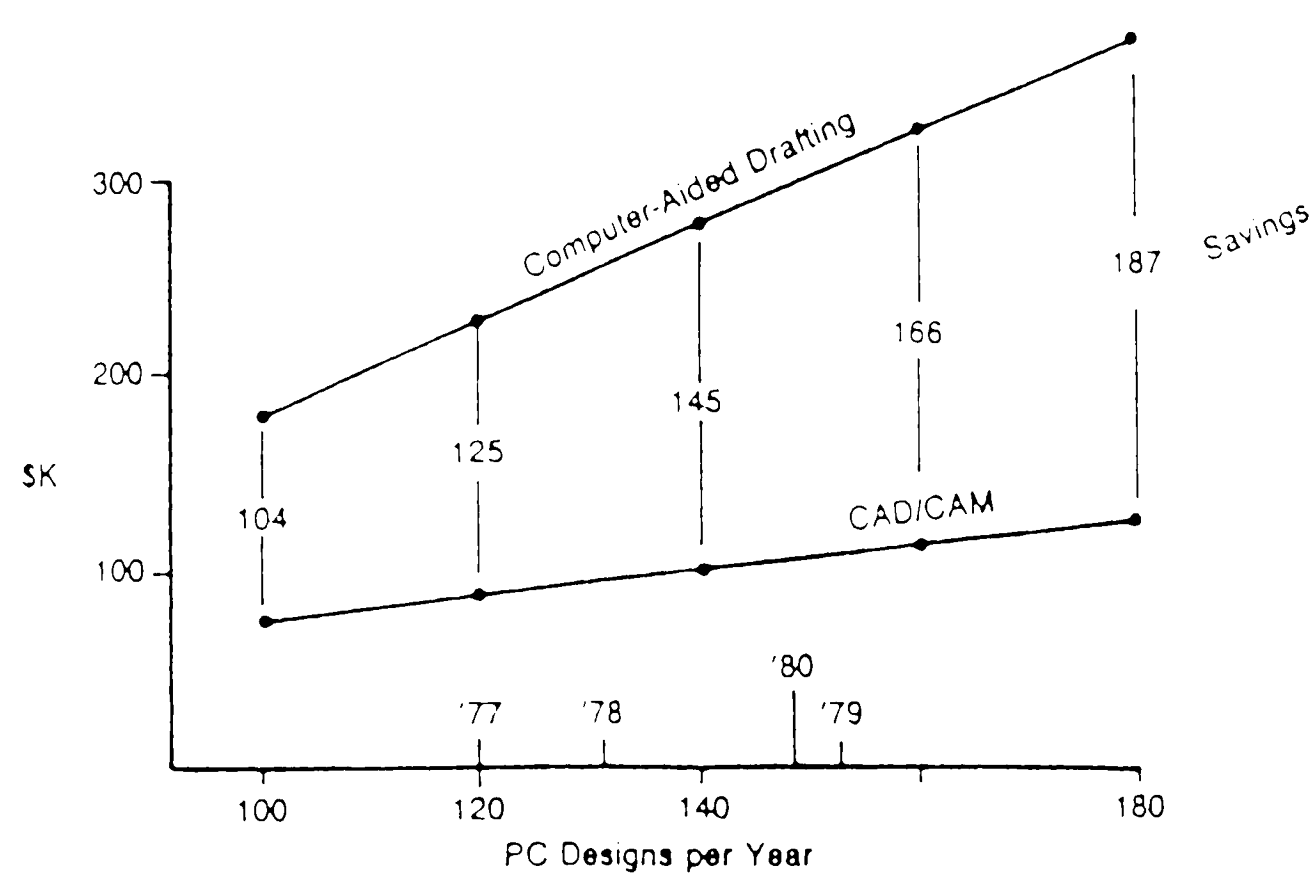

Figure 3-3: Computer-Aided Design PC Design Savings And Volume.

In the mechanical design area, Simmonds experienced a reduction in analysis turnaround times ranging up to 20:1, reduced mainframe time of 9:1, elimination of errors during data conversion, automation of extremely detailed worksheets and improved manufacturing fabrication. The projected cost savings was not realized due to the enormity of the PC and graphics work.

The fourth area of projected savings was the graphics area for assembly, technical documentation, and publications. Other offshoot programs developed such as offloading drafting to junior CAD operators, a method of reformatting design layering and modifying existing printed circuit assembly drawings, and single step generation of schematics. Additionally, a CAD clerk was now responsible for software flow diagrams, program charts, and drawing trees.

In terms of error reduction, Simmonds regarded the output from the system (hardcopy) to be extremely error free even with the increased complexity of the designs. They tracked 11 categories of cost factors for two years on design verification test and production releases. Errors were reduced from .26 to .20 per drawing. The cost reduction amounted to $9.50 per drawing for the reduction of errors including the time to correct.

One of the facts of the implementation of CAD/CAM at Simmonds is the reduction of the design and drafting staff. This is a major fear of industry toward technology advancement. However, these directly affected individuals can be freed to do more constructive, less menial tasks thus allowing more productivity from each person. The reduction of staff actually occurred in an organization content only, thereby increasing the engineering staff directly.

Simmonds concluded that the system was a great success. It exceeded their expectations in terms of reliability, payback, flexibility, utility and productive operator time. They felt that their CAD/CAM team was a highly motivated group of individuals who were willing to make the system a success.

On the opposite of the coin, Simmonds did not anticipate the need for a full-time applications programmer and instructor. Also, the system was not spread out to more designated user groups because of the hea y workload in the

	1976	1980	1982
Direct Labor Staff	102	96	164*
Less: Project Engineering	-18	-10	-37
Software, Applications	-----	-----	-----
Net Staff	84	86	127
Design, Drafting, Checking, and CAD/CAM staff	23	24	24
	-----	-----	-----
Percent of Organization	27%	28%	19%

** plus 32 job shoppers, of which 6 are design and drafting*

The reduction in actual drawings per year and per person are:

Standard Number of Drawings per Person per Year

	Drawings	/	Net Staff	=	Std. Drawings per Person
1980	1345	/	24.06	=	55.9%
1981	1410	/	22.8	=	61.8% (+10% vs. 1980)
1982	2160	/	28.6	=	75.5% (+35% vs. 1980)

Simmonds final assessment of the CAD/CAM system is reflected in the following chart for the first 20 months of operation:

	Predicted	Actual
Gross Savings	$240,000	$546,000
Less:		
Service Contract		($39,000)
Training		($41,000)
Library and Procedure development		($12,000)
Net Savings		$454,000
After-tax Savings		$227,000
Basic System Amortization	50%	70%

PC and graphics area. Overall though, they deemed it a success and an indispensable tool.

As an appendix to this published report, Mr. Van Nostrand answered the CAD/CAM survey (chapter 5) on CAD/CAM system performance and utilization issues. The reason or recognized need for investigating CAD/CAM for the Vermont operation was mainly technological and market reasons - to continue to compete successfully in this area.

3.1.1 Personal Observations / Comments On The Simmonds Case

One of Simmonds' disappointments with the system was the need for a full-time applications programmer and CAD/CAM system trainer. This seems to be true in many CAD/CAM installations. In the CAD/CAM Usage/Performance survey (Chapter 5), the majority of CAD/CAM users did not consider hiring a full-time programmer to conduct the system management and applications. This is truly a planning issue which needs to be addressed at the onset of system implementation planning. Experienced CAD/CAM application programmers are not easily available and also somewhat expensive but necessary for successful systems.

Simmonds success must be viewed in practical terms. The increased volume of work that they experienced after implementation of the system may have been due solely to the booming PC market. If they did not have CAD/CAM, they would have probably completed the tasks but with less efficiency and more personnel hours. The timing of the system implementation and the increased business helped Simmonds experience a great success.

Other companies expecting this kind of payback may be in for a surprise. CAD/CAM is after all a tool to aid in productivity. If the business cycle for a company's product(s) has a sudden downturn, CAD/CAM can not be the only aid to restore the financial soundness of the operation. CAD/CAM is a valuable selling point to prospective customers who expect shorter product order turnaround and it also necessitates the unquantifiable benefits mentioned before. Any management team that approves a CAD/CAM purchase based solely on it restoring the company's market position is in for harsh reality.

3.1.2 Other CAD/CAM Installation Success Stories

To end this segment of the report positively, there are many examples of successful CAD/CAM system implementations in the U.S. today. Using seven interactive graphics terminals, Grumman Aerospace (now Grumman Aircraft Systems) was able to reduce total design time by 50% and drafting hours by 10% compared with manual methods. Their manufacturing group experienced a 12% reduction in tool design time and 50% reduction in part programming time.

Potter & Brumfield (a division of AMF) installed a 3-D color graphics system to aid in the creation of of electromechanical components. The system is saving more than 25% or 11,000 labor hours on production of the company's new printed circuit boards.

The CAD/CAM survey (chapter 5) also reveals some success stories in CAD/CAM implementation, but also points out some realistic problems associated with CAD/CAM system implementation. Hopefully, the success stories outnumber the failures consistently in the future.

Chapter 4
Systems Thinking Perspectives

4.1 The Systems Thinking Concept Defined

System is a well-used term in and out of industry. However, in terms of this thesis a definition is : a configuration of man, machines, and methods to accomplish a specific goal or set of goals. As technology permeates and accelerates throughout industry, the system concept can become very unclear and misrepresented. The concept of the manufacturing enterprise as a single unit comprised of Business, Engineering, and Manufacturing "system" components places the "systems thinking" concept in proper perspective.

There is a people issue in the systems thinking framework and it is contained within each of the component systems. The binding mortar in this concept is the means of communication and its levels of distinction. The only way a system can become functional is for its components to be as strongly linked as possible. Communication is the non-visible link in the system which is as important as sunlight is to the ecological system. In terms of CAD/CAM the "systems thinking" approach can be analyzed in three separate but related aspects: Human, Organizational (including social aspects), and Technical. This also relates the current or "As-Is" organization before CAD/CAM implementation to the "To-Be" or future organization after CAD/CAM implementation.

4.2 The "Human Systems" Perspective In CAD/CAM Systems

4.2.1 A Changing Environment Brought On By Technology

Change can occur in two ways: 1. External changes that are related to the world itself such as energy shortages, weather, and 2. Changes that can be traced to changes in our mores, social values and expectations, and way of living. The role of technology falls in this second category. For every change, every innovation, and every invention, there are benefits or rewards to society as a whole, along with associated costs or risks.

CAD/CAM technology represents change. Change represents uncertainty, unfamiliarity, and risk. An important concept in the human systems perspective is the concept of "Human Factors". Basically human factors can be defined in three stages:

- The central focus of human factors relates to the consideration of human beings carrying out such functions as:

    1. Design and creation of man-made objects, products, equipment, facilities, and environments that people use.
    2. Development of procedures for performing work and other human activities.
    3. The provision of services to people.
    4. Evaluation of the things people use in terms of their suitability for other people.

- The objectives of human factors in these functions are :

    1. To enhance the effectiveness and efficiency with which work and other human activities are carried out.
    2. To maintain or enhance certain desirable human values (ie. health, safety, satisfaction).

- The central approach of human factors is the systemic application of relevant information about human abilities, characteristics, behavior, and motivation in the execution of such functions.

Prior to the Industrial Revolution, human factors had its origins in simple hand-made tools, utensils, and shelters. During the period from 1750-1890, the transition of the age of hand tools to the age of machines occurred. From 1870-1945, major human factors occurred in the expansion of the use of power to carry out manufacturing in agriculture, mining, transportation, etc. During the latter stages of this period (WWII) attention to the war invoked the concept of fitting the man to specific tasks. The age of specialization had begun.

The next phase of human factors occurred around 1945 to continues to this day. This phase deals with efforts to aid, relieve, and extend human mental capabilities. The human factors considerations moved outside of military applications and into industry, social, and economic venues [24]. CAD/CAM is one of the technological advancements during the latter portion of this period that has advanced mental capabilities of humans while relieving much of the drudgery of menial and repetitive tasking in the design and manufacturing environment. Today, design and manufacturing are receiving renewed emphasis as most important activities. Not since the 1800's has so much attention been concentrated on these human endeavors [15].

4.2.2 Managing Change According To People Issues

For effective CAD/CAM systems integration, there are 10 recommendations relating to personnel:

1. *Avoid "sneaking up" on your employees.*

   Before system implementation has begun, a clear strategy about what is trying to be accomplished is important. These goals must be communicated to the people affected, especially those directly using the system.

2. *While the technology is changing, change the organization.*

   Although this is easier said than done, the company environment must be right for the change. The types of changes which usually accompany advanced technology include:

   - Accelerated time frames due to reduced design, production and lead times.

- The actual manner of design and manufacturing is changed.
- Output is more closely monitored in terms of design and manufacturing.
- Communication is more frequent and complicated.

3. *Be prepared to accept negative consequences.*

   A perfectly painless implementation of technology such as CAD/CAM is a dream. Accepting the fact that employee stress levels may increase during the transition from old to new technology can aid in preparing a well balanced training program which addresses stress associated with change.

4. *As the amount of computerized communication increases, concurrently increase human-human communication.*

   The increase in computerization does not reduce the amount of human communication and interaction. In fact, as the need to gain better understanding of technology in business increases, people tend to rely on each other for support through training, break-in periods, and the stress caused by unfamiliarity when a problem occurs. A benefit of this can be reduced production system buffers, handshaking tasks, and approval cycle times because there will be a more cohesive, teamlike effort to understanding the technology in relation to the business.

5. *Attack the existing infrastructure to break down the wall to resistance to change.*

   Companies, especially well-established ones, have a set way or corporate "social norm" for doing things. This is one of the "systems" which has to change as a result of implementing technologies such as CAD/CAM. The tendency to rely on doing things a certain way because "we have always done it that way" limits progress. The built-in resistance to change will appear at all levels of the company. The key to lessening these effects is to understand the social climate of the company and promote the new technology in a "pro-change" mode.

6. *Expect to encounter some of the same old problems.*

   CAD/CAM or any new technology will not force the traditional problems of business to go away. With additional requirements and pressures, the problems may even become aggravated. However, the ability to accomplish new objectives with new technology may be the reason that old problems surface. For example, a vendor one company has dealt with in the past may have a quality problem in transferring data that now is unacceptable. The new technology has brought this problem to the surface and must be dealt with in order to make progress consistent.

7. *Do not expect 100% maximum results "out of the box".*

   The tendency to gain maximum results in a minimum time is a major reason CAD/CAM implementations fail. A reasonable amount of time to gain measured and planned results is very important. The intent here is not to downplay the system's effect on productivity and corporate objectives. However, CAD/CAM for many companies represents a major change in the way business is conducted. The anticipated results may not surface immediately if management expects instant, glowing results. Expectations must be moderate and usually are exceeded.

8. *Do not expect to eliminate jobs.*

   Positions that may appear to be eliminated by the implication of new technology are often transformed into another form. For instance, a draftsman on a board may not be replaced, but transformed into an electronic designer. Or a numerical control designer using APT may be transformed into a CAM expert using the NC capabilities of the CAD/CAM system installed. Generally, the quality of worklife improves due to better technology and current positions directly affected are elevated to a higher level of importance and opportunity for advancement.

9. *Use the new technology to monitor the system and users.*

   CAD/CAM technology can be used to monitor the performance of the system, either through vendor supplied or alternately developed software, to understand the benefits or drawbacks of its implementation. This results in a change in evaluation procedures because results are now quantified and measurable in real terms. However, the distinction must be made that certain aspects of CAD/CAM implementation are generally more successful than others in actual productivity improvements. Caution must be reserved in multi-disciplined corporations to not lump every CAD/CAM user into a specific performance envelope.

   The first year of actual experience with the system is an excellent monitor of past vs. current method improvements in various affected disciplines. The real merits to evaluate the positions should be accomplished after this first year. The monitoring must only be used as a means to base overall system performance and not be utilized as a bargaining tool with users who are more productive than others. This would surely have negative effects on teamwork.

10. *Change your strategy as you go.*

    This may be a reflection of past information, but the need to develop a "shape-able" strategy is important. Expect the unexpected and recognize the opportunities that the new technology brings.

The most successful corporations in this country have lasted a century or more because, as our society does, they change their corporate objectives, climate, and infrastructure to best suit their needs. This is not to say that they have keen interest in current needs, but long term objectives and needs. The term "only the strong survive" has to correlate to business philosophy of "only the adaptable and flexible survive".

4.2.3 Some Common Fallacies Of Technology-Induced Changes

The notion that change will affect the human resource practices within an organization is accepted. How and how much is a question that needs to be addressed. Also, how can the negative effects of technological change be identified and controlled? As an example, Northern Telecon was introducing advanced automation systems such as CAD/CAM and wanted to understand the problem in a more concise manner [20]. They constructed a model of the positive and negative psychological aspects of change and, along with reviewing other companies' literature about effects of change, came to the conclusion that there are a number of misunderstandings of the effects of technological change within an organization. Technological change will cause major changes in the way the organization operates in terms of culture, job designs, and human resource policies.

- *Fallacy 1:* Job extermination is the main human resource impact of technological change.

  This fallacy can be disproven through understanding that not advancing technologically will cost jobs through elimination of competitive ability in the marketplace. Many successful companies recognize that technological change is part of their growth and expansion plans. The term "rebalancing the work force" is a more positive message that advanced systems such as CAD/CAM can deliver. A no-layoff policy due to technology program combined with upgrading the status of the current workforce helps build confidence in the relationship between management and workers. Job skill training, career development, and improvement in the quality of worklife must be ongoing.

- *Fallacy 2:* The main impact of technological change is on hourly workers.

The idea that a robot will replace the worker and CAD/CAM will replace the engineer/designer is misleading. Hourly workers now represent only a small percentage of the costs to develop products, usually around 10% Direct labor. The technological change will affect the hourly worker, but not necessarily be aimed directly at him. This segment of the workforce will need to be trained for tasks that modern CAD/CAM systems bring about. Designers must get away from the drafting board, pencil, and paper and get acquainted with the keyboard puck, and screen. In many companies, the CAD/CAM system operators are categorized as hourly workers and need to be prepared for the shift to new ways of doing their job.

A main impact of new technology such as CAD/CAM will be on the professional and managerial sector. Professionals consider themselves isolated from negative effects of technological change, but this is only illusory. The trend is away from the hierarchical organization structure and a flatter organizational makeup with less levels of mid and upper management.

The affect on the hourly worker in terms of cost will be significant due to productivity and quality gains, but the increases in affects of technological advancement on professional people will decline. A difficult problem which develops from such technological advancements is the possibility of professionals "designing their jobs out of existence". This needs to be one of the considerations of companies as the trend to keep the professional staff numbers at current or reduced levels continues.

- *Fallacy 3:* Job design and other technical issues should be handled by experts.

The 1980's is truly the age of the specialist. The term "engineer" has been so diluted that there must be at least 50 different engineering titles in industry. This is partly due to the fact that technology has become so far reaching and specialized. The worker who deals specifically with the process or technology has been excluded from input into the decision making about his or her function. The reverse must become accepted if technological advancement is to work properly.

The complexity of modern technologies such as CAD/CAM requires that organizations depend less heavily on technical experts. The organizations need to depend on multidisciplinary groups which represent all parts of the organization. Technical experts are needed in the capacity to help implement change, but not to dictate it. They need to become facilitators of change for the group of specific workers affected directly by this new technology and be part of the team.

- *Fallacy 4:* New technology will reduce the need for interpersonal communication in the factory and office.

The factory of the future will not become a paperless, people-less environment. Humans and their communication and decision-making capabilities cannot be automated out of the design cycle. CAD/CAM is a tool, not the total solution to improved design and manufacturing cycles. The automated systems linked in the realm of CAD/CAM will actually require increased human communication from the hourly and professional employees. The increasing integration of design and manufacturing tasks need to be better coordinated with the management and workforce, thus the concept of teamwork is strongly emphasized [15].

The management and professional staff must become more aware of the interconnections of the manufacturing, design and business organization of the company. The modern office and manufacturing environment team operates through the framework of a coordinated, interconnected team that relies on communication. Technological change promotes more technological change. CAD/CAM systems are only part of the entire transition toward modern, information driven organizations. These systems do not only promote the technological change, but stimulate creativity and innovation to work towards advancing the state of the art, hence further technological challenge is attempted.

The organization must be sensitive as to when and how much the technological advancement must proceed before it overwhelms them. The fine balance between technological advancement and overkill can only be learned by proper planning and also partly based on historical experience.

- *Fallacy 5*: Technological change is bad for people.

Asking the workforce to list the negative effects of technology compared to its positive effects will usually result in a lopsided list in favor of the negative. This may be due to human nature to be resistant to change, however some of the charges can be justified such as boredom, job insecurity, alienation, increased stress, etc. Advances in technologies such as CAD/CAM offer the greatest potential to improve the quality of worklife and products. The organization is a socio-technical system and the changes in technology offer opportunities to improve skills, training methods, management skills, open organizational communication, and organizational development.

A major point to remember is that **people** are the most important asset to an organization. They are the most adaptable and yet least understood link in the chain of modern manufacturing systems. The future of successful companies in the United States lies in the ability to implement technological change in the most effective, people-oriented manner.

4.3 Organizational Aspects Of Technological Change

Most of the organizational concerns of implementing new technology center around whether the new technology will enhance the company's market position or be an expensive lesson in myopic planning.

Organizations function in their own unique fashion, directed by their company plan. Many times this plan is broad and technological innovation is assumed to be part of the plan. This section of the plan is vary far reaching in the different organizational groups within the company. CAD in itself represents a technological change that will require a lower level of organizational change. However, *integrated* CAD/CAM requires an effective coordination of effort in the organization at a high strategic level due to the need for coordination between engineering and manufacturing functions.

4.3.1 Cross-Functional Implications Of New Technology

Functionally organized firms, as many companies are, will realize certain implications of implementing CAD/CAM technology [2]. They are:

- The greater the magnitude of technical change sought, the higher the level of learning required in the organization.

  CAD requires localized levels of organizational learning due to its implications in the design cycle, and not in ultimate cultural changes such as integrating several historically independent functioning groups such as manufacturing and engineering. Integrated CAD/CAM requires higher level of detail in both the technical skills and procedures of the affected departments, and also requires organizational skill building in effectively developing an inter-functional group.

- The higher the level of learning, the greater the time to adjust.

  Three expectations can be summarized from this statement:

  - First, if more appropriate technical and organizational skills are in place prior to a given phase of CAD/CAM integration, the greater its effectiveness will be, measured as its impact on

the effectiveness of product development projects that will use the new technology.

- **Second, CAD/CAM's effectiveness will depend more on the pre-existing culture and strategies of the organization than on existing procedures and skills.**
- **Third, the pace of CAD/CAM integration will be dictated by its purely technical component than by the time necessary to establish the skills, procedures, strategies, and culture required to effectively implement those new technical capabilities.**

- In well-managed companies, CAD/CAM integration brings an improvement in all new product development project effectiveness.

  In order for CAD/CAM to be effective in helping to eliminate existing problems in a company, the company must already have attempted to tackle the organizational problems of the engineering/manufacturing interface.

Some of the pre-existing skills and experience to effectively implement CAD/CAM in the organization include developed computerized systems or knowledge in both engineering and production functions. Computer literacy and CAD/CAM literacy both in general and specific terms, must be addressed before the new system is unleashed in the organization.

Pre-integration procedures to allow coordination of design and production functions must occur in the proper sequence in order to allow proper integration. Parallel development must be a participative environment with all affected levels participating to speed the effort. Procedural cooperation of both production and design before the system is implemented must exist, because this type of cooperation , if forced upon them by upper management, will work for a short period of time before both groups return to their previous methods of separation of development.

Pre-integration functional strategies must be based on the notion that CAD/CAM is not the total solution to the product vs. functional structure of the company problem. An organizational strategic, long-term plan with integrated functional group goals in tandem with product evolution goals is critical. There

is no magical solution to the choice between the *ease of integration* provided by product oriented structures and the *depth of expertise* provided by functionally specialized structures. This dilemma is resolvable by pre-integration strategy and cooperation: basically planning.

The pre-integration culture of the organization toward cooperation and learning, and its effect on status, pay, education, benefits, and mobility will be best accomplished in an organization where each affected group sees each other as peers in a learning process. Competition is healthy between and within organizations, and there will naturally be some competition between the affected groups as to which group deserves (although biased) to benefit from CAD/CAM most. The real objective must be building some local expertise in each affected group which may be unique to them as long as it pertains to the ultimate goal of benefit to the organization as a whole.

4.3.2 Technology And Its Impact On The Workplace

A major effect of technological change is in the workplace. The workplace environment is generally affected and shaped by the systems comprising the work structure. New technologies can shape the worker's perception of the quality of life in the workplace environment. If CAD/CAM is implemented too quickly and in a broad and far-reaching manner, the natural reaction of the worker is to reject it, whether directly or indirectly in terms of management's point of view. The proper effects of how well the technology is implemented are very crucial to the overall system performance. The effect of this technological change occurs in three levels:

- Primary - Direct effect on the work, worker, working environment, product costs, investment, and basic requirement.
- Secondary - Demands on the operating system infrastructure: wage and work force management, production planning, scheduling and

control, quality control, and production organization.

- **Tertiary - Effects on the performance ability of the operating system; that is what the system can and cannot do well [30].**

The work environment is very susceptible to impacts of change. Figure 4-1 details the impacts. Choosing the right amount and methods of technological implementation such as CAD/CAM systems involve accepting some assumptions:

- People will be willing to cooperate if the wage is right.
- People are adaptable to a wide variety of tasks and conditions.
- People match themselves with acceptable jobs.
- Problems with any negative job reactions can be handled with :
    - Careful selection.
    - Adequate training.
    - Wage adjustments/monetary incentives.
    - Proper supervision.
    - Good discipline.
    - Open communications.
    - Proper grievance procedures.

The quality of worklife can successfully co-exist with high productivity. The higher the priority given to the impact of technological change on the work environment in the planning stages of a system, the better the chances of it being successful.

4.4 Technical Impacts Of Change

The technical issues of change brought on by CAD/CAM systems are multi-fold. The number of technical changes that a company experiences depends on the level of technology advancement in the organization at the time of the implementation. For example, aerospace companies have been at the forefront of CAD/CAM since its inception. The implications of bringing

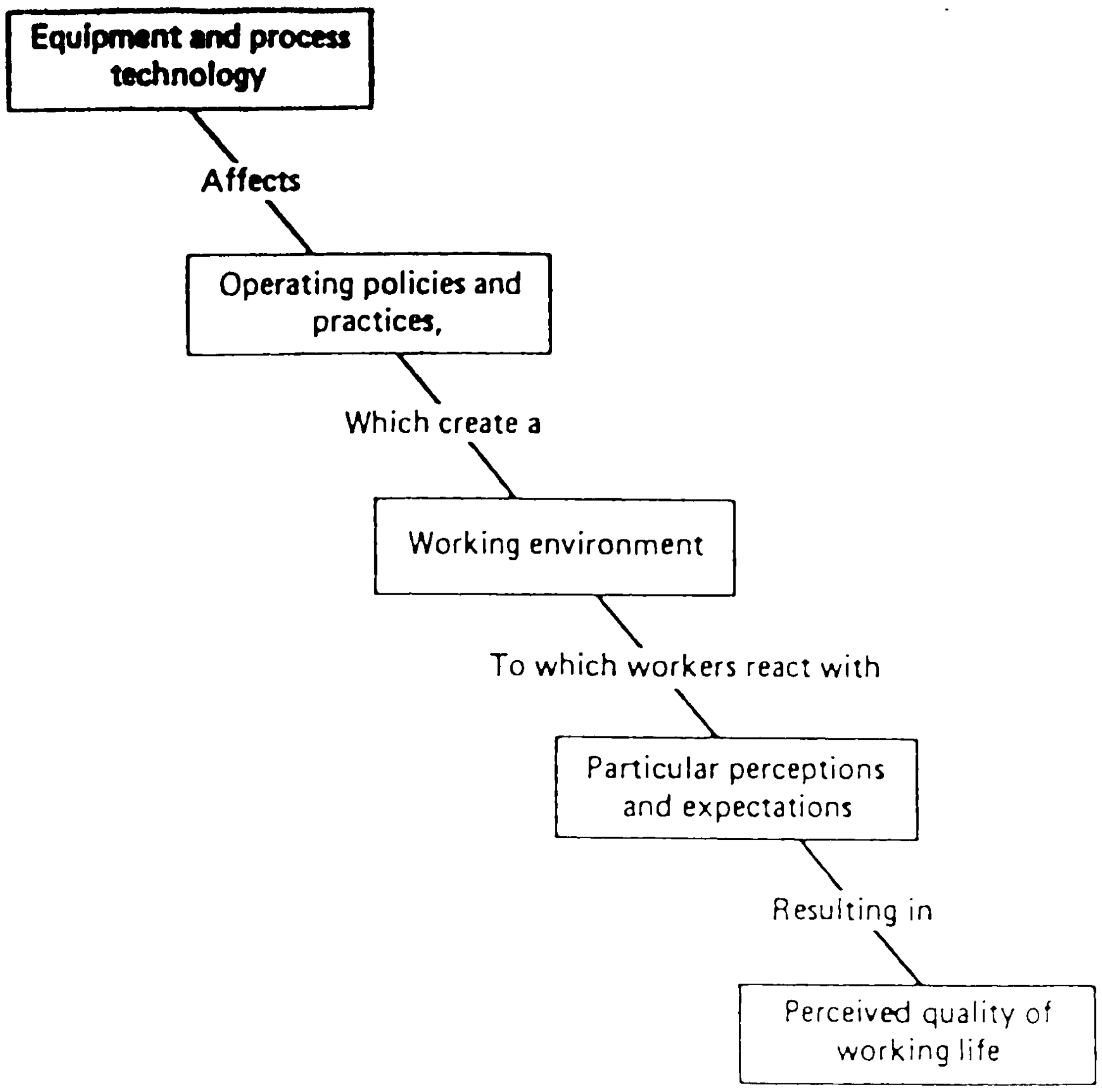

Figure 4-1: Technological Change and the Working Environment [30].

CAD/CAM systems into their organizations was a natural, and sometimes self-developed concept. Yet, companies such as a small die-casting foundry whose current state of technology centers around casting machines and not computers may find a much deeper technology culture shock induced by such a system implementation. How well it is planned is again, the critical component in its success or failure.

Some basic technical aspects of implementing new (CAD/CAM) technology in an organization deal with the impact on existing technology or methodology. For instance, the design task will be converted from a mainly paper and pencil environment to one with interactive computer graphic images and computer generated information on specifics of or analysis of the design. Such analysis can come in the form of finite element analysis, mass properties calculations, and basic design review. The inspection of the design can also be done in the interactive graphics mode instead of after the part has been built.

The manufacturing function will progress from a mainly build it, fix it, trial and error process to a computer model studied and implemented plan. Traditional machining operations or even numerically controlled operations will be linked to a CAD/CAM data base and specific application programs to generate the desired APT, postprocessing, and feedback tasking will be accomplished in hours compared to what previously took days. Machining accuracy can increase greatly and ability to develop complex machining tasks can be done through the powerful CAM packages offered in many CAD/CAM systems.

The ability to transmit technical data to project management teams is an aspect of the technological change. The interactive graphics terminal or workstation can function as the original tracings brought into a conference room to discuss any design and manufacturing review questions.

The accounting information generated by the CAD/CAM system will be greatly superior to that of traditional methods. The system can keep track of the records of the user time, project number, and specific part or drawing data. This allows easy and accurate costing of individual projects and can aid the cost estimator's task.

The way data is stored will drastically change in the organization. Typically, product manufacturers have a historical record on their estimated costs, time to develop and manufacture, and actual design and manufacturing costs by storing them throughout company departments in file cabinets. This may seem like an oversimplification, but it still exists. In some cases, a storage room full of previous products may serve as the physical database of products in the company, each with its own basic historic "paper" record attached. The CAD/CAM system will provide a central and logical storage point for the previously mentioned information. The data will be easily accessible through graphics or nongraphics terminals and stored on magnetic storage media. This will provide a greater method of controlling data on products either in progress or completed. It can eliminate the possibility of reproducing the same mistake.

Another technical aspect of change brought about by CAD/CAM is the "elevation" of the status of the design team members. The fact that drafting and design personnel must adapt to using a computer terminal instead of a drawing board can frighten some of them but generally will improve the group's visibility within the company and heighten the sense of accomplishment in the group. They will feel that they have become a vital part in the computer age.

How the CAD/CAM system can link up or "talk to" the current design, manufacturing, and management systems in place is another aspect. The mere fact that a CAD/CAM system is in place does not mean it is performing to its objectives. There must be some communication links established between the system and : the NC machines, the accounting and payroll computing system, the Coordinate Measuring Machines, and so on. This must be planned in advance to the system implementation and co-developed through the vendor, the client, and outside firms experienced with such matters.

Some more technical aspects include recognition of training needs that had not been considered in the organization, ergonomic considerations of the new work areas where CAD/CAM systems exist, having to build a working relationship with a CAD/CAM vendor for service and instruction, attending user community conferences and establishing working relationships with similarly affected companies, assigning computer privileges and security measures within the organization, and even expect the possibility of piracy of data within the organization.

Some of these training aspects, using CAM as an example, include:

1. Production staff will need to have increased conceptual skills, perceptual attitudes, and the ability to read/write operating instructions.

2. Professional/technical staff will need training in the production process, mathematics, and the ability to visualize objects and motions in three-dimensions.

3. Supervisors will need to be trained in organizing and integrating shop floor operations, leadership skills to motivate workers on potentially boring jobs, and human relation skills to help workers adapt to the new technology.

4. Strong basic skills in math, science, reading, and computer literacy will constitute the foundation for all new technology instruction [23].

The company must also come to terms with the fact that this technology change will not remain static but be a dynamic process. The decision to move from a central processor to a workstation environment is not a simple or inexpensive one. Anticipation of future products which may obsolete current products is always a concern in this type of industry. Keeping an eye on the past and another on the future is part of the new awareness needed to properly distinguish between technical success or overloaded failure.

These examples represent a portion of the technical aspects of change brought into a company by CAD or CAD/CAM implementation. Their impact, as mentioned before, depends on how much technology the company wants to assimilate into the organization in a specific time frame, and the resultant planning and effort made to parallel the goals.

Chapter 5
Analysis of CAD/CAM Usage/Performance Survey

5.1 Background

As part of this thesis, a CAD/CAM Usage/Performance rating survey (structured questionnaire) was developed and sent to 63 different companies. The survey was directed at various industries that either used CAD/CAM technology or were in the process of implementation, or were considering it. Only 2 of the companies surveyed had no plans to consider any level of CAD/CAM technology. Appendix 3 is a copy of the survey/questionnaire.

This survey was the result of an initial list of questions sent to Chrysler Corporation manufacturing division to assess their experiences with implementing CAD/CAM technology at their Michigan operation. The original list contained 7 multi-part questions which were designed to be broad enough for automobile companies other than Chrysler. The current survey was upgraded from this original list to include various industries which manufacture discrete products. The list grew to 26 multi-part questions and included a rating scales for some issues. This survey is meant to complement the literature gathering for this topic by adding an up to date actual measure of how well (or poorly) CAD/CAM systems are justified and implemented in various industries in the United States (and 2 participants from Canada).

Of the 63 surveys sent, 22 were completed and returned, including the original survey questionnaire to Chrysler. The outcome of the survey may have been different had all surveys been returned, however, the representative sample is sufficient to gain valuable information from. There was a separate list of 9 questions sent to CAD/CAM systems vendors which has to be discussed as a separate issue related to the survey (the final section of this chapter).

5.2 Representative industries

The industries represented, as reflected in the first question of the survey are:

- Aerospace Airframe Manufacturer (2)
- Aerospace Electronics
- Automobile Manufacturer
- Automotive Components
- Avionics
- Capital Equipment
- Chemical Company
- Die-Casting (5) includes Zinc, Aluminum for various applications
- Gas Turbine Engine Manufacturer
- Heavy-Duty Construction Equipment Manufacturer
- Heavy Industrial Process Machinery
- Helicopter Manufacturer
- Manufacturer of Self-Clinching Fasteners and Installation Devices
- Precision Wood and Plaster Mold Castings Shop
- Semiconductor Memory Products
- Walk-in Refrigerated Coolers and Freezers

5.2.1 User Profile And Departmentalization

The companies represented vary in size and business volume from a 50-employee organization with $3 million in annual sales to a 25,000- employee giant with over a billion dollars in annual sales.

Less than half the companies have a designated CAD/CAM department. The main thrust is to have the CAD/CAM organization located within the different departments it serves, such as production engineering, manufacturing and in one case, quality assurance. The sizes of the companies dictated the amount of system infiltration that occurred but in one case, the system is used by 2 draftsmen and 1 technician and is serving a purpose for this engineering department only.

In the majority of cases, design draftpersons comprise more than half of the user population. Engineers on the average comprise approximately 15 to 20% of the user population. Non-technical users are very few, usually less than 5%. Depending on the size of the organization and the engineering and manufacturing department percentages, the number of system users in the companies surveyed ranged from 5 to 50%. The impact of the system utilization is much greater on the entire company compared to the number of users.

5.3 Analysis Of Questions

5.3.1 Status Of CAD/CAM In The Companies

Except for the 1 company which was in the process of CAD/CAM system implementation, 100% of the companies used CAD for various percentages of the design work. The CAM status is not as well linked to the design process in the majority of the companies. Some key points in the question on how the companies are currently utilizing CAD/CAM are:

- Every company utilizes CAD.
  - Range from 100% of design done with CAD to 30% of the engineering design work.
  - 100% of new designs done on CAD system.
  - Applications range from 2-D point line to solids modeling.
- 7 of 22 utilize PC's for CAD applications.

The term CAD/CAM is a misnomer in companies that only utilize CAD. The applications sometimes prohibit CAM. For example electronics are very design intensive, but manufacturing is not CAM specific. The size of the companies displays the range in number of terminals, but interestingly, the majority of the users do not have true 3-d modeling systems in place.

In terms of CAM, 15 of the 22 companies utilize CAM in ranges from small-scale machining to full-scale integrated manufacturing. One company which manufactures heavy equipment specifically stated that they do not have any data transfer from CAD to CAM, but still have design and manufacturing CAD/CAM. This proves a need exists for better understanding of CAM by companies.

The actual CAD industry segment was an offshoot of the original NC application development in the 1960's. It is apparent that CAD is the dominant half of the CAD/CAM acronym. CAM is not fully recognized at the onset of system implementation by the majority of these companies, and they are beginning to realize significant benefits from implementing the CAM aspect.

Another segment related to this question dealt with other company divisions or departments to gain CAD/CAM experience from.

One of the die-casting companies and the chemical company are considered pioneers in implementing CAD/CAM into a traditional field respective to their business concerns.

5.3.2 Pre-Planning : How And Why

The responses to this question were very varied in scope. The responses varied in the following manner:

- Extensive evaluation period of 3 years before purchase.
- 12-14 month research evaluation.
- 6-month actual study.
- Upper-management dictated the purchase.

- CAD well researched, CAM not well researched.
- Multiple vendors investigated before purchase.
- Very little research other than literature.
- Justified by marketing division.
- Attended various display shows before purchasing.
- Have yet to implement due to cash-flow ROI justification.

The way companies pre-plan the system is very individualistic. Some companies are very skeptical or resistant to changing the ways of doing business and conduct research on CAD/CAM implementation far longer than necessary. A good yardstick is 6 to 10 months because the technology can change radically in longer time frames. It is true that most of the companies surveyed did conduct research before purchasing the system, but it needs to be an ongoing process. Only 3 of the 22 have an ongoing formal policy to continue the planning process for CAD/CAM system purchase. This can represent future upgrades or even new system purchase.

The needs of the company and the state of CAD/CAM system technology are continually changing and need to be constantly reviewed. Again, the CAM side of the planning phase is not given enough priority in the planning stage. CAM represents a major investment in future competitive posturing for most of these companies and better efforts to involve manufacturing departments in the planning process are needed.

5.3.3 System Expectations And How Based

The expectations of the performance of the CAD/CAM systems compared to methods before system purchase were consistent. They range from:

- 2, 3 and 4 to 1 productivity and time saving gains.
- Increased geometric part accuracy.
- Reduced design redundancy.

- Ability to do advanced 3-dimensional design work.
- Produce more complex designs.
- Simultaneous engineering.
- Not truly defined.
- Has not been achieved yet due to system implemented 6 months ago.
- 60% design time reduction / 20% quality improvement.
- Reduced product development cycle time.

The basis for these expectations ranged from:

- Previous experience, observing other users, blind faith.
- Not certain how it was based.
- Industry data.
- Benchmarking.
- Blind faith in sales rep.
- Industry analysis.
- CNC Machining centers do precise work, but need CAD/CAM to aid in programming.
- User community experiences.

The surprising fact is that CAD/CAM systems can still be sold through a sales pitch alone. These systems must be presented on a level where the customer has a comfortable position such as benchmarking and user community data. Benchmarks done with actual product cycle data can be extremely beneficial compared to a generic benchmark test. Industries need to strengthen the user community participation in CAD/CAM. There are cases where there are no real data to judge the success or failure of system implementation, such as in the case of the one die-casting company which pioneered some CAD/CAM studies. However, there are enough overlapping design and manufacturing commonalities in the user community to make an educated and informed estimate on system performance expectations.

5.3.4 Is Technology Customer And/Or Market Driven

This was a difficult question for most companies to distinguish. 11 of the respondents said that due to the nature of business today, the customer and the marketplace decide how the company dictates its technology policy.

Three companies remarked that the technology policy is dictated by the customer. Customers are requiring:

- Higher quality products at competitive pricing.
- More complex design capabilities from supplier.
- Ability to transfer data electronically - CAD/CAM is key.

Three stated that the technology policy of the company is market driven. These respondents tended to be large-scale contracting firms with little interface of electronic data exchange with the customer. Their product line is in a very competitive market and it is the key motivating force to advancing technology policy with system purchases such as CAD/CAM.

One company stated that technology is not necessarily dictated by market or customer, but is more a function of increased accuracy, efficiency and ability to do business. However, the value-added capability the system brings to the product line impacts both segments.

One other company said it does not consider this question relevant to their situation because they are a military contractor with fixed agreements to carry them into the 1990's. This is in direct contradiction to another military electronics contractor that is looking to enable its division to capture more large government contracts by proving technological superiority. Military contractors have recently been under government pressure to offer more competitive bids on contracts as well as define and justify their pricing policies. The military contractor that doesn't feel that they need to be in tune with their customer base cannot ignore that the taxpayer is the ultimate customer for their product.

5.3.5 Is Your Business Plan To Diversify Or Consolidate

7 of the companies specifically could not clearly define their business plan in this detail. 3 responded that they were military contractors, therefore large scale business precluded them from diversification and also they have other divisions to enable product differentiation.

7 of the companies specifically responded that they did not plan to diversify. These companies represent established products in a heavily competed area. They are mid-range earning firms in the $50 - $100 million range. The product line needs to be given major attention to enable regaining market share for these firms before they would consider diversification. All of the die-casting firms except for the automotive research firm are specifically looking to do more large-scale business and move away from the job shopping attitude that the industry is noted for. This is a significant trend for die-casting in general and a move that will eventually cause other smaller firms to close shop or become taken over by a larger firm.

Only 2 companies are interested in diversification, one is the Turbine engine manufacturer, the other is the giant chemical company. These 2 companies represent the healthiest industries of all the firms excluding military contractors. They are more interested in future projects because their current product line(s) are very well entrenched in their markets.

Finally, the military aerospace electronics firm is looking to become more "selective" in which contracts they look to bid on. They believe a better long-term business and technology strategy will enable them to compete in this important segment of the electronics industry.

5.3.6 How Technology-Oriented And Supportive Is Management

This question was very broad in scope and most companies did not elaborate on their answer (this points out that such a survey is a living document that must be refined several times before it is perfected). In this case, the time constraint of turnaround forced me to accept the answers at face value.

15 of the companies agreed that their company management is supportive of the CAD/CAM system as a necessary tool to do business. The intensity levels of how supportive are reflected by the fact that 2 of the 14 detailed that their management is very enlightened on CAD/CAM technology and are fully confident of its impact.

3 companies reported that their management is somewhat neutral on the subject and do not fully understand the concept. The major reason for the uncertainty is the lack of technical understanding of how the technology serves the business needs of the organization as a whole. The one aerospace airframe manufacturer stated that the reason management support is uncommitted is due to the fact that they are trying to achieve a CIM-type environment and no upper manager is sure how to accomplish the goal. They need to define what their CIM goal is at both upper management and factory floor level and find a true concept if CIM is really what they are after.

5.3.7 Quality Focus Issues

Because quality is a very important issue facing companies today, it was a goal of the survey to get a feel for any quality judgements or standards that companies in the survey sample have instituted, observed, or integrated into their CAD/CAM system operations. The quality issues have been categorized according to the following areas:

- Where is the focus on quality directed.

- What performance measures are instituted for CAD/CAM system.
- Are system reviews and user reviews part of the monitoring system.
- Is user feedback important to judging system performance.
- Where are the system bottlenecks.
- Have Engineering Change Orders (ECO's) been reduced.

Although these questions cannot fully determine if there is an effort to understand if CAD/CAM system quality is apparent in the firm, they are a basis to recognize if such issues are being addressed and becoming part of the overall systems thinking plan. Quality is a function of all components of a system and the quality of the CAD/CAM operation is critical in achieving company objectives.

5.3.7.1 Where Is The Quality Focus In The Company Directed?

This question is not intended to channel the idea of quality into a single corporate concept, but to understand if CAD/CAM system quality has been interpreted as part of the overall concept.

Except for 2 firms, every one stated that quality is one of their main objectives and that they focus on it seriously. The major definition of what quality is to these firms is: Customer satisfaction with the product which is competitively priced. This is a fair assessment of quality. The two companies that did not have a specific focus on the quality issue feel that their upper management direction on the issue is unclear. This is a serious error for these companies to make and communication of this issue may need to come from the bottom up.

3 companies stated that CAD/CAM quality is not really part of the focus on quality in the company because it is not part of the quality issue. This is evidence that a true Systems Thinking attitude does not prevail in the company.

The die-casting company which has yet to implement CAD/CAM is one of two companies that specifically stated that CAD/CAM system quality is or will

be part of the focus on quality. The other company (the aerospace electronics manufacturer) has a very valid point which was not considered - that CAD/CAM causes the focus on quality to come about, but that the issue for most companies is the product quality, not really the CAD/CAM system.

5.3.7.2 What Types Of Performance Measures Were Instituted

In 8 of the companies no CAD/CAM system performance measures are in place. This is quite an unexpected result. One company stated that CAD/CAM is an accepted part of doing business and this justifies no need to measure system performance. If companies are to understand if the CAD/CAM system they implement is successful or not, there must be a method of judging its performance to past practices. In another company interviewed prior to sending the survey, they said that they never took time to see if the system increased productivity to previous manual design/drafting methods, but did say they were able to develop more complicated NC type work.

The majority of the companies do have a measurement system intact. They range from:

- Design Graphics is a self-measuring body.
- System uptime response is good measure.
- Custom software to compare electronic data to production part.
- Plan underway to improve system-to-system communication quality.
- Simultaneous design quality and simulation scale.
- Auditing all incoming master production drawings.
- CNC touch probe to measure dimensional tolerance of the part .
- Responsibility of full-time System Manager.

5.3.7.3 Are The CAD/CAM System Users Monitored

An interesting fact related to the previous question on system performance monitoring is that 5 of the 7 companies that do not monitor system performance do monitor user performance. Does this mean that their management philosophies need to be restructured to reflect a true systems perspective? Yes. Management style of the 1980's cannot be so heavily handed as to judge a system by how well its operators are performing. They are only part of the overall picture and sometimes the system itself is the major factor to consider.

8 of the companies do not formally monitor the performance of the users. One of these believes they eventually may do so. The one company which does not have their system implemented could not respond to the question as well as the pattern shop with a relatively new installation. The users are generally monitored by management, except in the case of the design graphics group of the chemical company which is a self-measuring body.

5.3.7.4 Is User Feedback Part Of The Measurement System

For the companies that do not monitor the system performance, this is a moot point. However, the majority of the companies do consider user feedback (in the form of complaints, suggestions for updates, ergonomics, management policies, etc.) vital to the operation of the system. This is very valuable to recognize because users of the system are the most directly affected and critical component of the operation. Most successful companies have some method of screening and classifying the user feedback and this is a major way CAD/CAM system vendors can address system inadequacies or bugs. It is part of the key communication channels in the ultimate success or failure of the operation.

5.3.7.5 Where Are The System Bottlenecks

12 companies chose to answer this question, with the others either not certain where the bottlenecks existed or did not fully comprehend the question. The companies that did respond had very important answers and they can be summarized as:

1. Poor mainframe response time (echoed by 4 of the 12 companies).
2. Security and file plotting access.
3. Quality of design input problems.
4. Sharing data between 2 or more separate locations.
5. Crossing functional boundaries.
6. Lack of middle management acceptance and support.
7. High workload combined with inability to staff more than 1 shift.
8. We must "work through" currently developed programs to ensure efficiency.

The three main issues here are the response time, data exchange problems, and management problems. The hardware which several of the companies chose satisfied their requirements until the workload grew and complexity of data and user base expanded. The major contractors of this group bought a bigger computer, but recognize that this is not the best solution. The trend is to move to distributed systems which offload major processing responsibilities to stand-alone workstation with the mainframe serving as the main storage and retrieval area for data. The computing power of these workstations is approaching equalling or exceeding many of the currently installed CAD/CAM hosts which are several years dated. The price is very appealing and is a major factor in the trend.

The data exchange issue is still very touchy for the firms that deal with multiple CAD/CAM systems at their companies or have to electronically exchange data with their customers. The IGES/PDES graphics exchange standards along with communication network protocols such as MAP/TOP are still far from being totally accepted into companies. There are arguments that place the burden of IGES and PDES inadequacies on the user community and others that blame the developers for inadequacies. In terms of MAP/TOP, companies are not certain when to invest and how much to invest in such manufacturing and office communication protocols. The real issue is time. There must be a continued effort by the user and development community to achieve more standard communication protocols and data exchange specifications in order to bridge the data and communication gap still very existent in industry. Just as CAD/CAM took several years to become accepted in industry, communications standards will eventually occur.

The management issue is covered in some detail in chapters 2 and 4, but the main point to make here is that staffing capable people and finding enough capable people is very difficult. Many companies do not realize that a system manager is very important to aiding in the system success until after the system is purchased and running. Also, some areas of the country are not blessed with a high concentration of experienced in this field, making "home grown" operators and users a must. Most of the companies try to find people in their organization with an aptitude for CAD/CAM as a method to screen the staff. Not every technical person in the company is going to accept the system and will avoid or criticize it regularly. Of course, this is the real world and this type of problem can be expected.

5.3.7.6 Engineering Change Order Reduction

This is not as important to focus on as an issue that was pointed out to me by several of the companies surveyed. Only 1 company actually measured the reduction of ECO's and their reduction rate was 20%. The point brought out by several of the companies is that ECO's may not have been reduced, but the design and manufacturing staff can now concentrate on more critical tasks with less paper shuffling and busy work. This is an important value-added feature of the CAD/CAM systems. Other important features mentioned include more accurate part data, more confident designers, reduction of human errors in the production cycle, and renewed enthusiasm in the design and manufacturing groups.

5.3.7.7 Is System Management Part Of The Quality Focus

13 of the companies stated that proper management of the system, both internally and externally, are important in the success of the operation. Some key points in the responses are that this is usually transparent to the users, data management is also a key issue within the system management framework, and the organization of the company around the system is important.

3 companies stated that they do not believe system management is a key issue. Judging by the nature of these 3 companies, their businesses are irrelated (helicopters, die-casting, and heavy equipment) and the reasons for not considering this issue cannot be discerned.

The last point to make here is that the companies that intend to or do have a stand alone terminal environment consider the system management issue minimal. This may prove that the trend away from mainframe environments and toward workstations will change the nature of the data processing and exchange function within the companies from a central responsibility to a local one.

5.3.8 Was A Consultant Considered Or Used In Planning And Implementation

In several of the texts on CAD/CAM systems, it is stated that consultants are an important option companies have but rarely utilize to aid in the pre-planning and initial implementation phases of the system. 12 of the companies do not and will not use outside consultants. The main reason these companies do not use the services of a consultant is having enough in-house expertise to get the job done. This is somewhat surprising considering that many companies rely heavily on vendor sales pitches, benchmarks and literature when considering the system. The term consultant may simply scare many companies. They think of $100/hr. fees and the possibility of getting information they already know pointed out to them. Respectable consulting firms are often times worth the investment in coming to terms with a problem quickly and dispassionately.

It is not the contention of this report that a consultant is absolutely necessary, but there are some advantages to using an experienced firm to aid in setting a CAD/CAM strategy commensurate with the company's objectives. There are alternate means of obtaining consulting services other than traditional consulting firms. This can include:

- Industrial cooperative efforts to share and/or exchange technology and its associated costs.
- Federal or State sponsored university/industry research programs i.e. Lehigh University's Ben Franklin Partnership Program.
- Membership in CAD/CAM user groups prior to purchase (Vendors would be obliged to point the company to the local users group of the specific system).

The companies that do or did utilize the services of a consultant mainly were concerned about the training methods they should adopt. The services of

the consultant also were used in some cases for pointing out if a CAD/CAM system was necessary. In the Simmonds company case, the consultant pointed out that there was no guarantee that the company would achieve the objectives of productivity gains and capital justification. The use of this consultant added authenticity and validity to the pre-planning that Simmonds did and this helped convince upper management to go ahead with the project. Another advantage of using a consultant is the fresh approach an outsider can bring into an organization.

5.3.9 What Type Of Benchmarking Was Used

Half of the companies relied on vendor benchmarking (direct or indirect) as a primary means of system justification. This fact that half did not do benchmark testing relates to the fact that many companies do not monitor the CAD/CAM system itself for performance. The companies that did benchmarking but not using the vendor as the primary initiator of the test believe that vendor benchmarks are unreliable and not thorough. This is apparent in more complex applications and will become more apparent as industry needs become more complex. However, CAD/CAM systems are advancing rapidly toward solids modeling, precision graphics, true 3-d capabilities, and very fast response times. This could tend to make vendor's benchmark abilities more exacting and precise.

The other half that did some form of benchmarking with the vendor as the main or sub-participant were satisfied with the results. In cases where several vendors came up with fairly system configurations to meet the project needs of the customer, the quoted price was the deciding factor. In only one case was the choice decided not on a benchmark test of any kind but on the reputation of the vendor alone. This proves that a powerful marketing job can sell a system alone.

The helicopter manufacturer did not rely on benchmarking due to the fact that they needed 200 to 250 "tubes" in very short turnaround time (proof that the decision to purchase a CAD/CAM system may have been politically or financially delayed until the last minute). A related tie-in with this quick purchase decision is that this company is only utilizing the equipment as a 2-D drafting tool (the system is a powerful, true 3-D system capable of FEA and solids modeling).

Companies can not afford to invest in technology in shotgun approaches or they can end up buying expensive technology for minor applications. This is equivalent to buying a fire extinguisher to putting out a match when a simple puff of air would have sufficed.

5.3.10 System Customization

In terms of hardware customization, all of the companies are satisfied with the availability of products "off the shelf". In terms of software, half the companies have in-house software specialists to modify and mold the system to fit their needs. Some of these companies also will buy vendor supplied software when it is advantageous or only available from the vendor.

6 of the firms either purchase their software needs through the CAD/CAM system vendor or a 3rd party that is providing a product that is compatible with their current system configuration. This is a route that is beneficial to the smaller firm which has no real programming staff or the funds to create such a post. There are many quality software packages that exist for tying in with CAD/CAM projects. These include estimating packages, system uptime and reliability software packages, advanced graphics accelerators, NC pocketing algorithms, etc. The buyer must keep abreast of what is available instead of wait-

ing for the principal vendor or even a major competitor's capabilities to prove what is available.

The die-casting company that has not implemented CAD/CAM is in the process of developing software through a university/industry program. Related to this, the capital equipment manufacturer initially developed software through a similar partnership program but now is responsible for its own software needs.

The remaining companies have not realized a need to purchase or develop software for their application needs. The CAD/CAM system they have is serving the design and/or manufacturing objectives capably. This does not mean they will not eventually consider upgrading their system with specialized software. CAD/CAM systems are often the first step toward full systems integration in many companies. The steps taken must be done in technologically and financially feasible fashion.

5.3.11 CAD/CAM System Location

The most common configuration in half of the companies is the centrally located mainframe computer with workstations or tubes located in the departments where they are needed. This trend is changing to distributed environments with the central computer serving as storage and data base.

3 of the companies are utilizing a networked arrangement with strategically located workstations downstream from the CPU. The one company of the 3 also has the other situation with the mainframe serving the needs of "dumb terminals" (with no local processing capabilities) in contrast to the "intelligent workstations" (with CPU-type abilities) tied to the host CPU.

The remaining companies (except for the die-caster without a system) are using available space in the company to locate the system. They either did not have a plan where to locate the CAD/CAM facilities to benefit the company properly, or simply did not feel that a strategic location was part of the system implementation. This is an oversight on their part, but it seems that the nature of conducting tasks on workstations spread throughout a company will continue to replace the masses of terminals in a single, isolated area.

The strategic location of the system or workstations is essential to keeping the communication flow constant, consistent, and efficient. Of course, there may always be special cases such as multi-site locations linked to the host computer, but eventually networked, powerful, stand-alone workstations will replace these expensive and often bogged-down system configurations.

5.3.12 Future System Plans

Note: Because most companies answered this question in part similarly to the previous question on their level of technology and planning, a discussion is developed in this section on both.

15 of the companies have "CIM" plan for the future. How they intend to attain it or even define it is another choice. Some important comments by the companies on CIM include:

- Automotive Components Company: CIM is being implemented in only 1 segment of business. When we understand it better, other divisions will implement it.
- Chemical Company: CIM is an elusive target and they are pursuing it.
- Aerospace Airframes Company #1: CIM is necessary, but we need to involve all areas with real-time data transaction capabilities.
- Aerospace Airframes Company #2: CIM is underway with Flexible Manufacturing System already in operation.
- Aerospace Electronics Company: CIM is underway with CAD/CAM and MRP-II system link.
- Die-Casting Company #1: CIM goal is full process-control by computer.

- Pattern Shop: Goal is for better CIM.
- Walk-in Cooler/Refrigerator Company: Goal is to implement CIM in 18 months. "How" is the question.

Judging from these responses, CIM is not very consistently defined and understood in industry. Too many companies are forced to think CIM without having a clear definition or rules. It is doubtful if there will ever be a true definition of a CIM plan. It will be as diverse as the companies pursuing it. The successful companies may never achieve perfect CIM (if it even exists), but this is not to say that reaching to achieve it is not a spur to progress when in fact goals are the main means to continue success of any measure.

Only 2 companies of the 22, excluding the die-caster without a CAD/CAM system, specifically do not have a CIM plan. One other company does not have a CIM plan, per se, but believes that individual system components must meet Return On Investment (ROI) criteria. This answer was confusing and its meaning in relation to CIM planning was not found.

The following future plans of the companies surveyed are very valid and those worth a mention are as follows:

- Automobile Manufacturer: System standardization and data exchange is a key goal. Continue to pursue advanced systems technology.
- Automotive Components company:
  - Integrate their CAD/CAM system with the corporate division.
  - Increased use of 3-dimensional design and solids modeling.
- Helicopter Company:
  - Integration of Engineering and Operations departments.
  - More automated system capabilities.
- Precision Equipment Company: Increase number of applications, users, and terminals.
- Aerospace Airframe Company #1: Continued reduction of design costs and overhead support for shop floor through Computerized In-

telligent Manufacturing (CIM).

- Turbine Engine Company: Complete 100 % production, design, and process planning with complete graphics exchange between engineering and manufacturing.
- Aerospace Electronics Company:
  - Disciplined use of Systems leading to consistent production and quality improvements.
  - Improved training techniques.
  - Integrate CAD/CAM system with Management Information Systems (MIS).
- Semiconductor Memory Company: More PC's or workstations to serve CAD/CAM needs. (The Walk-in Cooler and Fastening Devices Companies also echoed this future expectation).
- Automotive Die-casting Development Division: Any change that would involve bringing CAM into the division.
- Zinc Die-Casting Company: Black-Box Design capability.
- Heavy Equipment Company:
  - Design done using manufacturing process data base to improve manufacturability and estimate costs more closely.
  - "Expert Systems" to be used.

As you can see, the majority of the companies have very specific goals for the future advancement of technology. Some of the goals are easily attainable, such as increasing the number of terminals (if the money is appropriated, of course). The black box design, or expert systems integration and higher integration of systems are three goals that have yet to be reached in industry in general.

5.3.13 What Would You Do Differently In Terms Of CAD/CAM Given The Opportunity

This question was answered in the most detail by all of the companies, except for 1 or 2. There may be some redundancy in the responses, but this serves to point out the most important issues common to the companies. The individual company responses are as follows:

- Automobile Company:
  1. Seek ease of integration with new systems.
  2. Assure adherence to networking and data exchange protocols.
- Automobile Components Company:
  1. More emphasis on training - both before and after purchase.
  2. Emphasize continuous improvement.
  3. More 3-d and solids modeling researched up front.
- Chemical Company:
  1. More concern with standards and data exchange than system functionality.
  2. More research into system response times.
  3. Better user interface capabilities planning.
  4. Take PC's more seriously.
  5. Look to more software, not vendor solutions.
- Capital Equipment Company:
  1. Sound File management system to be set up at the beginning.
  2. Train people to think CIM.
  3. Teach the old methodology first, then automate with CAD/CAM.
- Helicopter Company: No comment due to changing needs.
- Precision Equipment Company: Provide better training before and after purchase of CAD/CAM system.
- Aerospace Airframe Company #1:
  1. Develop a Strategic Plan and stick to it.
  2. Get management involved at the proper levels.
  3. Keep management out at the proper levels.
- Aerospace Airframe Company #2:
  1. Standard file structure is needed in the beginning.
  2. Set up a dedicated department with its own budget funded by the user community instead of a unit supported by corporate.
- Gas Turbine Company: Start with a true 3-d system with solids

modeling capabilities.

- Aerospace Electronics Company: Better management training is necessary especially in the early implementation stage.
- Semiconductor Memory Company: Decentralization of processing to workstations.
- Automotive Die-casting Research Center:
    1. More training and more people trained.
    2. More initial CAM research
- Die-casting Company #1:
    1. Make certain the system you purchase is adequate for the job.
    2. Better Pre-planning in all aspects.
    3. Better definition of future goals.
- Die-casting company #2:
    1. Better planning.
    2. Research the industry you are in fully.
    3. Evaluate as many vendors as possible.
- Die-casting company #3:
    1. Research Finite Element Analysis needs fully.
    2. Cost: buy what is only needed at first, then expand system logically.
    3. Be cautious of maintenance and software costs. Purchase software that you will definitely use.
- Process Machinery Company:
    1. Lease system first before deciding on purchase.
    2. Would have chosen a different vendor.
- Heavy Machinery Company:
    1. Due to rapidly changing hardware platforms, would have chosen a different vendor.
    2. Buy strategic software that will support the CAD/CAM system hardware.
- Fastener Devices Company: They are totally satisfied with their system.

5.4 Concluding Statements

The companies that participated in this survey were extremely open to the questions and their candor is appreciated. It is apparent that five significant trends or needs are expressed by the majority of the companies:

1. **Planning before the system purchase is critical in terms of the variety of needs to be satisfied.**
2. **Training is one often taken for granted side of the system that is inadequately provided and supported. A well trained staff will ease the transition to CAD/CAM for the company.**
3. The need for standardization, in terms of data/communication exchange protocols is critical.
4. Understand your CIM goals and definition before trying to set a date for its actualization.
5. Decide if 3-d, solids modeling, and other features can be part of your future goals for the system and then consider vendors.

Concerning the term CAD/CAM itself: Understand that integration in its simplest form is the "/" in CAD/CAM. It truly represents the coordination of the design and manufacturing team, along with associated affected departments in the organization. CAD/CAM without an integration of both CAM is simply CAD and CAM.

As a final note, one company remarked at the end of the survey that next time the survey should not be so long. They said that management does not have time to waste. However, time would be wasted if companies did not address these issues if they have CAD/CAM or are considering it. For the most part, the respondents to the survey were extremely helpful, honest, and willing to take more time to clarify any points. The purpose of this survey was not to waste valuable time of important people in companies, but to understand how CAD/CAM is utilized, accepted, and judged in companies.

Chapter 6
Addressing The Quality Issue in a CAD/CAM Systems Perspective

6.1 What is quality and why is it such a hot topic

Quality is one of the most widely discussed topics in industry today. This issue has been brought into focus in this country due to the proliferation of foreign competition in markets previously dominated by U.S. firms. The age of the global marketplace has arrived and a renewed focus on quality seems to be the route many firms are taking to head off the foreign invasion. The definition of quality varies from company to company as it does from individual to individual. Some common misconceptions include:

> "Quality means conformance to specifications."
> "Quality means better than the competition."

Some of the more valuable definitions include:

> "Understand the customer's requirements and meet them 100% of the time."
> "Quality is the never ending improvement of all processes within the organization" [17].

The latter 2 definitions reflect industry accepted perceptions of quality. Several participants in the survey discussed in Chapter 5 responded similarly with their definition of quality, while others offered differing definitions. There are many respected quality experts today such as Dr. W. Edwards Deming, J.M. Juran, and Taguchi, among others, and some of their concepts can be applied to technology quality issues.

6.2 What Company Executives Think About Quality

A 1987 Gallup Survey was conducted with 615 executives representing many large and small companies [14]. Most of the executives were CEO's, presidents, vice presidents, chairmen, and chief financial officers. Some of the highlights (or lowlights depending on your perception) include:

- Most believe the greatest quality challenge will come from other U.S. companies in the next five years.
- 48% believe service quality is a critical issue over the next few years, while only 39% believe product quality is critical.
- Only 38% of the companies use employee involvement teams in their quality programs, 39% use salaried employee involvement, yet 81% claim to have visible management leadership.
- 43% rate changing the corporate culture as the most important way to improve quality.

From these answers, there seems to be a bit of the "old" corporate philosophy of strong management control, while the final point of the need to change corporate culture signals that upper management in these companies is finally recognizing their major weakness. It is apparent that many companies will eventually start to change their corporate climate to focus on quality and technology issues, but there will be quite a bit of "1930's" management philosophies remaining. There is a need for new direction based on proper quality strategies and goals in many companies.

An article in *Quality Magazine*, which talks about Total Quality and CIM as partners states that most CEO's and executives did not know what they were getting into in the 1960's and 1970's when implementing MRP and CAD/CAM systems [9]. Prevention-based quality, rather than detection-based quality was part of the total quality answer. The total blame on why quality was not a major issue back then cannot solely be placed on management.

6.3 Organizational Climate Necessary To Support Quality

In order for CAD/CAM and quality to be partners in the goal to achieve quality, an organizational climate must be fitting to help meet these goals. The seed for quality must come from the highest levels of management and be apparent and well-publicized within all employment levels of the organization. The major factors in implementing the partnership include: Influence, Innovation, Responsibility, Teamwork, Satisfaction, Desire to Change, and Common Vision. A more detailed list includes:

- People need to feel that they have influence to change the things around them.
- People need to be willing and able to be innovative and challenge the status quo.
- There needs to be interdepartmental teamwork for CAD/CAM and Quality to work together.
- People need to have a basic satisfaction with their work life; their physical, emotional, and monetary needs must be met.
- While people must have work satisfaction, they must have a desire to change certain aspects of how their work is conducted.
- People must be willing to take personal responsibility to make changes.
- All people in the organization must have a sense of common vision as to where the company is headed and what path to take.

If CAD/CAM systems are implemented without having a quality vision in place, pitfalls can occur. This includes automating things should that not be, people will reject the system because the climate is not right, and mistakes are still made, but faster.

6.4 CAD/CAM System Quality

In terms of CAD/CAM systems, the issue of quality can be understood in terms of the customer's attitude toward product improvement which includes better design, lower cost, and quicker turnaround times. The CAD/CAM user is interested in achieving the improved end product and does not usually consider the CAD/CAM system as part of the quality issue. For example, in the CAD/CAM survey in Chapter 5, at least half of the companies said they have no real policy defining the CAD/CAM system quality, but 100% of them said that the quality issue is permeating throughout the organization.

If strategic planning is important to the future of companies, the inclusion and recognition that the CAD/CAM system is part of that system strategy is valuable. Quality of the system in terms of its performance versus expectations, vendor support, implementation, ease of integration to existing systems, ergonomics, and management of the system should be recognized and measured if possible. In the new environment of changing competition, product quality standards are constantly improving. CAD/CAM is one of the means for achieving continue product improvement through improvement of the concept-to final product cycle.

6.4.1 CAD/CAM System "Management For Quality" Principles

The active management leadership in instituting a successful CAD/CAM system is very important. There are various levels of understanding who is the customer within a company, but ultimately the purchaser of the end product is the final customer. For example, departments that receive data and information from other departments are essentially customers to that data. The transformation of the data and management of the way it is transferred is as important as the tolerance fit of the product. Some of the principles are:

- **The entire organization must recognize and strive for quality.**

Quality is everyone's job. The burden of improved product quality cannot be solely placed in the CAD/CAM department. If there is little direction from management as to the quality goal of the company, there can be no direction for the CAD/CAM department to follow. An objective of constant improvement to meet and exceed the customer's demands can apply in all departments.

- Once the goal is identified, integrate it into daily actions.

The CAD/CAM department will need to develop a roadmap of how they will direct the quality issue in their department. The management must understand that their own corporate roadmap may undergo necessary and continual change. This is true of the CAD/CAM department (or the department responsible for CAD/CAM development). Dr. Deming's 14 points of management's obligation to quality can apply to the CAD/CAM system. They are:

1. *Create constancy of purpose toward improvement of your service and/or product.*

   In terms of the system, constant effort must be made to tailor and improve the output of the system. If it relates to design standards, they must be developed to optimize the system. If it is in terms of CAM, it may be necessary to develop software for communication with a new machine tool.

2. *Adopt the new philosophy: We are in a new economic age.*

   The CAD/CAM department is a very important factor in advancing the competitiveness of the organization. The system must be utilized as a tool serving modern methodologies. A CAD/CAM system that serves aging economic and manufacturing philosophies is doomed for mediocrity.

3. *Cease dependence on mass inspection as a way to achieve quality.*

   In terms of the CAD/CAM system and its resulting output, tighter tolerances, clearer documentation, less bureaucratic sign-off procedures, modernized data base development, and less space requirements are some of the inherent quality improvement features a CAD/CAM system brings. However, proper system management, data organization, application usage, and training programs must reflect that the best possible effort to achieve the full quality benefits was planned.

4. *End the practice of awarding business on the basis of the price tag.*

   CAD/CAM systems differ in price and features to best suit

the company's needs. A system that is half the price of another, but is specifically designed with the electronic designer in mind will be of little benefit to a die-caster who needs solids modeling and 3-d capabilities. Also, the payback period of the system must not be a jeopardizing factor in choosing one system over another if cost is the only justification. However, there are many CAD/CAM systems within a specific price range that will perform the majority of requirements.

5. *Constantly and forever improve the system, which includes the people.*

   CAD/CAM systems which become failures after years of productivity are many times victim to lack of improvement, both from the vendor's side and the user's side. The vendor may have fallen on economic hardship and system upgrades are few and far between. The system becomes mired in "old" technology and does not incorporate features which other advanced vendors offer for the same price. However, the vendor may offer upgrades and productivity improvements, but the company does not want to upgrade because they are satisfied with the current system as is. They may not realize that the lifecycle for such a system is 5 to 7 years and get the most usage out of it. At the same time their competitors may have been offering superior product turnaround times and performance figures.

   This is not to suggest that every upgrade is necessary for all users, but that self generated system improvements (purchased or in-house developed software) may be a proper alternative.

6. *Institute training on the job.*

   The first 18 months of the CAD/CAM system are very important in terms of user's learning curve. The system cannot run on its own and that initial training course offered when the system was purchased has been forgotten. The users must constantly be apprised of what is available in terms of new software or hardware releases and they must actively participate in recommendations to management on new skill levels desired. A training program, whether in-house or from a vendor is very valuable in terms of filling gaps in the user's and sometimes the manager's understanding of how the system can do things better.

7. *Institute leadership to help people and machines do a better job.*

   Leadership doesn't have to be "heavy handed" and a good management team will understand that a need exists to skillfully guide the CAD/CAM team in achieving their objectives. Sometimes users can become unclear of the reason CAD/CAM was instituted. The management team must provide direction in what the results of the instituted system are and how the workforce fits in with these plans and how well they help achieve them.

8. *Drive out fear.*

   As was mentioned previously, change causes fear in people. The system must be regarded as a means to improve the quality of worklife, product, and competitiveness of the organization. Fears of job loss, demotion, inability to cope with technology, and being a central point of blame if the system is not a success must be addressed by the management team.

9. *Break down barriers between departments.*

   All too often, CAD/CAM systems become the "baby" of one department within the organization. This department becomes very visible within the organization and the walls of departmental separation continue to grow. Probably the most difficult task facing industries today is the elimination of departmentalized thinking within organizations. The term department should be eliminated as the first step in building a team. The tasks of the CAD/CAM system team should be shared and integrated among all other affected groups whenever possible. Management must recognize that the effects of CAD/CAM will be felt in the entire business and that the team which is most directly responsible for remains a part of the entire system.

10. *Eliminate slogans and targets for zero defects and new productivity levels.*

    Slogans are cheap methods for management to hide their demand for improved production levels. The real issue is to understand the problem, recognize a solution exists, and then manage it effectively. CAD/CAM systems may not always improve productivity levels but the intangible benefits derived from a system may prove to be measurable in the long-term for the organization.

11. *Eliminate work standards and management by objectives.*

    CAD/CAM work standards are counter-productive. The users have different learning curves and levels of understanding. The CAD/CAM system must be utilized as a productivity tool and not a barometer of who cranks out the most drawings. This is the quickest method to destroying teamwork and creating a 1940's style high-tech "sweatshop".

Management must be cognizant of this fact and avoid or eliminate it when it appears. Alternate means of judging system performance based on overall quality and productivity improvements can be the correct step. Measurements of users should be done to gain an idea of performance of the system during its first year of operation. After this time period, the real team building can develop after numerical measures on users are removed.

12. *Remove barriers that rob people of their right to pride in workmanship.*

    CAD/CAM systems may not be thought of a craftsman-building tools, but the users, software developers, and system management team definitely have the right to pride in their work. Technology can not be allowed to remove the individual sense of accomplishment for a task well done. This also applies to the team concept where all the individuals who pulled their effort must be able to be proud of their accomplishments. A CAD/CAM system and its managed environment that stifles pride in performance will be an underutilized and overmanaged system.

13. *Institute a vigorous program of education and self-improvement.*

    One of the basic needs of humans is to constantly learn. In a CAD/CAM environment, training is essential to keeping the workforce and management motivated, informed, and successful. The education does not always have to be formal. Rather, interaction between users of the system and even management is a valuable form of team building and assurance that communication is necessary. Managers need to not become so far removed from the trials and tribulations of the team and a basic understanding of the system is helpful in communicating goals and objectives within the team.

14. *Put everybody in the company to work to accomplish the transformation.*

    The CAD/CAM system will affect every aspect of the business. It will impact design, marketing, management, manufacturing, and also customer perceptions of the business. The issue of quality is everyone's job and the CAD/CAM system must be recognized as one step in aiming for that goal.

6.5 Quality Products Result From Quality Systems

In terms of how long the issue of quality has been around in industry compared to its current "buzzword of the 80's" status, Winston Churchill summed it up by saying "I became an overnight success after nearly 50 years of being available for it." Corporate success is measured by profit; profit is margin times volume. Quality creates happy customers; happy customers create high volume. Traditionally customer satisfaction has been the standard summation for quality. However, today customer satisfaction must become customer enthusiasm. In terms of CAD/CAM system customers, they must expect and demand the highest quality product which in turn helps them design and manufacture the highest quality product they can provide. This is therefore a two-fold recognition and realization of the quality issue.

The "Japanese Invasion" is a very hot topic in the United States industrial sector. There is one major contributing factor to this Japanese success in the American marketplace: quality. Quality improvements in the U.S. since 1950 have been evolutionary while that in Japan has been revolutionary (see figure 6-1). Fortunately, the CAD/CAM system world market has not been invaded by Japanese firms. This is not to say that it is not on the horizon. The focus in this country is American product quality needing to become Japan-like. The role CAD/CAM systems play in that aspect are very important. "Japan bashing" is not the solution in many competitive situations. They have obviously done their job the right way and we have to learn to adapt through becoming better ourselves and not just griping. Actions do speak louder than words.

How well a CAD/CAM system is planned is part of the quality issue, but how well it is utilized beyond the planning stage when the system is in house is a major issue in how product quality will be affected by CAD/CAM. Failures do occur. For example, two University of Melbourne, Australia students detailed

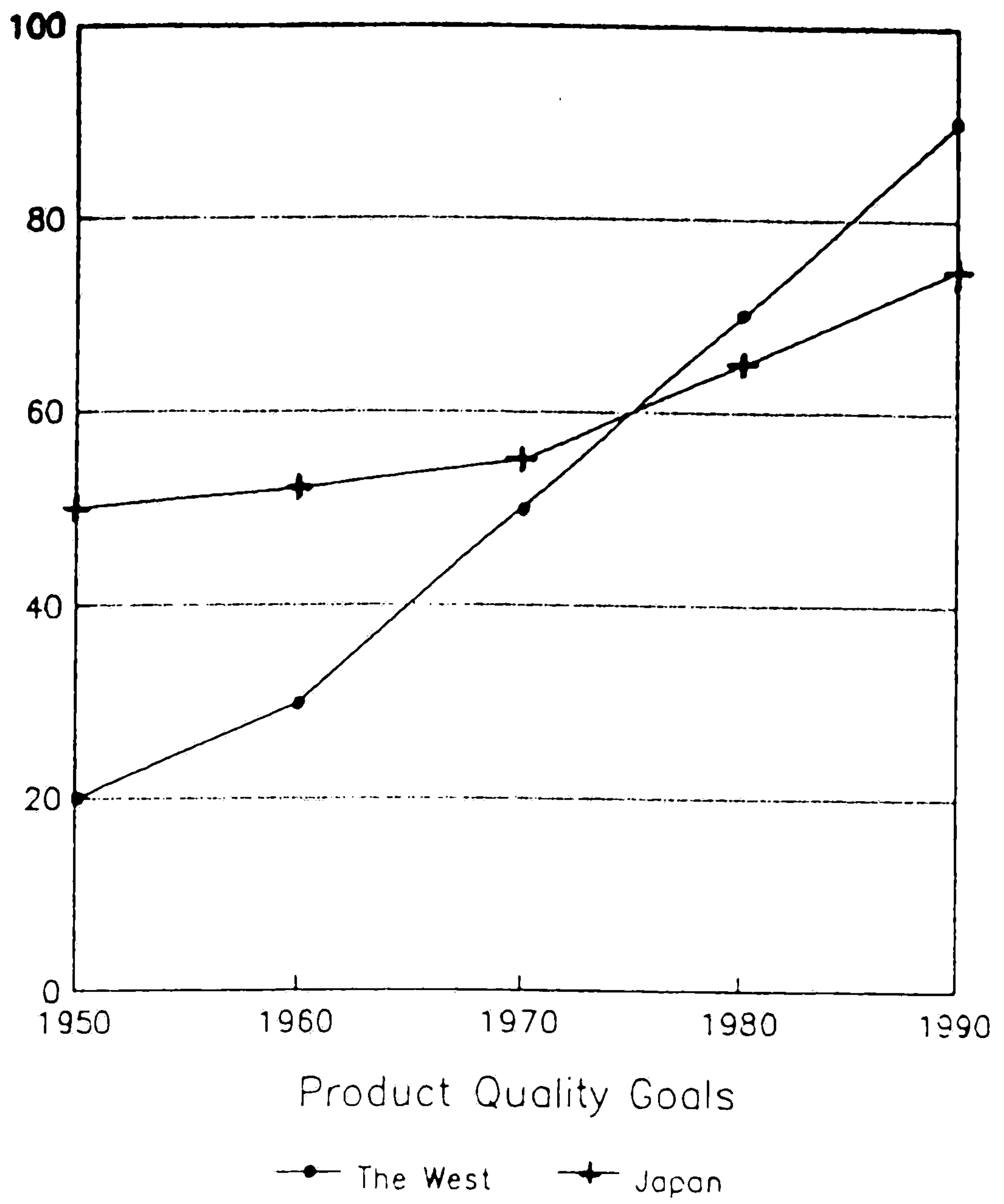

Figure 6-1: Evolution of Quality in the West vs. Japan. *(Source: Quality Progress Magazine)*

that in a survey of 70 firms with CAD/CAM systems installed, most were using them as drafting systems. They published their findings in the University's newspaper and commented that "This under-utilization of a costly piece of equipment was costing the firms dearly and those costs would eventually be passed on to the client" [5].

This example is not uncommon in the United States. The resulting higher costs of underutilizing the CAD/CAM system are passed on to the customer with a resultant drop in the customer's satisfaction for the product. Cost alone cannot justify the reduction in customer's perception of quality of the product, but CAD/CAM system proponents will have to work hard to justify using an expensive tool for relatively uncomplicated work. (This is the other side of the coin in the perception by the in house customer of the CAD/CAM system's quality).

6.6 How You Measure Quality

The benefits obtained through implementing complex systems such as CAD/CAM are often qualitative and not easy to measure by formal evaluation. Post-audits are usually done by financial accountants who have a difficult time measuring a CAD/CAM system's impact on product quality, delivery, and throughput. According to a study conducted by the National Association of Accountants and Computer-Aided Manufacturing International says that there can be quantitative measures to measure quality.

Quality can be measured financially by the reductions in the costs of product or part non-conformance, and also non-financially, but not quantitatively by the decrease in customer complaints. This again can refer to the two customers of CAD/CAM: end product customer and in house customer (engineering dept., manufacturing dept., etc.). A new system's effect on delivery can be quantified as the company's rate of getting products to customers on time, in terms of the end customer through the actual product on-time arrival, and in terms of the in house customer through the on-time arrival of critical data, and/or unfinished product.

6.6.1 Abandon the Status Quo Baseline - Make Quality Decisions

According to Harvard Business Review, businesses are not investing as heavily in CIM-type technology such as CAD/CAM systems mainly because they do not properly evaluate the alternatives. Manufacturers need much convincing before they decide to invest in such systems and abandon the status quo [21].

The status quo does not last. Technology races on and the status quo advances along with it. The companies that fall behind the competition in applying new technologies will experience loss of market share and eventually profit. The quality decisions to make about investing in such technology are based on knowing the status of technology, the competition, the needs of your company, and the perception of your product from the customer (both end customer and in house).

Part of making proper decisions is to make certain that your company not only understands what CAD/CAM is, but what CAD/CAM is not. CAD/CAM is not a classical type of electronic data processing system such as business computing activities are. There are more than one CAD/CAM solutions to your company's needs due to the availability of the various vendors, configurations, and prices. It also is necessary to understand that CAD/CAM is not the turnkey solution to the company's engineering, design, and manufacturing activities. CAD/CAM is an information management technique and has company-wide implications exceeding those of simply computerized drafting. With this in mind, quality decision making can be accomplished by the management team responsible for CAD/CAM implementation.

6.7 Some Barriers to Quality in the Workplace

Some of the main barriers to implementing quality strategies in most companies are:

1. *Communications*

   Lack of management interaction.

   Barriers to the free flow of information.

   Lack of constructive criticism and praise.

   Lack of consistent direction.

   Technician isolation from customer information.

2. *Attitude*

   Management Attitude:

   - General apathy.
   - Unwillingness to admit there are problems.

- **Unwillingness to accept new ideas and challenges.**

Technician Attitude:

- General Apathy.
- Lack of Teamwork.
- On-the-job retirement.

3. *Motivation*

   Performance appraisal.

   Limited opportunities for advancement.

   Lack of job satisfiers and self-esteem.

4. *Resources*

   Unproductive meetings.

   Excessive paperwork.

   Lack of proper tasking.

5. *Training*

   Lack of management recognizing the importance of continuing education.

6.8 Quality Benefits Derived from CAD/CAM Implementation

In the United States, improved product quality is not the major reasons many companies give for purchasing a CAD/CAM system. It generally ranks third behind behind market pressure, and increased productivity. Usually there are very noticeable quality gains expected from implementing a CAD/CAM system but there are also very intrinsic quality factors that can take years to comprehend. The following list details both keeping in mind the end product customer and the in house customer of the CAD/CAM system produced information:

- **Expected Quality Improvements:**
  - Reduction of production cycle from initial idea to final product.
  - Tighter adherence to product specifications and tolerances.

- Reduced product development and manufacturing costs.
- Redundant design work eliminated.
- Better analytical design methodology and ability to quicken design changes.
- Building a central database of information.
- Elimination of lost paper drawings and storage area.
- Up-to-date record keeping of product design information.
- Improved mathematical computational accuracy due to computer.

- **Unexpected Quality Gains:**

  - More motivated design and manufacturing team.
  - Improved information flow leading to better product quality.
  - Increased competitive posture in market.
  - Ability to transfer information electronically with customer.
  - Demonstrates management is concerned about company's future to workforce and customer base.
  - Ability to accept more complex and complicated design and manufacturing tasks.
  - Relocation and re-evaluation of engineering, design, and manufacturing staff duties.
  - Availability of floor space due to reduced drafting tables area.
  - Ability to purchase software packages to extend CAD/CAM and related capabilities.

The list goes on and on, but the important thing to remember is that quality is an ongoing and never ending goal. The foreseen quality benefits derived from CAD/CAM system implementation can be equalled or even exceeded by the unexpected, usually hard to measure benefits.

6.8.1 Who Benefits From CAD/CAM System Implementation

Few will argue that properly implemented CAD/CAM systems provide benefits for the entire company. This section focuses on individual departments and individuals who can benefit from such an implementation and briefly lists how.

- *The Customer* - The customer must benefit from the improved product quality, delivery time reduction, and possible lower price. There are many transparent details to the end product improvement which CAD/CAM can bring, but the customer usually is concerned with the overall end product quality.
- *The Engineering Staff* - The plusses of CAD/CAM system implementation include reduction of "busy work", a data base created for engineering activity, a more confident design team, ability to perfect designs, a more skilled staff, and reduction of paper shuffling and handshaking tasks.
- *The Manufacturing Staff* - Benefits include improved data transfer from design to manufacturing team, reduced trial and error Numerical Control tasks, ability to concentrate on less "busy work" tasks, and confidence that the manufactured product meets or exceeds specifications the first time.
- *Quality Control* - Assurance that computer-assisted methods are in place such as interface of CAD/CAM with inspection equipment to immediately resolve any out-of-tolerance issues, ability to have access to the design and manufacturing data in terms of minutes, not days, and more confidence in their task due to having a direct impact in the product in a very short time frame.
- *Marketing* - The ability to tout advanced design and manufacturing capability at the company is important to let the customer know that the company is committed to excellence. Also, the ability to have demonstrations at the company CAD/CAM site to visually see the design and manufacturing capabilities achieved through CAD/CAM is good public relations.
- *Management* - By recognizing the increased quality in terms of the product design and manufacturing team effort, and perception of the company's dedication to excellence through technology, management is recognized as innovative and enlightened for taking the risk of implementing CAD/CAM technology. They have helped build a foundation for a team built on progressive ideas. The image of the "ivory tower" of management must be removed from the plant worker's minds. Only aggressive and dedicated action will speak for themselves.

- ***The United States*** **- In order to remain a leader in world manufacturing, our technological might must continue to be bolstered by technological innovations such as CAD/CAM and the goal of Advanced Manufacturing Technology. Industries in this country cannot continue to compete only on a national scale, but must cooperate wherever possible to avoid losing markets to foreign competition.**

Although many companies are very committed to quality through Quality Control programs and various statistical analysis methods, CAD/CAM's role in quality is sometimes overlooked. CAD/CAM is in fact a very important part of achieving a quality product and improving the quality of worklife in the factory. Some of the more aggressive companies in this country who include a quality mission with their CAD/CAM goals have various methods to accomplish the task. These may include:

- Development of a Quality Circle team built from various department representatives that utilize CAD/CAM. Allow rotation of department members to participate so as to not segregate ideas.
- Establish quality goals and principles in the departments utilizing CAD/CAM on daily, weekly, and yearly horizons.
- Conduct regular bi-weekly meetings to discuss quality related issues in the CAD/CAM area and accept input with a firm committment to resolve the problems.
- Keep the rest of the company informed of your quality objectives and successes. Isolating your department from other departments you feel are unaffected by your accomplishments is a sure way to kill motivation of the company to continue advancing CAD/CAM technology.
- Experiment with some of the principles of quality taught by renowned quality leaders such as Taguchi, Deming, and Juran and also the quality control experts in the company. Try to customize some of these plans to your CAD/CAM system operation.

Don't give up trying. Nobody said it would be easy to successfully implement CAD/CAM, let alone targeting quality issues as a focus of the system. However, by keeping a perspective of total quality, CAD/CAM system implementation and utilization to meet company goals will be realized much faster than anticipated.

6.9 How Do Vendors View CAD/CAM System Quality

Based on a simple list of questions sent to 8 CAD/CAM system vendors, of which 2 responded in time for this report, they do seriously believe in providing a quality system and service to their customers. The 2 vendors who mainly responded in terms of the CAD/CAM system software are listed individually. They are CADAM Inc., and Hewlett-Packard Electronic Design Division.

6.9.1 CADAM Inc.

CADAM Inc. certifies its product software releases for six attributes of quality: Functionality, Usability, Installability, Serviceability, Reliability, and Performance.

- Functionality

  The product does what the customers need it to do.

  The marketplace has been examined, understood, and effectively addressed.

  The extent to which state-of-the-art hardware technology is exploited has been defined.

- Installability

  The ease with which the installation can be planned and executed.*Installation is considered to begin when a customer opens the shipment and is over when all end users are able to sign on and go to work.*

- Usability

  The ease with which a user can perform the tasks supported by the product (user friendliness). Audience definition is an important component of this attribute.

- Serviceability

  Ease with which a user can perform problem determination. During an error situation, system error messages should clearly the nature of the problem. Problem related customer information should make it easy to determine exactly what the problem is an how to resolve it or report it in such a way that it can be resolved by others.

  Ease with which a customer can obtain and install system maintenance.

* <u>**Reliability**</u>

  The traditional measure of code quality in terms of its defects.

* <u>Performance</u>

  Efficiency and speed with which a program does its work.

  Sensitivity to tuning and the ease with which a customer can address performance bottlenecks.

  Performance expectations should consider the level of function provided.

This basically is a quality measuring scheme for the system software, which is in terms of CAD/CAM systems, dynamic. It is usually never "bug-free" and is usually improved through feedback from users in what are called spot-fixes or patches, updates, and ultimately new releases of software. No information was obtained on how system hardware and total system quality is measured.

6.9.2 Hewlett-Packard Electronic Design Division

An important point made by HP is that quality is not as you perceive it but must be as the customer perceives it. If you have designed a CAD/CAM software package that is completely bug-free, but does not perform the functionality the customer expected, or is too difficult for the users to adapt to, or performs too slowly, it will not be perceived as a quality product. The customer needs must be truly defined in order for HP to provide a quality product.

Before a product is allowed to move from the (needs) investigation stage to the development stage, specific quality goals are defined for the product:

1. Functionality
2. Usability
3. Reliability
4. Performance
5. Supportability

These goals are not enough. The engineers must also give evidence that they have methodologies and methods in place to meet these goals. Once the product is in the development stage, these goals and metrics are used to keep it on its "quality track". Design reviews, code reviews, and intermediate checks are conducted to find and correct flaws. As software quality leaders such as Tom DeMarco states,

> "A defect found in design is cheaper to correct than one found in code; a defect found in code is cheaper to correct than one found in test; a defect found in test is cheaper to correct than on found when the product is in the customer's hands."

This lesson applies to products other than software and proves that quality built in to the product early is actually more economical than trying to inspect or correct it in.

One the product is released to the customer, the quality process does not stop. The technical support team is in place to aid customers and field engineers with problems with the product. A company-wide defect tracking system is in place to allow the customers an easy method for recording defects that are found and assurance that the factory will analyze the defects to determine the best method for fixing the errors. A teaching system is in place to teach the customers how to use the the defect tracking and desired enhancements system effectively.

All this information is used to determine if HP has met its quality goals and if these goals really coincide with the customer's perception of quality. Quality is a company-wide focus at HP currently in terms of both software and hardware products. They are also studying the industry as a whole in order to see if there are new methodologies or methods they can use in their never-ending and constantly changing quality efforts.

As a note to the software quality issue by vendors, figure 6-2 illustrates that software delivery performance of U.S. vendors is in need of more attention to quality details. This is one of the reasons why HP and CADAM have committed themselves more directly in quality of their products than in the past.

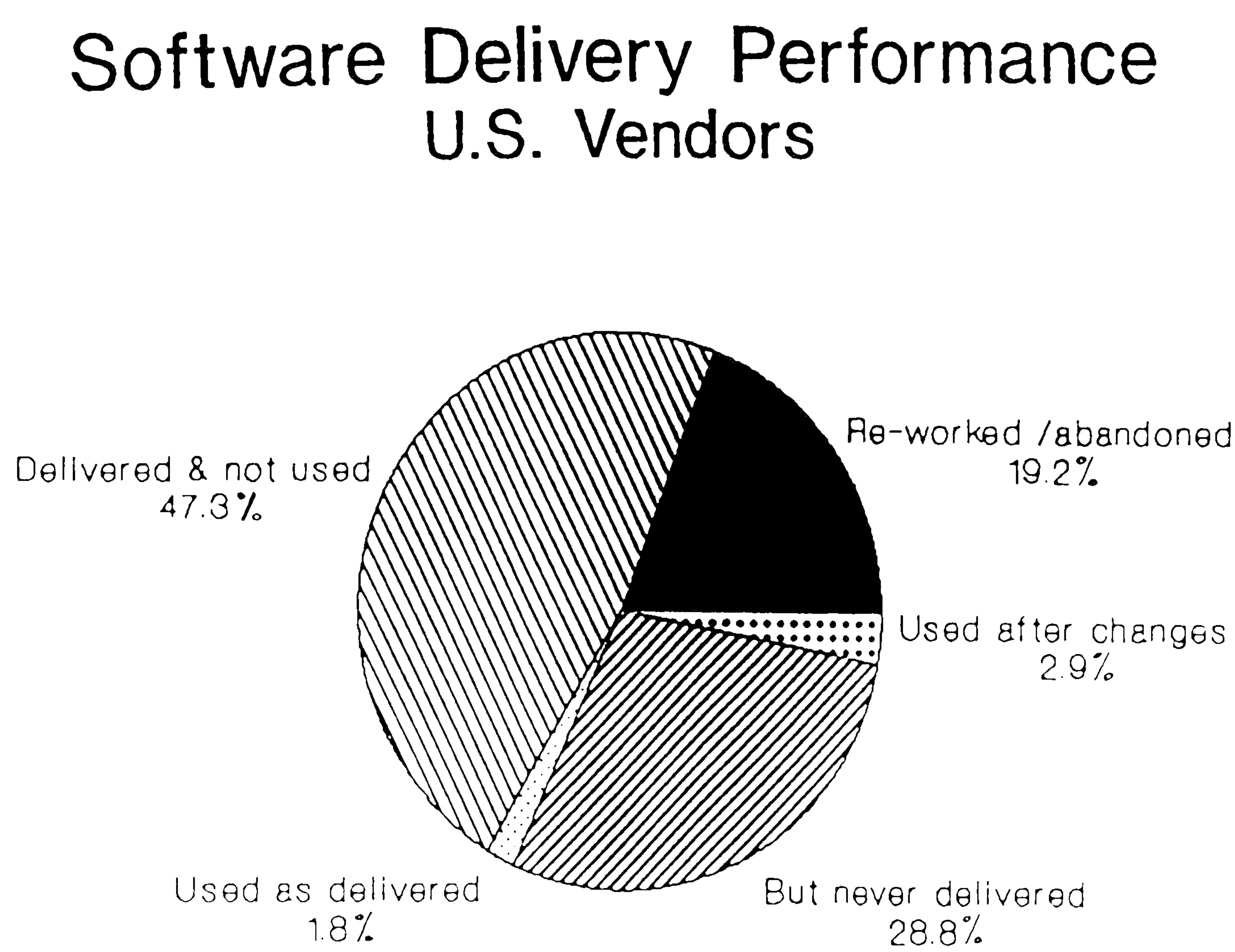

Figure 6-2: CAD/CAM Software Vendors Need To Improve Quality Programs [4].

Chapter 7
Hypothetical Scenario for CAD/CAM Implementation In A Die-Casting Company

Note: Originally, a real world model for CAD / CAM implementation in a die-casting company was to be discussed. However, circumstances in the actual company changed and this chapter was changed to a hypothetical scenario for an implementation plan for a die-casting company.

7.1 A Brief Introduction Of The Die-Casting Process

Die-casting is perhaps the most widely used of the pressure casting processes. Basically how it works is: the mold or die (which is an imprint of the product to be produced in two joined sections) is pressurized and the mold material, usually aluminum or zinc in a molten fluid state, fills the cavity at a very fast rate. The mold is properly sealed and fortified as to prevent any escape of the molten metal.

After the material fills the mold and sets or solidifies (aided by cooling procedures in the casting machine such as running water lines through the die), it assumes the shape of the mold which is the shape of the part. The mold is then opened and the part removed through some form of built-in or sometimes manual ejection. Die-casting metals are restricted to non-ferrous metals such as aluminum alloys and zinc.

The die-casting process features extreme accuracy, dimensional control, surface finish, and high production rates. Products range from hardware, plumbing, automotive parts such as transmission housings and frame elements, to intricate and sometimes quite small metal parts. Disadvantages of die-casting are : Expensive initial tooling, limitation of non-ferrous metals, and porosity of oxides trapped during injection. It is because of the difficulty of building dies, tooling, and problems of producing a uniform molded casting that CAD/CAM systems can be extremely beneficial to this industry.

There are two methods of pressurized die-casting:

- *Cold chamber process* which requires an operator to pour a proper amount of molten metal from a ladle into a chamber where a plunger applies the pressure to force the metal from the chamber into the mold.
- *Hot chamber process* where the hot chamber is submerged in molten metal so that each time the pressure piston withdraws, the shot chamber fills from the pool of molten metal.

The hot chamber process is more automatic and quicker than the cold chamber process, but is more expensive per casting machine. However, it requires less manual intervention and when integrated with modern automated casting equipment, is the only logical choice for high-volume applications. Figure 7-1 details the two processes.

7.2 Current Company Status and Plans

Our company, (call it XYZ company), was and currently is in the midst of a crucial decision: how can we compete with U.S. and foreign firms in the ever competitive die-casting market.

We are a 700-person subsidiary of a major conglomerate and act as an independent profit/loss center. Our annual business volume in terms of dollars peaked in 1982 at $250 million. Our market share has eroded due to increased foreign and domestic competition in the aluminum, aluminum-alloy, and zinc die-casting market over the past 6 years to a current level of $200 million. We attribute this trend to 3 factors:

1. Foreign and domestic competition has advanced their technological capabilities in die-casting.
2. Domestic customer base is shrinking while order size is increasing.

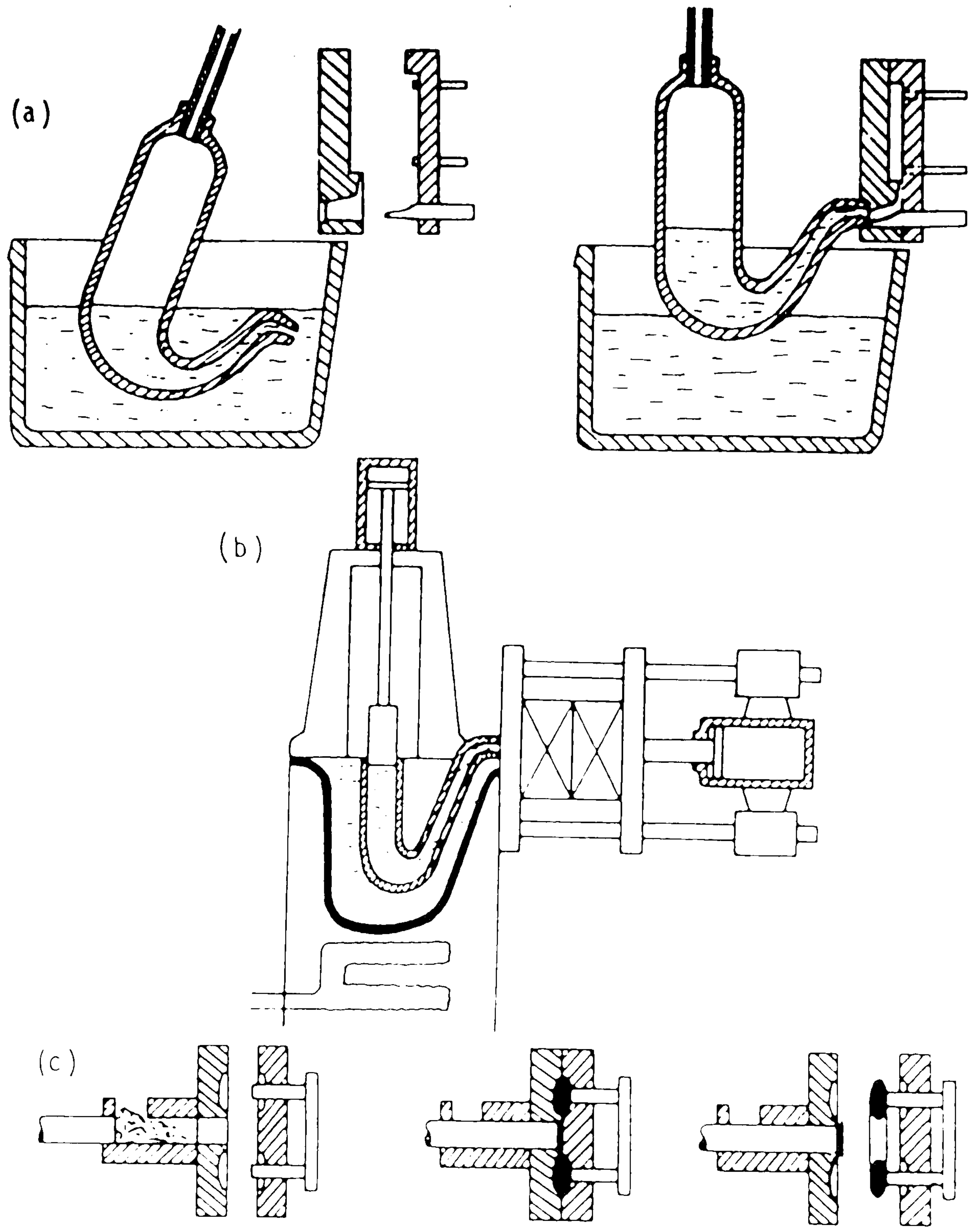

Figure 7-1: The Die-Casting Process: (a) Hot-Chamber, Air Activated, (b) Plunger Activated, (c) Cold-Chamber [27].

3. Major customers such as automotive are requiring that vendors of products such as die-casting must electronically exchange data and information by the early 1990's in order to do business [25].

Our management and technical organization, along with our union has had several crucial meetings to address our current problems. We have addressed several solutions which now have been deemed short term such as: cutbacks in labor through early retirement incentives, reevaluation of specific labor practices, cutbacks in our product prices in order to keep our people working and retain customers, and wage concessions by union and non-union staff.

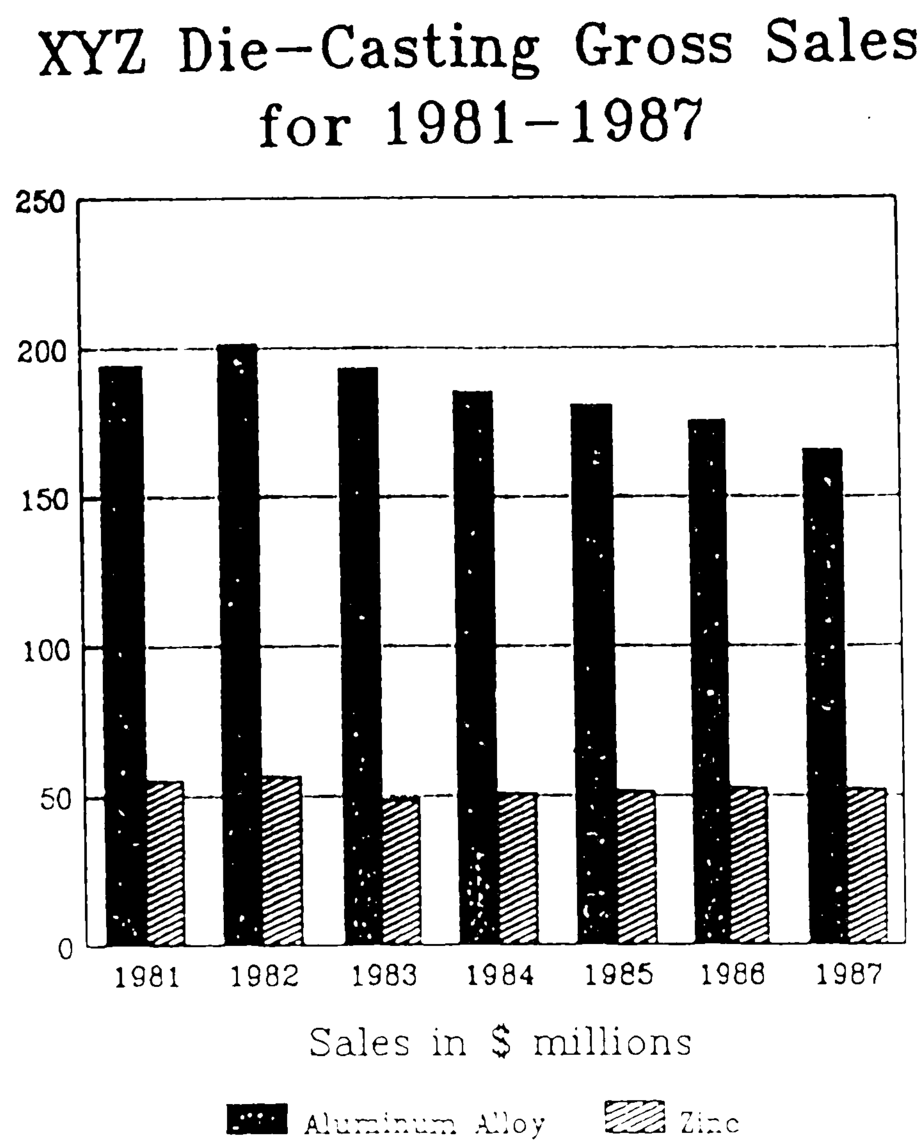

Figure 7-2: XYZ Die-Casting Gross Sales 1981-1987.

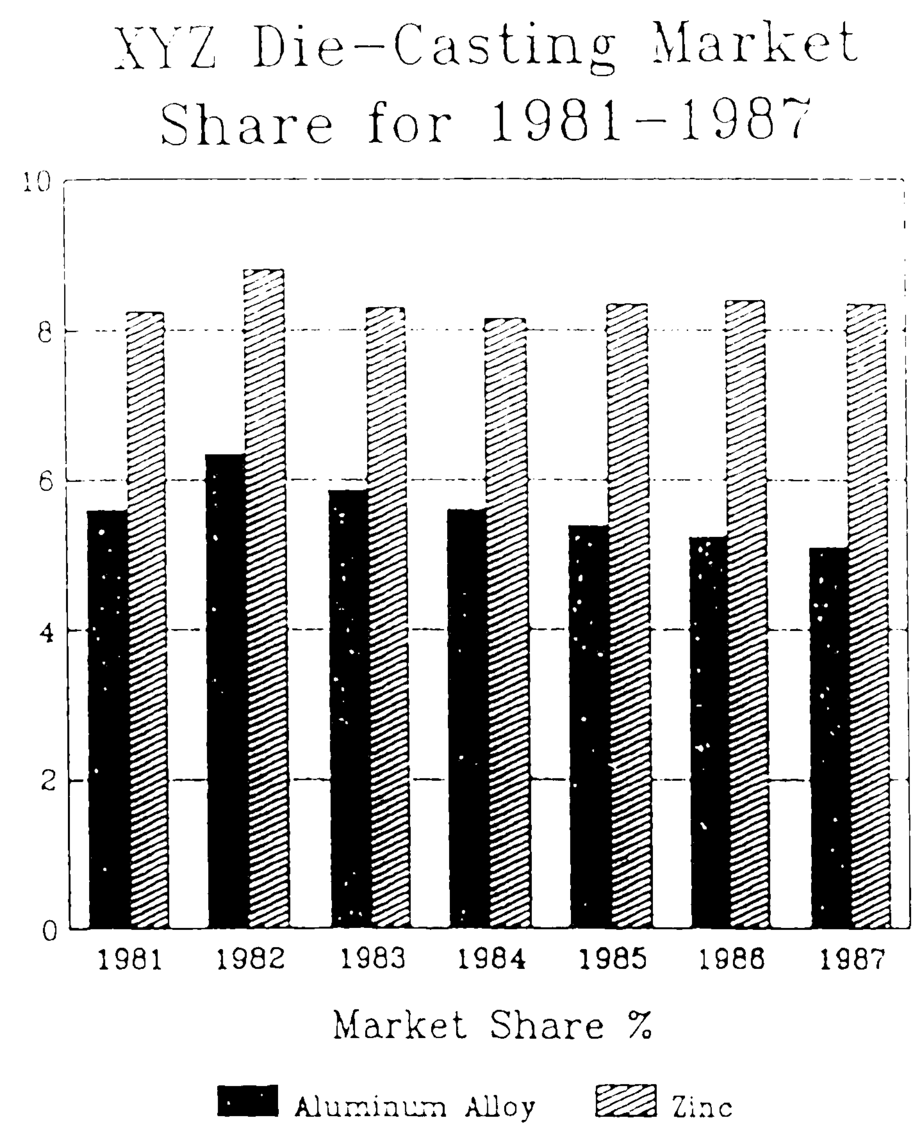

Figure 7-3: XYZ Die-Casting Market Share 1981-1987.

Needless to say, these methods were less than heartily accepted by all parties concerned.

One option that seemed to be offer the most long-term and even short term promise was to implement advanced technology: CAD/CAM. We have invested $20 million dollars in modern die-casting equipment over the last five years, automated our die-casting production line methods as much as possible, and have installed 2 NC machines and a Coordinate Measuring Machine (CMM). Figure 7-4 illustrates a recent hot-chamber machine we purchased in 1985. So far, the NC and CMM have only served as pilot project testbeds and are used in situations where we feel it is necessary. However, our design and manufacturing organizations are performing their tasks through minimal computerization.

We did not just happen upon CAD/CAM through luck. We have dealt with many customers that utilize this technology and have had several of them send us CAD developed part drawings and occasionally an NC tape to duplicate some machining work they have required on certain parts. We recognized that CAD/CAM existed, but were not certain if it was necessary for us at that time. As a whole, our industry has not embraced CAD/CAM on any large scale and little information of CAD/CAM in die-casting was available to us through professional societies. We did gather published information on CAD/CAM from technical publications in other areas, and also from a local university contact. This was a big factor in our continued query into CAD/CAM.

We felt that now the time has finally approached to make that decision. Our basic needs for considering CAD/CAM were not finally resolved until we acquired an outside CAD/CAM consultant to come into our operation and make an evaluation. He worked with this initial team of department representatives

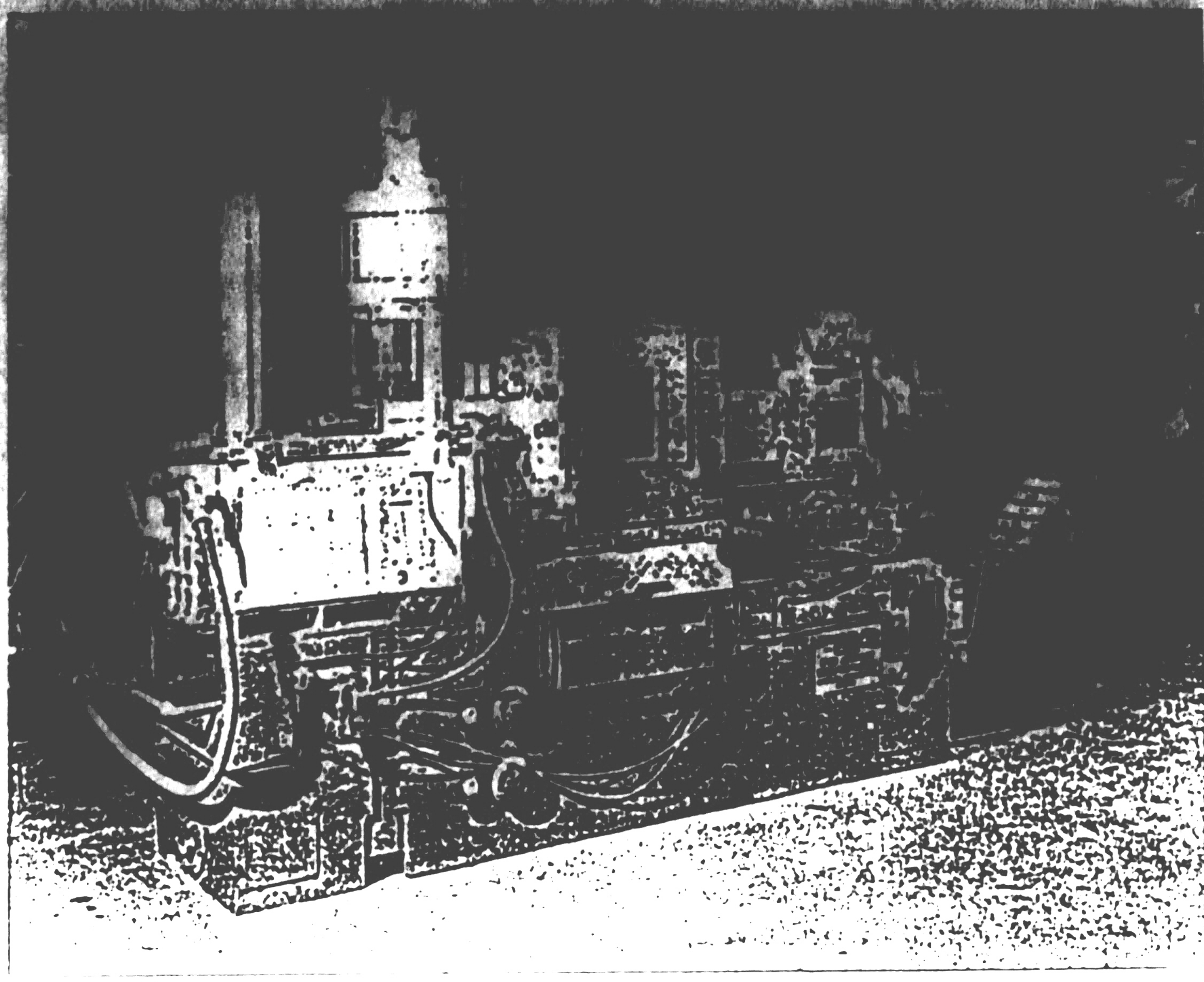

Figure 7-4: Automatic hot-chamber machine with end-type conveyor. [22]

for 3 months at what we consider is necessary expense and proposed the following:

- Determine our needs for CAD/CAM and where it will provide maximum benefits.
- Understand that it is an aid to our problems, not a complete solution.
- Realize that trying to cost justify the system in less than 2 years may be a critical error.
- Understand that there will be qualitative improvements in our design and manufacturing processes that are not easily measurable.
- Management and technical leaders must be totally supportive of this technological and strategic plan.

Our company has what we believe is a progressive management team. We have built our business from a medium to a large die-casting company through quality products, service, and meeting customer's demands. The recent struggles to compete in the aluminum and zinc die-casting market are not only unique to our operation. The industry as a whole is changing in terms of customer base requirements, such as reduced vendor base, higher quality products at competitive prices, reduced lead times, and electronic information exchange, along with smaller firms being swallowed up by the largest die-casting companies. It represents an unstable environment in a relatively healthy industry in terms of total industry growth predictions of 10% annually through 1992. Because of these reasons, we feel committed to improving our market position and believe that CAD/CAM is a step in the right direction and that our progressive management team will approve the project.

7.3 Our Needs And Expectations

After the consultant's contract expired, we allowed 3 more months for the department representative group to develop the proper framework for our CAD/CAM system plan. Each department in the company that we felt would be affected by CAD/CAM both directly and indirectly was to present their anticipated needs for advanced design and manufacturing techniques and also what they expected in terms of results. We felt this was the best means to effectively have each group participate and communicate their input to our CAD/CAM system planning. Each groups needs were expressed as follows:

- *Engineering:*

  We need to be able to develop the die and tooling detail drawings efficiently and in a manner that does not allow repetition of effort and mistakes such as occurs with our manual drafting and revision practices.

  We need to be able to accept and transfer electronic part information from the customer and use it in creating the die and tooling.

  We need to be able to analyze and correct our dies more effectively and quickly than through manual methods.

We would like to offer our expertise in die-casting to our customers so as to act as a design consulting team for and with the customer.

We want to quicken our design cycle so as to capture more quotes.

- *Manufacturing:*

We need to effectively integrate the Numerical Control machinery with computerized principles to take advantage of the speed and accuracy of the computer.

We need to be able to produce products that meet the extreme tolerances required by automotive, electronic, and aerospace customers.

We need to be able to effectively analyze our product quality in terms of homogeneous metrics and tolerances before the die has been completed. In other words, we need some kind of manufacturing modeling system to eliminate costly after-the-fact mistakes.

We need to be able to access engineering information as quickly and efficiently as possible.

- *Tooling:*

We need to be able to design and analyze our tools based on the engineering die information while the die is being designed. We call it parallel die and tooling design.

We need to have our tooling personnel responsible for utilizing some CAD/CAM equipment when it comes on board as to make certain we can effectively exchange information.

We need to be able to access customer part data to begin formulating tooling design tasks.

- *Estimating:*

We would like to have access to the initial customer part information and coordinate any information exchange with engineering, manufacturing, and tooling.

We would like to be able to obtain part volume, packaging, and any geometric feature calculations directly from the computer stored data.

We would like to be able to access any pertinent manufacturing and engineering information quickly from the computer so as to quicken and improve the accuracy of the cost estimating process.

- *Quality Control:*

We believe the CMM machine must be tied in with any design data base in order to effectively take advantage of the electronic accuracy

and expediency of the tools.

We would like to be able to randomly sample electronic representations of dies and tools before they are actually built.

- ***Marketing Dept.*** **We need this tool to be able to increase our customer base and improve our market position.**

  We need to be able to offer our customers more than just diecastings.

  We need to be able to offer our die-casting development and manufacturing experience.

  We need to be able to keep our company at full employment and stress that technology will help, not hurt our efforts.

- *Management:*

  We need to be able to effectively advance our capabilities through technology in order to meet our future demands.

  We need to carefully choose which technology can serve our purposes best and also make an economically feasible decision.

  We need to prove to our company employees and customers that we are committed to improving our situation through successful decision making.

Each group shared some common expectations of the system and some differing ones. They are lumped together and summarized as follows:

1. Increased drafting productivity of 3 to 1.
2. Reduced product production cycle by 25%.
3. Increased market share of 10%.
4. Improved quote/capture rate by 25%.
5. Ability to estimate new jobs to within an 8 % range.
6. QC rejected parts reduced from 15% to 5%.
7. Ability to calculate volume, stresses, and metal flow errors electronically.
8. Ability to interface production planning function with CAD/CAM data base.
9. Ability to machine more complex 3-d surfaces.
10. Reduce NC part programming task by ratio of 3 to 1.
11. Eliminate "busywork" and paper shuffling by engineering and

manufacturing staff.

12. **Think about distributing terminals or workstations to key areas of office and plant and consider networking hookup.**

We also tried to anticipate any benefits of CAD/CAM for our company that are not easily obvious or measurable. We came up with the following list which was heavily based on literature we surveyed:

- Quality improvements that cannot be readily measured.
- Improved work environment for design and manufacturing staff.
- Increased motivation levels of engineering and manufacturing staff.
- Standardized and localized, and more efficient data storage.
- Ability to tie in other production support, engineering design software and modeling type systems.

One particular team member in our marketing group pointed out that instead of only focusing on our anticipated needs and capitalization of perceived weaknesses, we should also focus on what we do well as an organization and how CAD/CAM can positively affect it. We took to the task of asking each group for any additional input to the "what we do well and how CAD/CAM can positively affect it" premise. We found out that what we do well as a die-casting company is:

1. We provide top quality die-castings to a variety of industrial applications.
2. We offer respectable lead times from point of order to receivership of product.
3. We have a very experienced die-casting engineering and manufacturing staff that should be better known to our customer base.
4. We have modernized our die-casting equipment in the plant as much as possible.
5. We offer a good working environment for our employees.

7.4 Conducting A Detailed Multi-Departmental Survey To Shape Our Decision

To aid in our understanding of how our current system operates, we set up a detailed questionnaire for each department affected by CAD/CAM directly. This is intended to help us determine if our investment in CAD/CAM will please both our manufacturing/design team and the financial people. The survey basically covered a large portion of the areas involved in CAD/CAM:

- Drawings
- Engineering Changes
- Parts Classification
- Manpower
- Manufacturing
- NC Machine Tools
- Design Analysis

We made certain that the functions of the specific departments were applied properly to our assessment. For example, *engineers* perform functions in both design of the casting through liaison work with the customer, and also the die, tooling and trim dies. An *analyst* performs stress calculations of the current dies and tooling. A *project engineer* provides specific assistance to specific orders of engineering functions to advance specific activities related to design and manufacture of the dies and the resulting casting. A designer in our company also is the drafter. We have some junior draftsmen who prepare detailed engineering drawings using pre-determined procedures and also using customer part drawings, and any assembly assemblies. The designer prepares the layouts in design or equipment, and deciphers material according to our company standards and practices. We also have similar designers of tooling and trim dies. The seven section questionnaire is detailed in Appendix 4.

These statistics along with the original planning needs give us a good view of the die-casting operation at XYZ. We accumulated all the data from the departments and came up with some figures to support our decision to implement CAD/CAM.

We have: 30 engineers, 6 project managers, 2 computer analysts, and 10 administration personnel (total of 48) to produce 3500 drawings per year. Basing our analysis of costs per drawing compared to expected 3:1 CAD/CAM productivity gains:

1. Cost per drawing (average): $475
2. Cost per Engineering Change (average): $95

Category	Quantity	Saving per Drawing	Total Saving
Simple Casting	400	$ 350	$ 14,000
Complex Casting	325	1975	641,875
Simple Tooling	400	57	22,800
Complex Tooling	325	375	121,875
Machined Part	150	40	6,000
Simple Assembly	250	275	68,750
Complex Assembly	125	1575	196,875
NC Drawing	25	375	9,375
Total			$1,081,550

Figure 7-5: Anticipated Yearly Savings Of Current Methods vs. CAD/CAM.

If we consider that we have 75,000 active drawings on file in our company, this represents over 25 years of design-drafting time alone. Based on our cost of

$3 million per year to produce our current level of drawings, the current drawing file in 1988 dollars represents over $75 million. With this kind of dollar figures presented to our management, we convinced them that a drawing is a very significant and valuable information element in our company. The need for CAD/CAM is perceived as very real and measurable in our company.

7.5 The next Step: CAD/CAM System Specification

At this point, we had consumed 5 months of CAD/CAM planning effort. We felt that we had sufficient input from the consultant and our planning team efforts to develop a specification for what we want the system to accomplish. With the aid of our original consultant's instructions, we produced a specification document. This document was to serve as the basis for vendor and pricing selection, and it also would serve as a cost justification basis. The detail of the document is not included here, but the major points are listed as follows:

1. *SCOPE*
   - Projected System Use Basic Objectives
2. *GENERAL REQUIREMENTS*
   - Mini-Computer or Workstation Functions
   - Ergonomics
   - Data Base Requirements
   - Communication
   - User Interface
   - Upward Compatibility
3. *WORKLOAD PARAMETERS*
   - Work Distribution
   - Work Scenario
4. *HARDWARE REQUIREMENTS*
   - Central Processing Unit
   - Analytic Processor

- **System Console**
- **Alphanumeric Programming Terminal(s)**
- **Interactive Graphics Terminal**
- **Large Tablet Digitizer Workstation**
- **Immediate Access Storage Subsystem**
- **Backup Subsystem**
- **Magnetic Tape Subsystem**
- **Plotters**
- **Line Printer**
- **NC Paper Tape/Punch Default Option**

5. *OPERATING SYSTEM SOFTWARE*
    - General Description
    - Operating System Capabilities
    - Programming Support
    - Communications Software
    - File Transfer Capabilities
    - Language Processors
    - Utility Programs
    - Data Base Management

6. *APPLICATIONS SOFTWARE*
    - Fundamental Capabilities
        - Data Base Structure
        - Computer-aided Mechanical Drafting
        - Geometric Modeling
        - Manufacturing Engineering
        - Mechanical Design
        - Coordinate Measuring Machine Interface
        - Parts, Models, Drawings
        - Numerical Control Capabilities
        - Coordinate Systems and Views
        - Basic Geometric Entities

- Surfaces
- Library Capabilities
- Standard Libraries
- Family of Parts
- Parts Protection
- User/System Interface
- Construction Capabilities
- Non-graphic Information Management
- Output and Postprocessing Capabilities

- For Applications Software:
    - General Description
    - Data Base Structure
    - User/System Interface
    - Construction Capabilities
    - Non-graphic Information Management
    - Output/Postprocessing Applications
    - Finite Element Modeling
    - Pre-Engineering Aids
    - General Description of Toolpath Creation and Generation

7. *VENDOR COMMITMENT*
    - Benchmark
    - Terms And Conditions
    - Warranty
8. *SYSTEM SUPPORT*
    - On-site System Support and Field Engineering
    - System and Equipment Support
    - Training
    - Documentation
    - Maintenance
    - Vendor Support Centers
    - Acceptance Testing

9. ***TRAINING***

- **User Training**
- **General Maintenance Training**
- **On-going Training Classes**

10. *DOCUMENTATION*

- General
- System Overview
- User Manuals
- Installation Date
- Training Materials
- Other Technical Data

11. *SHIPMENT AND INSTALLATION*

- Shipment
- Installation

12. *FUTURE REQUIREMENTS*

7.6 Vendor Chosen Through Benchmarking

The next step we wished to accomplish as the CAD/CAM recommendation group was sending the system specification to several vendors. We were convinced by our previous approximation of our current system costs compared to anticipated CAD/CAM costs of doing business and felt it necessary to have several vendors of CAD/CAM systems bid for the contract based on a benchmark evaluation. We chose a recent die-casting of moderate difficulty which represents the changing nature of our business. It is an automotive transmission part with several machining, assembly, and finishing operations to be done.

This part initially took our design staff 67 hours to produce using current methods. Based on our rate of $45 per hour for design activity, this casting die was completed at a cost of $3,015. Seven CAD/CAM vendors were initially studied by our CAD/CAM team, but due to the fact that we have 2 brands of

computers in house for accounting and materials management functions that also supply CAD/CAM systems, we narrowed the field down to 4 vendors. In addition to the part to be designed, we included the CAD/CAM system specification to receive configured system price estimates. The following results were obtained with system cost data included.

Vendor	Manual	CAD/CAM	Ratio	System Price
ABC CAD	67 hrs	30 hrs	2.23 : 1	$425,000
DEF CAD	67 hrs	34 hrs	1.97 : 1	$375,000
GHI CAD	67 hrs	29 hrs	2.31 : 1	$475,000
JKL CAD	67 hrs	31 hrs	2.16 : 1	$500,000

Figure 7-6: Vendor Benchmark Results and System Pricing - 1st Screening.

Based on the result we received, we gathered the CAD/CAM team together and discussed the results over a period of 2 days. We came to the agreement that one final benchmark test between vendors ABC and GHI would be done. We felt a bit biased to GHI because we have their brand of computer for accounting information processing. However, our NC representative made certain that we must keep an open mind to the other vendor, which has an excellent reputation in the user community (based on some research done in our initial search for CAD/CAM information from non-vendors sources).

This time we had the two vendors work on a complex part which we had a bit of trouble with. This casting had very complex geometric features, a new high silicon content alloy subject to cracking, and several secondary operations for us to consider in the design. This part ended up taking several reworks and die drawing changes before it was correct. The total hours involved were 145 (cost $6,525). This was a much more successful benchmark part.

Vendor	Manual	CAD/CAM	Ratio	System Price
ABC CAD	145 hrs	61 hrs	2.38 : 1	$425,000
GHI CAD	145 hrs	48 hrs	3.02 : 1	$475,000

Figure 7-7: Final Vendor Benchmark Results And System Pricing.

Both vendors reduced their system prices to reflect the competitive situation in the industry. We were very impressed with the results of GHI's test and decided that this was to be the system for us. In addition to the system specifications, we had to consider site preparation, hiring a system programmer/manager, and one or two experienced CAD/CAM operators. We estimated the total system investment for the first year is $685,000. Based on our anticipated savings (which we modified after the benchmark test to $750,000, we believe the system will be a great benefit to our operation. Our team members had several meetings before we began to implement our system and we believe that our savings in terms of dollars will not explain the entire success of the system. We anticipate doing more complex work, increased workforce motivation, and a revitalized customer base due to our decision.

Final Result: We Purchased The System. Now we will continue to revise and update our CAD/CAM plan in terms of personnel selection, site selection, and installation. The CAD/CAM team will plan weekly meetings to discuss the progress of the objectives we have set and the course of action to be taken to meet these objectives.

computers in house for accounting and materials management functions that also supply CAD/CAM systems, we narrowed the field down to 4 vendors. In addition to the part to be designed, we included the CAD/CAM system specification to receive configured system price estimates. The following results were obtained with system cost data included.

Vendor	Manual	CAD/CAM	Ratio	System Price
ABC CAD	67 hrs	30 hrs	2.23 : 1	$425,000
DEF CAD	67 hrs	34 hrs	1.97 : 1	$375,000
GHI CAD	67 hrs	29 hrs	2.31 : 1	$475,000
JKL CAD	67 hrs	31 hrs	2.16 : 1	$500,000

Figure 7-6: Vendor Benchmark Results and System Pricing - 1st Screening.

Based on the result we received, we gathered the CAD/CAM team together and discussed the results over a period of 2 days. We came to the agreement that one final benchmark test between vendors ABC and GHI would be done. We felt a bit biased to GHI because we have their brand of computer for accounting information processing. However, our NC representative made certain that we must keep an open mind to the other vendor, which has an excellent reputation in the user community (based on some research done in our initial search for CAD/CAM information from non-vendors sources).

This time we had the two vendors work on a complex part which we had a bit of trouble with. This casting had very complex geometric features, a new high silicon content alloy subject to cracking, and several secondary operations for us to consider in the design. This part ended up taking several reworks and die drawing changes before it was correct. The total hours involved were 145 (cost $6,525). This was a much more successful benchmark part.

Vendor	Manual	CAD/CAM	Ratio	System Price
ABC CAD	145 hrs	61 hrs	2.38 : 1	$425,000
GHI CAD	145 hrs	48 hrs	3.02 : 1	$475,000

Figure 7-7: Final Vendor Benchmark Results And System Pricing.

Both vendors reduced their system prices to reflect the competitive situation in the industry. We were very impressed with the results of GHI's test and decided that this was to be the system for us. In addition to the system specifications, we had to consider site preparation, hiring a system programmer/manager, and one or two experienced CAD/CAM operators. We estimated the total system investment for the first year is $685,000. Based on our anticipated savings (which we modified after the benchmark test to $750,000, we believe the system will be a great benefit to our operation. Our team members had several meetings before we began to implement our system and we believe that our savings in terms of dollars will not explain the entire success of the system. We anticipate doing more complex work, increased workforce motivation, and a revitalized customer base due to our decision.

Final Result: We Purchased The System. Now we will continue to revise and update our CAD/CAM plan in terms of personnel selection, site selection, and installation. The CAD/CAM team will plan weekly meetings to discuss the progress of the objectives we have set and the course of action to be taken to meet these objectives.

Chapter 8
Conclusion

CAD/CAM has definitely surfaced in the past 20 years as a necessary strategic tool for enabling worldwide manufacturing and design efforts to be completed efficiently and effectively. The growth rate of the technology has far outpaced the ability of companies to handle all of the technological, organizational, and human implications.

Many companies involved in the design and/or manufacture of products in this country as well as overseas have come to rely upon CAD/CAM as an economic necessity. These companies vary in size from a small shop of several employees using a PC based CAD design package to a user community of hundreds of people in multi-billion dollar conglomerate utilizing millions of dollars of CAD/CAM system software networks and hardware to develop product.

Nearly every one of these companies have plans to continue to expand their CAD/CAM operation into a more advanced design and manufacturing environment. The big question is how to define and develop advanced manufacturing and design technology. There are many examples of companies developing such strategies and using catch-all buzzwords to express them, but no one has a single approach that will fit everyone. However, the approach taken by a company depends on what their definition of advanced manufacturing and design technology is and how they plan to achieve it.

The major areas where CAD/CAM problems occur in most industries are in the lack of systems planning, and the subsequent training of personnel after the system has been installed. Companies must realize that the investment in human capabilities must keep pace with the technological investments. CAD/CAM systems must be effectively integrated with people to minimize the effects of change brought on by the introduction of new technology in an organization.

The users of the system are not the only ones who must adapt to the new technology. The company management must adopt new practices of recognizing how to justify such systems from a human and financial point of view. Traditional people management and financial justification procedures must be questioned and even abolished to make way for techniques to manage effectively and justify such an investment.

CAD/CAM systems certainly improve product quality and reduce important production measures such as design and manufacturing lead times and cost per unit (of production), they can also improve the quality of worklife in the company by reducing tedious work, paper shuffling, and give the workforce a morale boost by introducing them to the computer age. The systems thinking approach recognizes that the purchase, installation, and use of a CAD/CAM system involves integration of people, information, and computers to achieve the desired objectives.

In conclusion, the future of CAD/CAM is bright but must be viewed with some concern. We, in the U.S., must be able to adapt our corporate state of mind to look for solutions to our competitive manufacturing situation instead of blaming other countries for undercutting our economic base. CAD/CAM systems are only a tool that, when properly utilized and integrated into the corporation, can help regain and improve industrial success in this country.

References

[1] **SME.**
Manufacturing In The 21st Century.
1988.
To be published by the Society of Manufacturing Engineers.

[2] P. S. Adler and D. A. Helleloid.
Effective Implementation of Integrated CAD/CAM: A Model.
In *IEEE Transactions On Engineering Management*, pages 101-106. IEEE, New York, 1987.

[3] Doug Lewis, General Dynamics CEO.
CAD/CIM Alert Reprint.
1987
Published by Management Roundtable, Inc. Chestnut Hill, MA.

[4] Staff Article.
Workstation Market Shows Major Changes In Last Five Years.
CAD / CIM Alert VIII, No. 4:12, August 31, 1988.

[5] Staff Article.
Australia Fails To Realize CAD's Full Potential.
1988 Elsevier Science Publishers, Ltd., England.
May, 1988

[6] Baron, R.C.
Leap Over The ROI Barriers.
Automation Magazine 3:50-52, July, 1988.

[7] Besant, A.B., Lui, C.W.K.
Computer-Aided Design and Manufacture, 3rd Edition.
Ellis Horwood Limited, Chichester, West Sussex, England PO19 1EB, 1986.

[8] Bolland, E, Goodwin, S.L.
Corporate Accounting Practice Is Often Barrier to Implemenation to CIM.
Industrial Engineering 11:24-26, 1988.

[9] Ciampa, D.
Total Quality, Just-In-Time, Computer-Integrated Manufacturing: Partners, Not Competitors.
Quality Magazine April, 1988:84-85, 1988.

[10] Staff Article.
CAD system Lifecycle.
The Journal of Computer-Integrated Manufacturing Management.
Winter, 1986

[11] **U. S. Dept. of Commerce.**
A Competitive Assessment of the U.S. CAD/CAM Industry.
U.S. Department of Commerce.
Feb., 1987

[12] Constantinou, S., Rathmill, K.
Evaluation procedures to be used during the development of CAD systems.
Computer-Aided Design 14:321-328, 1982.

[13] John C. Arnold.
The CIMPLAN Framework.
Coopers & Lybrand Internal document.
1987

[14] Cound, D.M.
What Corporate Executives Think About Quality: The Results of the 1987 Gallup Survey.
Quality Progress Reprinted from the February 1988 Issue Of Quality Progress:7-10, 1988.

[15] Gardiner, K.M.
Global Manufacturing For The Future.
In *Proceedings, 80 Seminario de Commando no Brasil*. Jornada Internacional de Automatizacao Industrial, Sao Paulo, Brazil, August, 1988.
pp. 28.01-28.14.

[16] Groover, M.P.
Automation, Production Systems, and Computer Integrated Manufacturing.
Prentice-Hall, Englewood Cliffs, New Jersey, 1987.

[17] P. T. Hertz.
The Deming Method : Managers must understand that they need the workers.
Quality 25th Anniversary Issue:32-34, 1987.

[18] Horngren, C.T., Foster, G.
Cost Accounting, A managerial emphasis.
Prentice-Hall, Englewood Cliffs, NJ 07632, 1987.

[19] Lawrence Gould.
IBM Goes After CIM Business.
Managing Automation 3(9):17-21, Sept., 1988.

[20] Young, A, Levi, D., Slem, C.
Dispelling Some Myths About People and Technological Change.
Technical Report, Institute Of Industrial Engineers, November, 1987.

[21] **Kaplan, R.S.**
Must CIM Be Justified By Faith Alone.
***Harvard Business Review* b:4, 1986.**

[22] **Kaye, A.**
Die-Casting Metallurgy.
Butterworth Scientific, London, England, 1978.

[23] Majchrzak, A.
The Effects of CAM Technologies on Training Activities.
Technical Report 3, Society Of Manufacturing Engineers, 1986.
Volume 5, No. 3.

[24] McCormick, E.J., Sanders, M.S.
Human Factors in Engineering and Design.
McGraw-Hill Book Company, New York, New York, 1982.

[25] Pennington, N.
Die caster computerizes; keeps with customer demands.
Modern Metals Magazine.
1986

[26] Preston, E. J.,Crawford, G.W., Coticcha, M.E.
CAD / CAM Systems - Justification, Implementation, Productivity Measurement.
Marcel Dekker, Inc., New York, New York 10016, 1984.

[27] Alting, L.
Manufacturing Engineering Processes.
Marcel Dekker, Inc., New York, New York, 1982.

[28] Schlenker, L.
Trends In European CAD.
Design Graphics World VII:12-16, July, 1988.

[29] Nostrand, R.C.
CAD / CAM Justification and Follow-up: Simmonds Precision Products Case Study.
Technical Report, Simmonds Precision Products, 1984.

[30] Skinner, W.
Manufacturing. The Formidable Competitive Weapon.
John Wiley & Sons, New York, 1985.

[31] Staff of Computer Aided Design Report.
CAD/CAM,CAE Users: Current Applications and Future Directions.
CAD/CAM Publishing, Inc. San Diego, California 92109, 1988.

[32] Swindle, R.
Financial Justification of Capital Projects.
In *CASA SME Autofact : Autofact '85 Conference Proceedings*, chapter 5, pages 18 Sections. CASA SME Publishing Dept., Dearborn, Michigan 48121, 1985.

Appendix A
List of CAD/CAM System Hardware and Software Vendors

ACCUGRAPH
50 Gervais Dr.
Don Mills, Ontario, Canada
(416) 441-2211

Products:
Hardware platforms, proprietary systems

ADRA SYSTEMS
59 Technology Drive
Lowell, Massachusetts 01851
(617) 937-3700

Products:
CAD software, proprietary platforms

ALLIANT
One Monarch Drive
Littleton, MA 01460
(617) 486-4950

Products:
Minisupercomputers

AMERICAN CHANNELS
10 Waltham Street
Lexington, MA 02173
(617) 862-4441

Products:
CAD/CAM software

APOLLO COMPUTER, INC.
330 Billerica Road
Chelmsford, MA 01824
(617) 256-6600

Products:
Engineering Workstations

APPLE COMPUTER
20525 Mariana
Cupertino, CA 95014
(408) 996-1010

Products:
Macintosh Personal Computers

ARIES TECHNOLOGY
600 Suffolk Street
Lowell, MA 01854
(617) 453-5310

Products:
Mechanical CAE systems

AUTODESK
2320 Marineship Way
Sausalito, California 94965

Products:
CAD Software

AUTOMATION TECHNOLOGY PRODUCTS
1671 Dell Avenue
Campbell, CA 95008

Products:
Solid Modeling Software

(9408) 370-4000

AUTOMATIX INC.
1000 Technology Park Drive
Billerica, MA 01821
(617) 667-7900

Products:
CAD software

AUTO-TROL TECHNOLOGY
12500 N. Washington Street
P.O. box 33815
Denver, CO 80233
(303) 452-4919

Products:
CAD/CAM, CAE,
Documentation software

BRIDGEPORT MACHINES
500 Lindley Street
Bridgeport, CT 06606
(203) 367-3651

Products:
Machining, NC programming software

CADAM, INC.
1935 N. Buena Vista St.
Burbank, California 91504

Products:
CAD/CAM software

CADNETIX CORPORATION
5775 Flatiron Parkway
Boulder, Colorado 80301
(303) 444-8075

CALAY SYSTEMS
2698 White Road
Irvine, California 92714
(714) 821-2011

CALMA - Division of General Electric
501 Sycamore Drive
Milipitas, California 95035-7489
(408) 434-4000

Products:
CAD/CAM, CAE software

CAMAX SYSTEMS, INC.
7225 Ohms Lane
Minneapolis, MN 55435
(612) 831-0604

Products:
CAD/CAM software

CELERITY
9692 Via Excelencia
San Diego, CA 92126
(619) 271-9940

Products:
Superminicomputers, minisupercomputers

CIMLINC

Products:

700 Nicholas Blvd.
Elk Grove Village, IL 60007
(312) 228-7300

CAD/CAM software and turnkey systems

CIS MEDUSA (a subsidiary of Computervision)
201 Burlington Road
Bedford, MA 01730
(617) 276-1288

Products:
Solid Modeling Software

CISIGRAPH
33533 W. 12 Mile Road, Suite 100
Farmington Hills, MI 48018
(313) 489-0220

Products:
Mechanical CAD/CAM, CAE software

COGNITION
900 Technology Park Drive
Billerica, MA 01821
(617) 667-4800

Products:
Mechanical CAE systems,
Expert systems for engineering

COMPUTERVISION
(a Subsidiary of Prime Computer)

100 Crosby Drive
Bedford, Massachusetts 01730
(617) 275-1800

Products:
CAD/CAM software and systems

CONTROL DATA CORP.
8100 34th Avenue South
Bloomington, MN 55431
(612) 853-4400

Products:
CAD/CAM, CAE systems and software

CUBICOMP
21325 Cabot Blvd.
Hayward, CA 94545
(415) 887-1300

Products:
Design and solid modeling software

DAISY SYSTEMS
P.O. Box 7006
Mountani View, California 94039
(408) 773-9111

DASSAULT SYSTEMS, U.S.A.
777 Terrace Avenue
Hasbrouck Heights, New Jersey 07604
(201) 288-6536

Products:
CAD/CAM software

DASSAULT SYSTEMS World Headquarters
40 Boulevard Henri Sellier

92150 Suresnes, France

DATA GENERAL
4400 Computer Drive
Westboro, MA 01580
(617) 366-8911

Products:
Workstations, minicomputers

DIGITAL EQUIPMENT CORP.
Three Results Way
MRO3-1/E8
Box 1003
Marlboro, MA 07152
(617) 897-5111

Products:
Workstations, mini and microcomputers

ENGINEERING SYSTEMS CORP.
3636 S. Sherwood Forest Blvd.
Suite 400
Baton Rouge, LA 70816
(504) 769-2226

Products:
3-d Design software

EVANS & SUTHERLAND
540 Arapeen Drive
Salt Lake City, UT 84108
(801) 582-5847

Products:
CAD/CAM and solid modeling systems and software

GERBER SYSTEMS TECHNOLOGY
425 Sullivan Avenue
South Windsor, CT 06074
(203) 282-1478

Products:
CAD and NC software

HEWLETT PACKARD COMPANY
Electronic Design Division
8245 No. Union Blvd.
Colorado Springs, CO 80918-0617
(719) 590-7788

Products:
Workstations, systems solutions and software for CAD/CAM, CAE

IBM CORPORATION
1133 Westchester Avenue
White Plains, NY 10604
(800) 268-7687

Products:
Micro, mini, and mainframe computers, CAD/CAM, CAE software

ICAD
1000 Massachusetts Avenue
Cambridge, MA 02138
(617) 868-2800

Products:
Expert Systems for mechanical design

ICONNEX
1501 Reedsdale Street

Products:
Mechanical CAE for conceptual design

Pittsburgh, PA 15233
(412) 321-8890

IGC TECHNOLOGY CORP.
305 Lennon Lane
Walnut Creek, CA 94598
(415) 945-7300

Products:
CAD software, translator

INFINITE GRAPHICS
4611 E. Lake St.
Minneapolis, MN 55406
(612) 721-6283

Products:
CAD/CAM, CAE software

INNOVATIVE COMPUTER-AIDED TECHNOLOGY
14979 Prairie Ave, Suite 3
Lawndale, CA 90260
(213) 644-2949

Products:
CAD/CAM software

INTERGRAPH CORP.
One Madison Industrial Park
Huntsville, Alabama 35807
(205) 772-2000

Products:
CAD/CAM, CAE systems, workstations

ISICAD
P.O. Box 61022
Anaheim, CA 92803
(714) 533-8910

Products:
Workstations, CAD and
Solid modeling software

MACNEIL-SCHWENDLER Corp.
815 Colorado Blvd.
Los Angeles, CA 90041-1777
(213) 259-9111

Products:
FEM/FEA software

MANUFACTURING AND CONSULTING SERVICES
9500 Toledo Way
Irvine, CA 92718
(714) 951-8858

Products:
CAD/CAM, solid modeling software

MARC ANALYSIS RESEARCH CORP.
260 Sheridan Avenue
Palo Alto, CA 94306
(415) 326-1971

Products:
FEM/FEA software

MASSCOMP
One Technology Way
Westford, MA 01886

Products:
Computers, engineering workstations

(617) 692-6200

MATRA-DATAVISION
30 Commerce Way
Woburn, MA 01801
(617) 938-1230

Products:
CAD/CAM, CAE and solid modeling software

McDONNELL DOUGLAS
Manufacturing Industry System Company (MISCo)
P.O. Box 516
St. Louis, Missouri 63166
(314) 232-0232

Products:
CAD/CAM software

MICRO CONTROL SYSTEMS
27 Hartford Turnpike
Vernon, CT 06066
(203) 647-9235

Products:
CAD and CAE software

MICRO ENGINEERING SOLUTIONS
32969 Hamilton Court, Suite 200
Farmington Hills, MI 48018
(313) 553-8470

Products:
CAD/CAM software

MENTOR GRAPHICS
8500 S.W. Creekside Place
Beaverton, Oregon 97005-7191
(503) 620-9817

Products:
CAD/CAM systems and software

ORCAD SYSTEMS
1049 S. W. Baseline Street, Suite 500
Hillsboro, Oregon 97123

PACKAGED COMMUNICATIONS TECHNOLOGY
24 B. Andover Drive
West Hartford, CT 06110
(203) 247-8911

Products:
CAD/CAM software

PALETTE SYSTEMS
2 Burlington Woods Park
Burlington, MA 01803
(617) 273-5660

Products:
General purpose CAD, CAPP, CIM software

PDA ENGINEERING
2975 Redhill Avenue
Costa Mesa, California 92626
(714) 540-8900

Products:
CAD/CAM, FEA and Mechanical CAE software

PERSPECTIVE DESIGN LTD.
9 Pembroke Street
Cambridge, England CB2 2QI
0223/323636

Products:
Solid Modeling Software

PERSONAL CAD SYSTEMS
1290 Parkmoor Avenue
San Jose, California 95126

PRIME COMPUTER, Inc.
Prime Park
Natick, MA 01760
(617) 655-8000

Products:
CAD/CAM systems and software

RACAL REDAC (U.S. Subsidiary)
One Redac Way
Littleton, MA 01460
(617) 486-9231

RACAL REDAC (World Headquarters)
Green Lane, Newton
Tewkesbury, Gloucester GL20 8HE
England
0684/294161

RIDGE COMPUTERS
2451 Mission College Blvd.
Santa Clara, CA 95054
(408) 986-8500

Products:
Superminicomputers

SCHLUMBERGER, CAD/CAM DIVISION
(previously APPLICON)
4251 Plymouth Road
Ann Arbor, MI 48106
(313) 995-6000

Products:
CAD/CAM systems and software

SCIENTIFIC CALCULATIONS
(Division of Harris Corp.)
7796 Victor Menden Road
P.O. Box H
Fishers, New York 14453
(716) 924-9303

STRUCTURAL DYNAMIC RESEARCH
CORPORATION (SDRC)
CAE International Division
300 Technecenter Drive
Milford, Ohio 45150

Products:
CAD/CAM, CAE, solid modeling,
and documentation software

(513) 576-2400

SILICON GRAPHICS
2011 Stierlin Road
Mountain View, CA 94043
(415) 960-1980

Products:
Graphics engineering workstations

SUN MICROSYSTEMS
2550 Garcia Avenue
Mountain View, CA 94043
(415) 960-1300

Products:
Engineering workstations, servers, UNIX system software, data communication and networking products

SWANSON ANALYSIS SYSTEMS
Johnson Road, P.O. Box 65
Houston, Pennsylvania 15342-0065
(412) 746-3304

Products:
FEA/FEM software

TEKSOFT
3320 W. Cheryl Drive
Phoenix, AZ 85051
(602) 942-4982

Products:
CAD software

TEKTRONIX, INC.
P.O. Box 500
Beaverton, OR 97077
(503) 627-7111

Products:
Workstations, terminals, 2D CAD software

UNICAD
1695 38th Street
Boulder, CO 80301
(303) 443-6961

Products:
3D CAD software, Application Development Environment, and database management system

UNISYS
2970 Wilderness Pl.
Boulder, CO 80301
(303) 449-1138

Products:
CAD software, turnkey CAD system based on MASSCOMP hardware

VECTOR AUTOMATION
Village of Cross Keys
Suite 250
Baltimore, MD 21210
(301) 433-4200

Products:
CAD software

VALID LOGIC SYSTEMS
2820 Orchard Parkway
San Jose, California 95135

VERSACAD

(a subsidiary of Prime Computer)
2124 Main Street
Huntington Beach, California 92648
(714) 847-9960

Products:
CAD software

XEROX (Engrg. Design and Documentation Systems)
Intersections of Rts. 7 & 659
P.O. Box 2000
Leesburg, VA 22075
(703) 729-8000 x3184

Products:
CAD/CAE, document management software, engineering workstations

Appendix B
Glossary of Terms

There are many terms used in this thesis that may be unfamiliar to the reader. This is not intended to be an exhaustive CAD/CAM terms glossary, which can be found in several of the bibliography references.

The following are widely used throughout the glossary:

Designer - Includes engineers, draftspersons, cartographers, and all who regularly use a CAD or CAD/CAM workstation.

Operator - Used synonymously with designer but implying the more manual aspects of CAD/CAM workstation operation.

User - The organization using CAD/CAM, or the manager who determines CAD/CAM procedures.

Workstation - Synonymous with terminal, but may contain higher levels of local functional capabilities.

Algorithm - The general method or procedure adopted in order to enable a computer to perform a task or solve a problem. Every computer program will be based upon an algorithm. But whereas a program is one specific set of instructions set out in a form which can be run on a computer, an algorithm is a much more general concept and any one algorithm can be translated into a program in many different ways, using different programming languages.

Application program or package - A computer program or collection of programs to perform a task or tasks specific to a particular user's needs or class of needs.

Assembly drawing - A drawing which can be created on the CAD/CAM system to represent a major subdivision of the product, or the complete product.

Benchmark - The program(s) used to test, compare, and evaluate in real time (see *Real Time*) the performance of various CAD/CAM systems prior to selection and purchase. A synthetic benchmark has pre-established parameters designed to exercise a set of system features and resources. A live benchmark is drawn from the prospective user's workload as a model of his entire workload.

Beta Site - A user's CAD/CAM site or facility selected by mutual

agreement between the user and his vendor for testing out a new system, application package, or hardware or software enhancement before its sale to other customers of the vendor.

Bit Map - In a raster display system, where the screen is made up of a regular array of picture points or pixels, the intensity and/or color of each pixel will be encoded in a sequence of binary digits (bits) of information. The complete description of an entire image is therefore known as the bit map or pixel map and will normally be stored in the buffer memory associated with the display unit.

Buffer Memory - The specialized memory elements associated with a raster display in which the bit map of the image currently appearing on the screen is stored.

Bug - A flaw in the design or implementation of a software program or hardware design which causes erroneous results or malfunctions.

CAD - Computer-Aided Design. A process which uses a computer system to assist in the creation, modification, and display of a design. CAD can included modeling assistance through simulation, analytical analysis, or other integrated analytical design techniques.

CAD / CAM - Computer-Aided Design/Computer-Aided Manufacturing. Refers to the integration of computers into the entire design-to-production cycle of a product or plant.

CAM - Computer-Aided Manufacturing. The use of computer and digital technology to generate manufacturing-oriented data. Data drawn from a CAD/CAM data base can assist in or control a portion or all of a manufacturing process, including numerically controlled machines, computer-assisted parts programming, computer-assisted process planning, robotics, and programmable logic controllers. CAM can involve: production programming, manufacturing engineering, industrial engineering, facilities engineering, reliability engineering, and quality control. CAM techniques can be used to produce process plans for fabricating a complete assemble, to program robots, and to coordinate plant operation.

Cathode Ray tube (CRT) - Also called a tube, the principal component in a CAD/CAM display device. A CRT displays graphical representations of geometric entities and designs and can be of various types: storage tube, raster scan, or refresh. These tubes create images by means of a controllable beam of electrons striking a screen. The term CRT is often used to denote the entire display device.

Central Processing Unit (CPU) - The computer brain of a CAD/CAM

system which controls the retrieval, decoding, and processing of information, as well as the interpretation and execution of operating instructions, the building blocks of application and other computer programs. A CPU comprises arithmetic, control, and logic units.

CIM - **The concept of a totally automated factory in which all manufacturing, design, planning, and business functions are integrated and controlled by a computer information system. CIM enables production planners and schedulers, shop floor foremen, designers, engineers, accountants, and management to utilize the common database.** (CIM is often used as a "catch-all" acronym for advanced design and manufacturing principles).

Command - A control signal or instruction to a CPU or graphics processor, commonly initiated by means of a menu/tablet and electronic pen or mouse, or by an alphanumeric keyboard.

Compatibility - The ability of of a particular hardware module or software program, code, or language to be used in a CAD/CAM system without prior modification or special interfaces. Upward compatible denotes the ability of a system to interface with new hardware or software modules or enhancements.

Computer Graphics - A general term encompassing any discipline or activity that uses computers to generate, process, and display graphic images. The underlying technology of CAD/CAM systems.

Computer Numerical Control (CNC) - A technique in which a machine-tool control uses a minicomputer to store NC instructions generated earlier by CAD/CAM for controlling the machine.

Computer Program - A specific set of software commands in a form acceptable to a computer and used to achieve a desired result. Often called a software program or package.

Configuration - A particular combination of a computer, software and hardware modules, and peripherals at a single installation and interconnected in such a way as to support certain applications.

Convention - Standardized methodology or accepted procedure for executing a computer program. In CAD, the term denotes a standard rule or mode of execution undertaken to provide consistency of data. For example a drafting convention might require all dimensions in english units.

Cycle - A preset sequence of events (software, hardware, or plans) initiated by a single command or instruction.

***Data Base* - A comprehensive collection of interrelated information stored on some kind of mass storage device or media, usually a disk. Generally it consists of information organized into a number of fixed-format record types with logical links between associated records. Typically it includes operating system instructions, standard part libraries, completed designs and documentation, source code, graphic and application programs, as well as current user tasks in progress.**

Data Base Management System - A package of software programs to organize and control access to information stored in a multi-users system. It gives users a consistent method of entering, retrieving and updating data in the system, and prevents duplication and unauthorized access to stored information.

Data Communication - The transmission of data (usually digital) from one point such as a CAD/CAM workstation or CPU to another point via communication channels such as telephone lines or networks.

Debug - To detect, locate, and correct any bugs in a system's software or hardware.

Detail Drawing - The drawing of a single part design containing all the dimensions, annotations, etc., necessary to give a definition complete enough for manufacturing and inspection.

Device - A system hardware module external to the CPU and designed to perform a specific function (i.e. a CRT, plotter, hard copy unit, etc.).

Direct Numerical Control - A system in which sets of NC machines are connected to a mainframe or superminicomputer to establish a direct interface between the DNC computer memory and the machine tools. The machine tools are directly controlled by the computer without the use of tape.

Direct-View Storage Tube (DVST) - One of the most widely used graphics display devices, DVST generates a long-lasting, flicker-free image with high resolution an no refreshing. It handles an almost unlimited amount of data. However, display dynamics are limited since DVST's do not permit selective erase. The image is not as bright as with refresh or raster.

Directory - A named space on the disk or other mass storage device in which are stored the names of files and some summary information about them.

Disk (Storage) - A device on which large amounts of information

can be stored in the data base. Synonymous with magnetic disk storage or magnetic disk memory.

Distributed Processing **- Refers to a computer system that employs a number of different hardware processors, each designed to perform a different subtask on behalf of an overall program or process. Ordinarily, each task would be required to queue up for a single processor to perform all its needed operations. But in a distributed processing system, each task queues up for a specific processor required to perform its needs.** Since all processors run simultaneously, the queue wait period is often reduced, yielding better overall performance in a multitask environment.

Edit - To modify, refine, or update an emerging design or text on a CAD/CAM system. This can be done on-line interactively.

Element - The basic design entity in a computer-aided design whose logical, positional, electrical, or mechanical function is identifiable.

Enhancements - Software of hardware improvements, additions, or updates to a CAD/CAM system.

Entity - A geometric primitive - the fundamental building block used in constructing a design or drawing (i.e. line, arc, spline). Or a group of primitives processed as an identifiable unit. Thus, a square may be defined as a discrete entity containing four primitives (vectors), although each side of the square could be defined as an entity in its own right.

Feedback - (1). The ability of a system to respond to an operator command in real time either visually or through some form of a message at a graphic device. (2). The signal or data fed back to a commanding unit from a controlled machine or process to denote its response to a command. (3). The signal representing the difference between actual response and desired response and used by the commanding unit to improve performance or the controlled machine or process.

File - A collection of related information in the system which may be accessed by a unique name. May be stored on disk, tape, or other mass storage media.

Finite Element Analysis - A method used in CAD for determining the structural integrity of a mechanical part or physical construction under design by mathematical simulation of the part and its loading conditions.

Finite Element Modeling - The creation on the system of a

mathematical model representing a mechanical part or physical construction under design. The model, used for input to a Finite Element Analysis program, is built first by subdividing the design model into smaller and simpler elements such as rectangles, triangles, bricks, or wedges which are interconnected. The finite element model is comprised of all its subdivisions or elements, and its attributes (such as materials and thickness), as well as its boundary conditions and loads (including mechanical loadings, temperature effects, and materials fatigue).

Firmware - Computer programs, instructions, or functions implemented in user-modifiable hardware (i.e. a microprocessor with read-only memory). Such programs or instructions, stored permanently in programmable read-only memories constitute a fundamental part of CAD/CAM system hardware.

Flexible Manufacturing System (FMS) - An FMS will normally consist of a "cell" containing perhaps two or more machine tools, some gauging or calibration equipment, and a robot that will be responsible for loading and unloading the tools, etc. An FMS represents a compromise between CNC or DNC systems, which are only concerned with controlling the operations of the tools themselves, and CIM which aims to control and coordinate long, overall sequences of operations.

Floppy Disk - A small, limited space magnetic storage media device to provide backup storage, generally in microcomputer systems.

Hardcopy - Sometimes used to mean any reproduction on paper of an image derived from a CAD/CAM system, by whatever means it has been generated. May be a laser printer, or scanner device.

Hardware - The physical components, modules, and peripherals comprising a system (i.e. computer, disk, CRT terminals, etc.).

High-Level Language - A problem oriented programming language using words, symbols, and command statements which closely resemble English-like statements. Each statement typically represents a series of computer instructions. Relatively easy to learn and use, a high level language permits the execution of a number of subroutines through a simple command. Examples are: BASIC, FORTRAN, C, PASCAL, and COBOL. A high-level language must be translated or compiled into machine language before it can be understood by a computer.

Host Computer - The primary or controlling computer in a multicomputer network. Large-scale host computers typically are equipped with mass memory and a variety of peripheral devices, including magnetic tape, line printers, and possibly hardcopy devices. Host computers may be used to support, with their own memory and processing capabilities, not only graphics programs running on a CAD/CAM system, but also related engineering and business analysis.

Initial Graphics Exchange System (IGES) - A CAD/CAM data base specification developed through ANSI to standardize communication of drawings and geometric product information between computer systems.

Integrated System - A CAD/CAM system which integrates the entire product development cycle, analysis, design and fabrication, so that all processes flow smoothly from concept to production.

Integrated Circuit (IC) - A tiny complex of electronic components and interconnections comprising a circuit which may vary in functional complexity from a simple logic gate to a microprocessor. An IC is usually packaged in a single substrate such as a slice of silicon or gallium-arsenide. The complexity of most IC designs and the many repetitive elements have made CAD/CAM an economic necessity.

Intelligent Workstation / Terminal - A workstation in a system which can perform certain data processing and graphics functions in a standalone mode, independent of another computer. Contains a built-in computer, usually a microprocessor or minicomputer, and dedicated memory.

Interactive - Denoted two-way communications between a CAD/CAM system or workstation and its operators. An operator can modify or terminate a program and receive feedback from the system for guidance and verification.

Interactive Graphics System (IGS) or Interactive Computer Graphics System (ICGS) - a CAD/CAM system in which the workstations are used interactively for computer-aided design and/or drafting, as well as for CAM, all under full operator control, and possibly also for text processing, chart and graph generation, or computer-aided engineering. The designer (operator) can intervene to enter data and direct the course of any program, receiving immediate visual feedback via the CRT. Bilateral communication is provided between the system and user(s).

Interface - (1). A hardware and/or software link which enables two systems, or a system and its peripherals, to operate as a single integrated system. (2). The input devices and visual feedback capabilities which allow bilateral communication between the designer and the system. The interfaced to a large computer can be a communications link (hardware), or a combination of software and fixed or hard-wired connections. An interface might also be a portion of storage accessed by two or more programs, or a link between two subroutines in a program.

Learning Curve - A concept that projects the expected improvement in operator productivity over a period of time. Usually applied in the first 12 to 18 months of a new CAD/CAM facility as part of a cost-justification study, or when new operators are introduced. An accepted tool of management for predicting manpower requirements and evaluating training programs and requirements.

Library - A collection of standard, often-used symbols, shapes, components, or parts stored in the CAD data base as templates or building blocks to speed up future design work on the system. Generally an organization of files under a common library name.

Magnetic Disk - A flat circular plate with a magnetic surface on which information can be stored by selective magnetization of portions of the flat surface. Commonly used for temporary working storage during computer-aided design.

Magnetic Tape - A tape with a magnetized surface on which information can be stored by selective polarization of portions of the surface. Commonly used in CAD/CAM for off-line storage storage of completed design files or other archival information.

Management Information System - A package of software programs that enables management to obtain company, financial, or project data from the system.

Memory - Any form of data storage where information can be read from and written to. Standard memories include RAM, ROM, and PROM.

Microcomputer - A smaller, low-cost equivalent of a full-scale minicomputer. Includes a microprocessor (CPU), memory, and necessary interface circuits. Consists of one or more Integrated Circuits (chips) comprising a chip set. Ultra-powerful microcomputers with high speed and memory capacity are often referred to as "Super Microcomputers".

Microprocessor - The central control element of a microcomputer, implemented in a single integrated circuit. It performs instruction sequencing and processing, as well as all required computations. It requires additional circuits to function as a microcomputer.

Minicomputer - Traditionally a general purpose, single processor computer of limited flexibility and memory performance.

Modeling, Geometric - Constructing a mathematical or analytic model of a physical object or system for the purpose of determining the response of that object or system to a stimulus or load. First, the designer describes the shape under design using a geometric model

constructed on the system (2-d or 3-d). The computer then converts this pictorial representation on the CRT into a mathematical model later used for other CAD functions as design optimization.

Modeling, Solid - A type of 3-d modeling in which the solid characteristics of an object under design are built into the data base, so that complex internal structures and external shapes can be realistically represented. This makes computer-aided design and analysis of solid objects easier, clearer, and more accurate than wire-frame graphics.

Network- An arrangement of two or more interconnected computer systems to facilitate the exchange of information in order to perform a specific function. For example, a CAD/CAM system might be connected to a mainframe computer to off-load heavy analytic tasks.

Numerical Control (NC) - A technique of operating machine tools or similar equipment in which motion is developed in response to numerically coded commands. These commands may be generated by a CAD/CAM system on punched tapes or other storage media. Also, the processes involved in generating on the system the data or tapes necessary to guide a machine tool in the manufacture of a part.

Off-line - Refers to peripheral devices not currently connected to an under the direct control of the system's computer.

On-line - Refers to peripheral devices connected to and under the direct control of the system's computer, so that operator-system interaction, feedback, and output are in real time.

Operating System - A structured set of software programs that control the operation of the computer and associated peripheral devices in a CAD/CAM system, as well as the execution of computer programs and data flow to and from peripheral devices. May provide support for activities and programs such as scheduling, debugging, input/output control, accounting, editing, assembly, compilation, storage assignment, data management, and diagnostics. An operating system may assign task priority levels, support a file system, provide drivers for input/output devices, support standard system commands or utilities for on-line programming, process commands, and support both networking and diagnostics.

Optimization, Design - A process that uses a computer to determine the best graphic design to meet such criteria as fuel efficiency, cost of production, and ease of maintenance. In CAD, algorithms may be applied to rapidly evaluate many possible design alternatives in a comparatively short time.

Part **- (1). The graphic and nongraphic representation of a physical part designed on a CAD system. (2). A product ready for sale, an assembly, subassembly, or component.**

Part Program - A sequence of instructions used in Numerical Control, so called because because the usual arrangement is to write one program to cover the sequence of operations that one tool must perform on one part or workpiece.

Peripheral (device) - Any device, distinct from the basic system modules, that provides input to and/or output from the CPU. May include printers, keyboards, plotters, disks, tape drives, etc.

Postprocessor - A software program or procedure that formats graphic or other data processed on the system for some other purpose. For example, a postprocessor might format cutter centerline data into a form which an NC machine controller can interpret.

Preprocessor - A computer program that takes a specific set of instructions from an external source and translates it into the format required by the system. IGES can be thought of as a geometry preprocessor.

Process Planning - Specifying the sequence of production steps, from start to finish, and describing the state of the workpiece at each workstation. Recently, CAM capabilities have been applied to the task of preparing process plans for the fabrication or assembly of parts.

Product Cycle - The total of all steps leading from the design concept of a part to its final manufacture. How many of these steps can be aided or automated by CAD/CAM depends on the particular features or capabilities provided by the system.

Productivity - As applied to labor productivity, it is the physical units of output per manhour, or the dollar output per manhour.

Program - A precise sequential set of instructions that direct a computer to perform a particular task or action, or solve a problem. A complete program includes plans for the transcription of data, coding for the computer, and plans for the absorption of the results into the system.

Protocol - The rules for controlling data communication between devices in computer systems or computer networks.

Quality - See Chapter 6.

***Quality Assurance (QA)* - Denotes both quality control and quality engineering described in this appendix.**

***Quality Control (QC)* - Establishing and maintaining specified quality standards for products.**

Quality Engineering - The establishment of execution of tests to measure product quality and adherence to accepted criteria.

Random Access Memory (RAM) - A main memory read/write storage unit which provides the CAD/CAM user direct access to the stored information. The time required to access any word stored in the memory is the same for any other word.

Raster Display - A CAD/CAM workstation display in which the entire CRT surface is scanned at a constant refresh rate. The bright, flicker-free image can be selectively written and erased.

Real Time - Refers to the tasks or functions executed so rapidly (in the users perspective) by a CAD/CAM system that the feedback at various stages in the process can be used to guide the designer in completing the task. Immediate visual feedback through the CRT makes possible real time, interactive operations of a CAD/CAM system.

Redundancy - The policy of building duplicate components into a system to minimize the possibility of a failure disabling the entire system. For example, redundancy of hardware performing steps critical to the performance of a CAD/CAM facility guarantees minimum interruption of service. Redundancy also aids in maintaining continuous throughput.

Refresh (or Vector Refresh) - A CAD/CAM display technology that involves frequent redrawing of an image displayed on the CRT to keep it bright, crisp and clear. Refresh permits a high degree of movement in the displayed image as well as high resolution. Selective erase or editing is possible at any time without erasing and repainting the entire image. Requires large amounts of high-speed memory.

Reliability - The projected uptime of a system, expressed by the anticipated meantime between failures (MTBF).

Robotics - The use of computer-controlled manipulators or arms to automate a variety of manufacturing processes such as welding, painting, and assembly.

Routine - A computer program, or a subroutine in the main program. The smallest separately compilable source code unit.

Simulate **- To create on a CAD/CAM system or workstation, the mathematical model or representation of a physical part under design. Thus the behavior of the finished part under various structural and thermal loading conditions can be estimated, and design modifications made before final production.**

Simulation - A CAD/CAM computer program that simulates the effect of structural, thermal, or kinematic conditions of a part under design. Simulation programs can also be used to exercise the electrical properties of a circuit. Typically, the system model is exercised and refined through a series of simulation steps until a detailed, optimum configuration is arrived at. The model is displayed on a CRT and continually updated to simulate dynamic motion or distortion under load and stress conditions. A great variety of materials, design configurations, and alternatives can be tried without committing any physical resources.

Software - The collection of executable computer programs including application programs, operating systems, and languages.

Source - A text file written in a high level language and containing a computer program. It is easily read and understood by people but must be compiled or assembled to generate machine-recognizable instructions. Also called source code.

Storage - The physical repository of all information relating to products designed on a CAD/CAM system. It is typically in the form of magnetic tape or disk. Also called memory.

Storage Tube - A common type of CRT which retains an image continuously for a considerable period of time without redrawing (refreshing). The image will not flicker regardless of the amount of information displayed. However, the display tends to be slow compared to raster scan, the image is rather dim, and no single element by itself can be modified or deleted without redrawing.

System (CAD / CAM) - An arrangement of CAD/CAM data processing, memory, display and plotting modules, coupled with appropriate software, to achieve specific objectives.

Task - (1). A specific project which can be executed by a CAD/CAM software program. (2). A specific portion of memory assigned to the user for executing that project.

Text File - A file stored in the system in text format which can be edited and printed on-line as required.

Tool Path - Centerline on the tip of an NC cutting tool as it moves over a part produced on a CAD/CAM system. Tool paths can be created and displayed interactively or automatically by a CAD/CAM system or even through software programs, and reformatted into NC tapes by means of a postprocessor, to guide or control machining equipment.

Turnaround Time - The elapsed time between the moment a task or project is input into the CAD/CAM system and the moment the required output is obtained.

Turnkey - A CAD/CAM system for which the supplier/vendor assumes total responsibility for building, installing, and testing both hardware and software, and the training of user personnel. Sometimes erroneously called standalone, which implies more to system architecture.

Utilities - Another term for system capabilities and/or features which enable the user to perform certain processes.

Vertical Integration - A method of manufacturing a product, such as a CAD/CAM system, whereby all major modules and components are fabricated in-house under uniform company quality control and fully supported by the system vendor.

Workstation - The work area and equipment used for CAD/CAM operations. It is where the designer interacts (communicates) with the computer. Frequently consists of a CRT display and an input device and possibly a digitizer and hardcopy device. In a distributed processing system, a workstation has local processing and mass storage capabilities.

Write - To transfer information from the CPU main memory to a peripheral device, such as a mass storage device.

Appendix C
CAD/CAM Usage/Performance Survey

1. What is the nature of your business (i.e. automotive, zinc die-casting, aerospace airframes)?

2. What is the current status of technology (its level of advancement) at your site related to Computer-Aided Design and Manufacturing (CAD/CAM)?

3. How large is your installation in terms of employees and business volume?

   What percentage of CAD/CAM users are not specifically in the CAD/CAM department?

   What are the percentages of engineers/draftspersons/technical assistants/non-technical users on the system (of the company as a whole)?

4. **If CAD/CAM technology is not available at your facility, what is hindering its implementation?**

Cost?

Lack of research or interest?

Management focus is not technology directed?

Current methodology is sufficient?

---

5. What are the future expectations, regarding CAD/CAM technology at your company?

---

6. Is your technology customer driven or market driven? By this I mean is CAD/CAM a necessity for competing in your markets, or has it become the norm to deal with target customers regarding your product/services through modern technology such as CAD/CAM?

---

7. In terms of CAD/CAM, what type of performance was expected (gains in productivity, capabilities to manufacture more complex products, expanded markets, etc.) compared to conventional or previous methods?

---

8. What were these expectations based upon?

---

9. Did vendor quotes and benchmarking influence CAD/CAM system selection and how?

---

10. How deeply was CAD/CAM researched at your company or division prior to purchase (from a technical and business perspective)?

---

11. Are there any satellite divisions in your company which had prior CAD/CAM experiences to draw from?

12. **In regard to the future direction of technology implementation or upgrading at your facility, is your management team supportive and enlightened on the subject? Explain.**

13. Is your business becoming less diverse, less job-shop oriented, and now aimed at large scale contracts (if applicable)?

14. Is your CAD/CAM system monitored for performance (quality issue):

    Are any systems currently in place for the measure of (quality) performance and what are they?

    Are system reviews held on a regular basis and by whom?

    How is it determined if existing hardware/software is not performing to expectations?

    Are the system users proficiencies monitored?

    Where are bottlenecks recognized and where have they been eliminated?

Has the amount of engineering change orders and/or reworks decreased markedly as a result of CAD/CAM and has your engineering staff been freed to concentrate on more critical tasks?

---

15. Is your firm seeking a CIM approach to manufacturing operations or is CIM not realized or necessary (Computer Integrated Manufacturing)?

---

16. Is the issue of "Quality" permeating throughout your operations and is CAD/CAM system quality considered in this focus?

---

17. Was finding CAD/CAM personnel a problem or was expertise successfully "home grown"?

---

18. Was and is system management a key area of the system success? Explain.

19. Would you consider or have you considered a consultant to help achieve the transition toward CAD/CAM implementation?

20. In regard to system customization, is it in-house developed, third party developed, or vendor specific customization?

21. Did the possibility of multiple CAD/CAM systems emerge as a result of your experience with only 1 vendor as a means of improving system quality or related issues?

22. Is the CAD/CAM system located in a strategic location in the plant environment, or was its location dependent on available floor space constraints?

23. How does your company define "quality"?

---

24. Rate your CAD/CAM system (0-100) on the following categories:

Price/Performance:

Reliability:

Ease of use/Learning curve:

Acceptance by Engineering:

Acceptance by Management:

Acceptance by Manufacturing:

Minimum trouble with vendor software/hardware upgrades:

Ability to customize:

Transportability of data to/from customer:

---

25. Is your CAD/CAM system a success or failure *(circle one)* based on the:

Business objectives of your company?

Quality improvement objective?

Manufacturing and engineering objectives?

---

26. Based on your experiences, what would your company do differently now if given the opportunity to research and install a CAD/CAM/CAE system at your facility from scratch? Please attach extra sheets if necessary.

Please complete the following:

Name: ______________________________

Company: ______________________________

____

Title: ______________________________

Appendix D
Departmental CAD/CAM Survey

SECTION ONE: DRAWING STATISTICS

1. What are the total number of current drawings? (This should include manual and any computerized system).

   Designed Parts ________
   Assemblies ________
   Purchased Parts ________
   Reference Dwgs. ________

2. What are the total number of current drawings by size?

   "A" ________
   "B" ________
   "C" ________
   "D" ________
   "E" ________

   Parts List ________ Other ________

3. How many new drawings are released yearly regardless of size or complexity?

   ____

4. Are the parts list(s) of materials made part of assembly?
   Comment: ________________________________

5. Do you have different drawings which might fit into a given shape but have different dimensions? (Check One)
   Yes _____ No _____

   Does this frequently happen?
   Yes _____ No _____

6. Do you have drawings with several parts on one drawing with dimensions in a list (tabulated drawing)?
   Yes _____ No _____ Quantity _____

7. Attempt to categorize all new drawing releases (yearly) by the following. Note: these categories represent different "slices" of the same data.

   Total number of drawings by size:

"A" __________
"B" __________
"C" __________
"D" __________
"E" __________
"Roll" __________
"Other" __________

Total number of drawings by complexity:

Simple Casting __________
Complex Casting __________
Simple Tooling __________
Complex Tooling __________
Machined Piece Part __________
Simple Assembly __________
Complex Assembly __________
Purchased Part __________
NC drawing __________
Other __________

9. What amount of time per drawing is spent filling in forms or entering data into a mechanized system?

____

10. In order to evaluate the types of drawings you require, please indicate with a "yes" or "no" whether you prepare the following types of drawings. Please also try to indicate where the highest proportion of activity occurs either as a %, or by the total quantity in each category.

Architectural "Takeoff" __________
General Product Layouts __________
Structural __________
Piping __________
Electronic __________
Castings __________
Forgings __________
Machined Assemblies __________
Purchased Parts __________
Other __________

11. Do you prepare piece part drawings as individual drawings, or do you detail parts on the assembly drawing for which they are required?

____

12. If estimates have been difficult, also try estimating hours and cost of drawings as follows: Estimate

engineering total cost for preparing a "small" ("A & "B) size and a large (all others) drawing. Include overhead and total hours.

Small Drawing	**Hours ______**	**Dollars ______**
Large Drawing	**Hours ______**	**Dollars ______**

SECTION TWO: ENGINEERING CHANGES

Estimate the following hours or dollars required to make changes:

Total Changes Yearly ___________

Total Changes Affecting Revision Level Only
Hours ___________ Dollars ___________

"Minor" Changes
Hours ___________ Dollars ___________

"Major" Changes:
Hours ___________ Dollars ___________

2. Identify the reasons for change and the quantity for each on a yearly basis:

New Industrial Standard ___________
Customer Service ___________
Value Engineering ___________
Product Improvement ___________
Customer Request ___________
Manufacturing Adjustments ___________
Product Development ___________
No Reason Listed ___________
Other(s) ___________

SECTION THREE: MANPOWER

1. What is the total engineering manpower being considered in estimating costs for this questionnaire?

Administration (# of persons and avg. cost/hour)

Supervisory Persons	_______	**Avg.** Cost/Hour	_______
Project Engineering Persons	_______	**Avg.** Cost/Hour	_______
Design Engineering Persons	_______	**Avg.** Cost/Hour	_______
Tooling Engineering Persons	_______	**Avg.** Cost/Hour	_______
Layout and Drafting Persons	_______	**Avg.** Cost/Hour	_______
Engineering Services Persons	_______	**Avg.** Cost/Hour	_______
Cost Estimating Persons	_______	**Avg.** Cost/Hour	_______
NC Persons	_______	**Avg.** Cost/Hour	_______
Other Persons	_______	**Avg.** Cost/Hour	_______

(Explain) ____

Total Persons _______ Total Hours _______

2. How many hours are used and what is the cost to prepare engineering changes yearly?

Revision Level Changes
Hours __________ Dollars __________

"Minor" Changes
Hours __________ Dollars __________

"Major" Changes
Hours __________ Dollars __________

SECTION FOUR: CLASSIFICATION

1. **Do you have a classification system?**
   Yes ____ **No** ____

2. **Please Describe:**

   ____

   ____

3. **How many inquiries are made yearly?** __________

4. **How many retrievals of similar parts are made?** __________

5. **How many identical parts are found?** __________

6. Do you utilize a computer in this system? __________

7. Do you have "tabulated" drawings? __________
   If "yes", how many? __________

8. Do you have "family" or "format" drawings? __________
   If "yes", how many? __________

9. Does the quality of current blueprint copies cause extra drafting labor? Yes _____ No _____

10. Are original drawings misplaced or not kept up-to-date? Yes _____ No _____

11. Do you have a microfilm system? Yes _____ No _____

12. Do you have a microfiche system? Yes _____ No _____

13. Are you considering implementing a classification system? Yes _____ No _____

SECTION FIVE: MANUFACTURING

The following questions are needed to augment design costs and to establish the total costs for issuing a new part or assembly.

1. **Total active routings?** __________

2. **Total new routings yearly?** __________

3. **Total changes to routings?** __________

4. **Avg. size of production orders issues to shop?** __________

5. **Total orders with a quantity of one issued to the shop yearly?** __________

6. Total production orders issued yearly? __________

7. Could a family of parts assist in creating a family routing and reduce manufacturing time?
   Yes _____ No _____

8. Total new casting patterns yearly? __________

9. Pattern costs? __________

10. Total tool design costs yearly? __________

SECTION SIX: NUMERICALLY CONTROLLED MACHINE TOOLS:

1. Attach a list of tools including name and type. (Including Coordinate Measuring Equipment)

2. Identify total parts per year machined on each.

3. Indicate efficiency of NC vs. manual tools.

4. What percentage of potential NC applications are now on such equipment?

5. Identify data preparation time per part as follows:

   Standard Sequencing and Tooling _____ _____
   Enter Geometry _____ _____
   Generate Tool Path _____ _____
   Verification (plots) _____ _____
   Others _____ _____

6. Identify average order size and/or frequency of such order sizes over each N/C machine tool.

SECTION SEVEN: DESIGN ANALYSIS

1. **Attach a list of design applications including the following:**

   Title.

   Brief Abstract.

   Cost per Year to Operate.

   Priority or Importance.

   Man Hours in Preparation.

   Mode of Operation (i.e. on-line, batch).

   Computer Used.

   Remote or Local.

   Number of Runs Yearly.

2. **Which are these applications do you feel might lend themselves to integration with CAD, such as die and tooling design?**

3. **Are any of the applications integrated with CAD or NC machine tool centerline cutter data now?**

4. **What data base, if any, do you use in design analysis techniques?**

5. **What is the total manpower and classification of persons who work in the design analysis activity?**

VITA

STEPHEN K. DEUTSCH

Born: December 23, 1959, Fountain Hill, PA

Father: Charles A. Deutsch

Mother: Dorothy A. Deutsch

EXPERIENCE:

CAD/CAM Software Engineer, General Dynamics Data Systems Division, Fort Worth, TX from 7/84 to 8/87.
Developed manufacturing algorithms and code for automation software for Numerically controlled systems. Utilized CADAM System and Geometry Interface Module with FORTRAN and Assembler coding to automate sheet metal and wing spar part generation.

Research Assistant, Lehigh University, Bethlehem, PA. from 8/87 to present.
Involved with Ben Franklin Partnership technology project to implement CAD/CAM at a local die-casting company. Am helping develop an expert system for die-casting cost estimation.

Primary CAD Designer, Fuller Company World H.Q., Allentown, PA. from 10/79 to 12/81.
Involved in mechanical, schematic, and plant design for material processing industry via Applicon 2-d and 3-d CAD. Also developed specific CAD applications, trained new users, and periodic system management.

Summer employment at P.B.and N.E. Railroad, Bethlehem, PA. 1978, 1979

EDUCATION & ACHIEVEMENTS:

B.S. in CAD Graphics Technology, Brigham Young University, Provo Utah, 5/84. **GPA 3.2/4.0**

AAS in Architectural Technology, Northampton County Community College, Bethlehem, PA., 6/79. **GPA:3.25/4.0**

Attended **Pennsylvania State University**, Fogelsville, PA. from 12/81 to 6/82 (2 terms).

Phi Theta Kappa Honor Society, Moravian College Language Recital Award, Dean's List 3 semesters undergrad. Lehigh University research

assistantship for MSE program.

STUDENT AND PROFESSIONAL ACTIVITIES:

Vice President of the HTC Club at BYU

Student member National Computer Graphics Association at Brigham Young University

Student Graduate Council Representative for Manufacturing Systems Engineering at Lehigh

Conferences Attended: CAM-I, AUTOFACT, CUE, Lehigh MSE Seminar Series