ABSTRACT

Computer Aided Manufacturing for Production Environment

by
Biren K. Parikh

Investments in new technology like Computer Aided Manufacturing (CAM) increased in the past few years because of the foreign competition in the world market as well as on the home ground. Improper investment in CAM and CIM resulted in the "Islands of Automation" instead of an integrated system. These "Islands of Automation" have created new problems for production planning and factory communication.

The objective of the thesis is to develop the methodology to selection and implementation of the CAM system in the production environment. It is to be noted that a CAM system is part of the overall CIM implementation, so integration of CAD with CAM is the important part of the methodology.

In the thesis, an effort has been made to develop a CAM system by using a Quatro Pro package. The program is initially developed for a shaft manufacturing system, but with minor alterations and a proper database it can be used for other applications as well. It is a process planning program which can retrieve the drawing on each terminal on the shop floor. Use of this program can reduce the engineering alteration time, in-process paper work, improve communication, and quality of product.

COMPUTER AIDED MANUFACTURING FOR PRODUCTION ENVIRONMENT

by
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Computer Aided Manufacturing for Production Environment

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CHAPTER 1
INTRODUCTION

Computer Aided Manufacturing (CAM) can be defined as the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources. The term CAM is not used consistently; sometimes, CAM refers simply to the control of computerized conveyance, storage and production machines. Other times, it is defined very broadly to include production control functions, such as production planning and control concept.

American manufacturing companies are investing in CAM technology to increase productivity and to enhance their competitive position in the world market. However, only investing in the new technology cannot be the answer to Japanese and Germans. Japanese are investing in these same technologies but are implementing them more effectively and efficiently and thus, achieving greater productivity.

In definition CAM refers to a process where computer technology is applied to the manufacturing processes of a product for better profit. Unfortunately, CAM is implemented piece by piece in existing manufacturing facilities to minimize production loses. This results in the development of series of "Islands of Automation" rather than an integrated system, and in some cases this is a desired case. When implementing CAM technologies, companies must understand the need to review the current organizational structure and operating procedures, making the necessary modifications to bridge the gap between automation and CAM systems. Some examples of CAM system functions are:

* Numerical Control Part Programming by Computers
* Computer Automated Process Planning
* Computer Generated Work Standard
* Production Scheduling
* Material Requirement Planning
* Shop Floor Control

This thesis primarily deals with the implementation of computer aided manufacturing system into a production environment, along with the CAM program developed using macros of Quatro Pro.

CHAPTER 2
DEFINITION OF THE PROBLEM

It is known that there are many different CAM systems on the market today, and no one system is the best for all applications of manufacturing phases. Investing in the most expensive system available in the market will not be the solution for productivity needs. Companies have to understand the need of system selection strategy well in advance before they can plan to invest in the type of CAM system.

The CAM system is the main investment in computer integrated manufacturing(CIM). Though there is an increase in the investment of CIM technologies, many companies are failing to achieve the maximum benefits which they could get from these systems. This can be attributed to the lack of an enterprise-wide strategy for selecting, implementing, and evaluating computer based systems. Following are the problems associated with the CAM systems implementation:

2.1 Communication Gaps Between Major Functions

Traditionally, a manufacturing enterprise has been divided into four major functions: business system, engineering system, production system, and human resources system. These systems have been further fragmented into many divisional and departmental systems. To achieve maximum profit, it is important to maintain smooth communication flow between departments. In many cases, the traditional separation between design and manufacturing is extended into the computer age. A factory communication system should permit all the facility's industrial devices such as NC, weld controllers, robots, vision system, and to communicate with one another and the computer equipment . Two main problems of communication are: (1) How can these devices be made to communicate with each other? (2) How can we avoid a failure to communicate?

2.2 Management Training

CAM is an integrated environment affecting many people. The success and failure of the system can hinge on the strength and adequacy of the training,along with the support given by top management. All persons involved must be trained concerning how the system will help them, and what their role is in the system. Computer technology advances at such a rapid rate that many managers have not been properly educated in the application or management in computer assisted methods. Training is needed throughout the organization. Top executives reviewing organizational plans for computer and communications systems need to have technical expertise to make intelligent decisions. Middle managers need to learn how to manage in the new environment because they will have the responsibility for making sure the use of the system is successful. End users need to learn CAM concepts and how to use specific computers, applications, and on-line services. In order to utilize computerized systems more effectively, management commitment, foresight, and willingness to learn are most needed.

CHAPTER 3
PROBLEM SOLUTION APPROACH

The solution of the problem lies in the CAM system selection, implementation, and evaluation. In order to achieve the success of the CAM system, we should concentrate on the following areas:

- **System Selection**
- **System Implementation**
- **System Evaluation**
- **Design and Development of Customized CAM System**

The first portion of this theory addresses to the CAM system selection process. The selection process includes the assessment of automation needs to ensure an appropriate system selection along with the planning of CIM. The last part of system selection deals with establishing a system evaluation criteria and a benchmarking procedure.

The second portion of the theory is the implementation procedure of the system within the CIM network. The system planning and organizing functions are associated with responsibilities of management. The facility planning deals with site selection, system layout, and system environment. The major portion of the implementation phase lies in the development of standard practices and procedures to facilitate effective utilization of the CAM system. Company practices and procedures must be modified to reflect these changes in order for the implementation to be successful. [1]

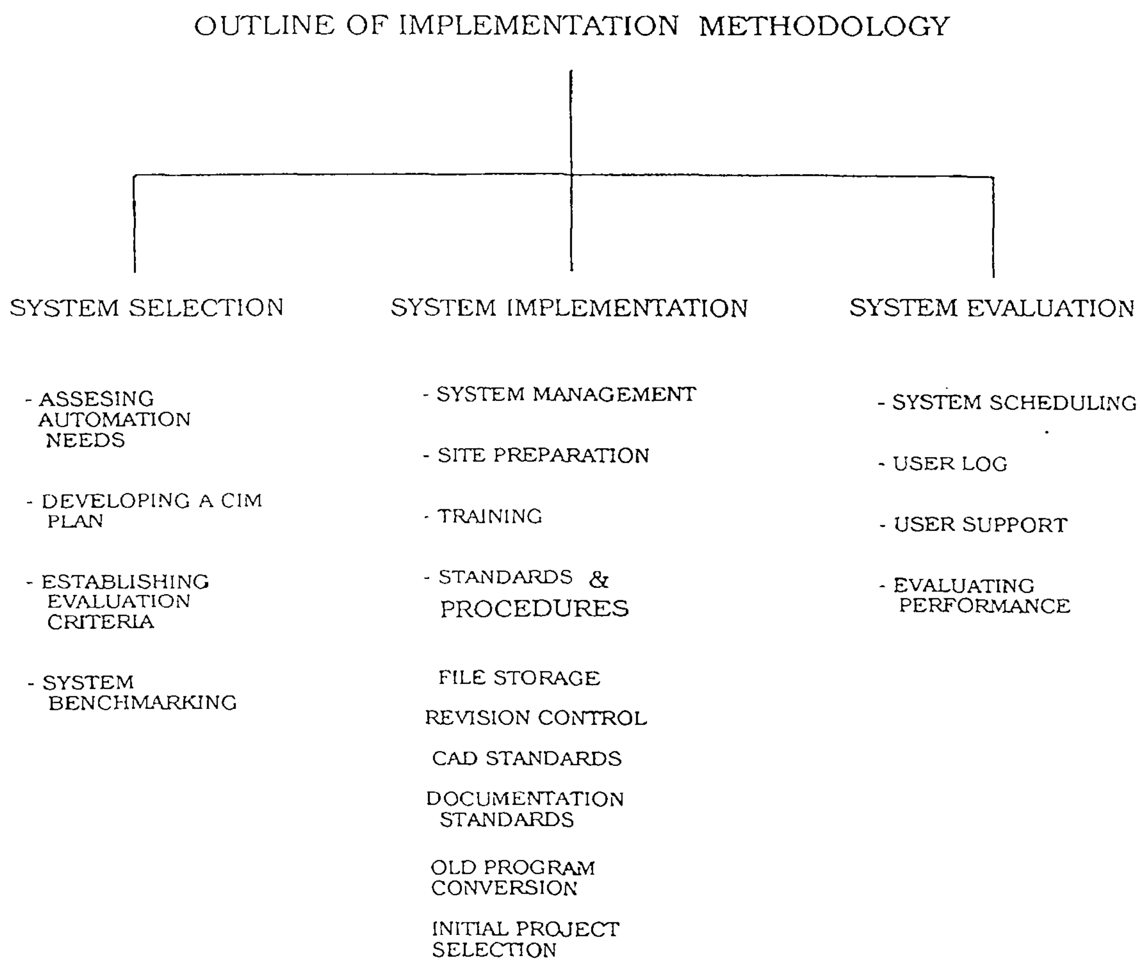

Figure 1 Outline of Implementation Methodology

The third portion of the theory deals with evaluating the CAM system. Productivity is the greatest concern to many users of the CAM system. The subject of evaluation of the CAM systems and productivity associated with this technology has been elusive.

In the last portion of the theory, we will discuss the design and development of a customized CAM system, along with a case study of the shaft manufacturing system. The design of the CAM system database includes the sets of requirements and relationship between those requirements.

CHAPTER 4
SYSTEM SELECTION

This chapter will outline the selection procedure of the CAM system. The theory for the system selection can be broken down into the following efforts:

1. What to Automate?
2. Planning for CIM
3. Evaluation Criteria
4. System Benchmarking

The main efforts for the system selection are 1 and 2. The other two efforts (3 and 4) are minor.

4.1 What to Automate?

The problem of deciding what to automate is one of function allocation. That is, given that the system must perform certain basic functions, which one should be performed by a machine and which should remain a job for the human operators? There are two extremes, one side is the manual process and the other side is completely the computer operated process. The planner's problem is picking a point along a continuum between these two extremes.[3]

The important thing to remember is that just because we can automate a given function, it is not necessarily true that we should automate it. In addition, this problem varies from company to company. This means there is no standard to designate which functions should be automated. Following strategic steps may identify the function to be automated:

4.1.1 Operational Requirements and Constraints

Operational requirements such as how fast, how high, how often, how accurate, etc. are required to accomplish this mission. It is important to realize that the derivation of operational requirements is not always easy and does not necessarily flow naturally from the stated purpose of the system. One might take the approach of specifying some operational requirement in terms of "as much as possible". The utopian safety design may not be an actual requirement. In most cases, there is an acceptable minimum amount of some requirement which can be specified.

Once operational requirements have been specified, we have the criteria by which the performance of various design options can be evaluated. However, we have to remember real-world restrictions place limitations on what we can or cannot build. In other words, operational constraints deals with how soon we need it, how much we can pay, what technology is available, who must be able to use it, etc.

Taken together, operational requirements and constraints yield the yardsticks by which our systems are measured. Any system must meet the criteria. Once the criteria is selected, the next step is to perform the AS-IS analysis on the function to be automated.

4.1.2 AS-IS Analysis

Complete AS-IS Analysis includes:

* Understand the Information Flow
* Understand the CAM Modules
* Identify Critical Success Factors
* Identify the Business Planning Tasks

The current information flow of the operation to be automated must be fully understood. This includes the way information is received and released, as well as, the flow within the particular operation. The analysis will highlight any barriers to automation which must be considered in the decision to automate. It will also pinpoint requirements for the system to successfully integrate into an existing company-wide information network. The study of current information flow and how it will be affected by the implementation of computer aided methods will be very useful during the restructuring of the staff organization to manage the new technology.

The analysis approach should be based on critical success factors. These factors are a limited number of activities where "things must go right" for the organization to succeed. Consequently, they represent areas of activity that demand constant and careful monitoring by management.

The crucial alternative which arises at this juncture is the option to implement a relatively simple module or a fairly tough one. The following activities need to be considered: [4]

* A well thought-out project management plan reflecting time schedules, manpower, and resources.

* Education and training requirements to properly implement any module.

* A comprehensive decision-making framework.

* Identification of the key individual to drive each project.

* Determination of improvement potential candidate:

-short-term

-long-term

* Determination of improvement potential by work function.

* Development of a ranking criterion to prioritize.

* Risk analysis.

* A thorough understanding of cost relationships.

In short, the output of AS-IS analysis should provide a clear understanding of manufacturing facilities under consideration, its strengths and weaknesses. The driving force of the organization's productivity and efficiency should be identified.

4.1.3 NEED-TO-BE Analysis

In this step it is necessary to determine the improvement alternatives, and identify a wish list of candidate technologies which would complement the strategic goals of the business. At this point the decision will normally impact one of the eight strategic functions. Those are:

Facility

Capacity

Direction of Capacity Integration

Production Technologies

Work Force

Quality

Materials and Production

Organization

Improvement alternatives, such as material management, technology processes, production management, and improved information systems are possible candidates for implementation. When appropriate modules are identified and prioritized in such an organized and planned manner, the risk of complete or partial failure at the implementation stage is significantly reduced.

4.2 Planning for CIM System

A CIM planning system may vary from company to company. Strategic planning for CIM requires teamwork throughout the company or enterprise. There should be three levels of team management [7]:

Executive Management Team.(EMT)
Functional Management Team.(FMT)
Operational Management Team.(OMT)

The goals and actions of the teams should be such that they provide the stimulus to generate interest and motivation, provide resources, and show management commitment to the implementation of the CIM program. These management teams bring together work groups to support their responsibilities.

4.2.1 Executive Management Team

The EMT is a strategic management team who has the responsibility of guiding the enterprise toward the common goal of the CIM system. The EMT should be highly visible in CIM actions of subordinate management teams. They should also be active in setting the proper environment for a CIM program, providing encouragement, and assuring management's commitment and support for the CIM program.

4.2.2 Functional Management Team

The FMT is a CIM tactical management team. The FMT should be under the leadership of a major functional manager. The FMT has the responsibility of guiding each major function to the common goal of CIM. This level of team manager assigns the most capable persons to CIM projects, selects leaders of action teams, and is active in the process of building the team. The FMT is highly visible in interfunctional issues, such as communication, database, operational and multifunctional actions. It has a good perspective on the automated systems of the various departments and their relationship with neighboring departments.

4.2.3 Operational Management Team

The OMT is the third layer in the team management structure. One of the primary responsibilities of the OMT is to motivate people at the operational level and get everyone involved. Other involvements are to seek suggestions for improving specific tasks or systems, to encourage employees to become action teams and to allow for them to become team leaders, and to provide training on new CIM before and after the formation of action teams.

This approach to planning CIM was placed in three levels to reflect the management levels of the enterprise. This technique provides for greater functional participation, controls, and integration.

4.3 Establishing Evaluation Criteria

The information gathered from the first two efforts, the functional management team can begin to develop specific evaluation criteria to select a CAM system. Using the knowledge gained at seminars or trade shows, the FMT can establish an initial list of approximately ten vendors that can fulfill the identified automation needs and meet the basic criteria established in the CIM plan. This list is often referred to as the long list.

The next step for the functional management team is to develop a technical specification that will describe specific functional requirements and capabilities of the systems to be proposed by the vendors on the long list. Again, the knowledge obtained during the research stage should be used to complete this specification. Preparing a technical specification is an important part of the CAM system selection process that serves many purposes. The first and most obvious purpose is that it can be used to solicit system proposals from the vendors on the long list. The vendors will be more than happy to receive a well written technical specification because it signifies that they are dealing with an educated customer and half of their sales effort has been completed for them. Preparing the specification can also be thought of as part of the educational process, in that, it makes members of the task force more aware of current capabilities of CAM systems and the required characteristics necessary for the system to perform effectively in their operation environment. Finally, the technical specification is used as a guide during the development of the system benchmark.

However, when preparing the technical specification it is important not to become too detailed. Vendors find specifications tiresome and will often ignore them when submitting a proposal. The specifications should be written in a simple and concise manner describing the compan's needs. These methods will be evaluated at the system benchmark. Once the technical specification is complete, it should be submitted to all vendors on the long list simultaneously, giving them sufficient time to prepare for the system proposals. A functional management team member who is well versed in CAM technology should be selected as the vendor contact to answer any questions that will arise during the vendor's review of the specification. The following list gives a typical technical specification which can be described by the vendor.

Technical Specifications for CAM system:

1. Intended System Use
2. Current Methods of Operations
3. Anticipated Method of CAM System Operation
4. Software Requirements
5. Hardware Requirements
6. Maintenance Requirements
7. Training Requirements
8. System Warranty and Acceptance Requirements
9. Vendor Objective Statement

4.4 System Benchmarking

The process of benchmarking systems should be very straightforward after the first three steps are successfully completed. The functional management team should narrow down the long list to approximately five potential vendors after the proposals are returned by the vendors. This is commonly referred to as the short list.

The functional management team must now prepare a benchmark as a final evaluation before making the system selection. A benchmark should be performed even if there is only one vendor on the short list to confirm the system's capabilities. The benchmark should be reasonably difficult but should not require an excessive amount of time. It is important to keep in mind that the purpose of the benchmark is to test the system, not to operate the system. Therefore, the evaluation team should be concentrating on the following:

•User Interface

•Menu or Command Structure

•File Structure

•Ability to Grow and Customize the System

•Hardware Capabilities

•Maintenance Requirements

•State of Technology

Based on the information gathered from technology publications and trade shows, the evaluation team must determine if the vendors hardware and software is current with the state of the art computer technology. They must also evaluate the vendors commitment to update system capabilities to remain current with the ever changing state of computer technology.

The functional management team should make it clear to the vendors on the short list, that one of the requirements of the benchmark is to perform the system on the same system configuration that was listed on the vendor's proposal. The vendors are naturally going to want to demonstrate their software on their fastest computer and their flashiest workstation.

This trends to bias on the evaluation because the operator will try to impress the customer with the capabilities of the advanced hardware, and the customer assumes that the hardware mentioned in the proposal has the same capabilities. Figure 2 shows the system evaluation chart for comparison of different systems. This is an effective way of matching system capabilities with company needs during a benchmark.

After benchmarking the systems on the short list, members of the functional team should visit customer sites of the vendors they were most impressed with. [5] The vendor should be more than willing to let you visit a

SAMPLE SYSTEM EVALUATION FORM

SYSTEM CAPABILITIES	WEIGHT (0-1)	SCORE (0-1)
USER INTERFACE - EASE OF USE - DISPLAY QUALITY - MENU/COMMAND STRUCTURE - ON-LINE HELP	.7	6
SYSTEM FUNCTIONS -TOOLPATH GENERATION - MACRO CAPABILITIES - POST PROCESSORS - DATA BASE STRUCTURE - MAINTENANCE REQUIREMENTS	1.0	.8
SYSTEM TRAINING - TRAINING AVAILABLE - ABILITY TO CUSTOMIZE	.9	4
INTEGRATION - ABILILTY TO INTERFACE WITH EXISTING AND FUTURE SYSTEMS	.8	8
STATE OF TECHNOLOGY	.9	7
VENDOR SUPPORT	.7	3

TOTAL = (WEIGHT) (SCORE) <u>30.6</u>

Figure 2 Sample System Evaluation Chart customer site. If not, this should raise some serious questions about the vendor's level of customer satisfaction. Visiting a customer site provides an excellent opportunity to investigate the vendor's customer service record and get some ideas on system implementation.

Once this has been completed, the evaluation team is ready to make an educated decision on a CAM system selection. After the final selection has system evaluation been made, the company should try to negotiate a payment plan that spreads out over the length of the implementation period. The payments will be contingent on the satisfactory installation and start up of the system. This will make it easier for the company to maintain the vendor's support during the inevitable problems that occur during a system start up.

CHAPTER 5
SYSTEM IMPLEMENTATION

The first computers commercially available in the 1950's were large expensive machines that were hard to use and manage. These machines were initially purchased to perform data processing operations. Management Information Systems/ Data Processing (MIS/DP) groups evolved to manage these large computer systems and became the central suppliers of computing services to the corporation. Problems developed as different functional groups within the organization began to compete for computing resources. [6]

With the development of the minicomputer in the 1970's, the functional groups within companies began purchasing minicomputers dedicated to their specific needs. As the cost of computer hardware continued to decline, more and more departments invested in computer solutions customized to meet their specific functional requirements. [6] This lead to "Islands of Automation" that exist in many organizations today. These "Islands of Automation" pose a new problem to the corporation, that of integration. Most often the systems purchased by the individual groups consist of dissimilar hardware and software, making the transfer of information between the systems difficult and inefficient. In addition, each of the individual systems developed a unique database which often contained redundant information. Without an effective means of transferring information between systems, the main purpose of CIM "improved communication" will be defeated. [7]

The successful implementation of the CAM system is the primary concern of the system manager whose responsibilities will range from site preparation before installation to monitoring system performance after implementation, highlighting the changes that must be implemented on a functional level to effectively utilize the new system. This methodology covers the following areas:

1. System Management
2. Site Preparation
3. Training
4. Standards and Procedures

5.1 System Management

Before the system is installed, a strategy for managing the new computer system should be resolved. The manager of the system will be responsible for scheduling and allocating systems resources, maintaining the system (system backup, database management), establishing standard procedures for system use, and monitoring system performance. The following section discusses two possible management strategies to accomplish this task, functional management and management information systems/data processing (MIS/DP).

5.1.1 Functional Management

A functional management strategy would require that the system be managed by the functional departments (i.e., Engineering , Manufacturing). Functional managers would have a much better understanding of the requirements that the system must fulfill and how it must interface to other computerized and non-computerized operations within the company. This knowledge will better enable them to establish standard procedures for effective system operation. In addition, department managers will be more aware of project deadlines allowing them to reschedule system resources to meet critical deadlines. With a better understanding of the functional task, it will be easier for department managers to monitor system productivity and spot inefficiencies. A weakness of functional management strategy would be the task of system management which includes performing system backups, managing the database, solving system problems, etc. On older and larger computer systems, this can be a complex and time consuming task. However, as computer systems have developed, they have become much easier to maintain, simplifying many of the above tasks and decreasing the amount of skill and effort required to maintain them. [8]

5.1.2 MIS/DP Management

This strategy is most often used by large companies that employ mainframe computer systems to support many users on-site as well as at remote sites. The task of managing systems such as these, which have large complex databases, require a full-time MIS/DP group. In this situation, it would be more efficient to have the MIS/DP group manage the CAD/CAM system rather than duplicate their knowledge and experience at the functional level. It is important for the MIS/DP group to work in close interaction with the functional groups they support, in order for this strategy to be successful.

Other than the situation just described, a functional management strategy is the preferred way to implement and manage a CAD/CAM system. This is due to improved user friendliness of new computer systems and the trend toward a distributive CAD/CAM strategy. In the near future, design and manufacturing engineers will have desktop computer systems, minimizing the role of maintenance on intensive large central host computers.

5.2 Site Selection and Preparation

Every major interactive graphics vendor can supply with an installation guide(e.g. site preparation guide or an installation guide). These guides provide detailed vendor-specific information needed for planning and preparing site for the graphics equipment that has been selected. This includes information on site considerations, environment conditions, electrical requirements, and even helpful hints. The system manager must sit down with vendor technicians a few weeks prior to system delivery to determine the site installation requirements. In this meeting, they should discuss on the system and the operation environment necessary for the computer installation. The considerations for typical system facility planning are as follows:

5.2.1 System Environment

A controlled and monitored environment for the CAM system is necessary to assure accurate and reliable flow of data and information among the system's components. The main consideration is temperature variation or gradient. On any CAM equipment, the gradient should not exceed the level given in the site preparation guide, normally 10ºF per hour. Also airborne particles in the form of dust, smoke, or grease should not exceed that of a normal office environment.

5.2.2 System Layout

There are many variations of system layer as there are business systems. Also there are as many advantages to each layout as there are disadvantages. However, one fact is constant; the central processing unit and disk unit must be in a controlled environment.

The first major consideration is the location of the CAM system. Whether the system is centralized or the workstations are scattered in remote locations, they should be readily accessible to all users with minimum use of time and travel. Thus, the system or workstations should be placed in an easily accessible central location.

5.3 Education and Training

The increasing number of people using CIM creates a tremendous training and education task for the organization. Education is needed throughout the organization. Top executives reviewing organizational plans for computer and communications systems need to have enough technical expertise to make intelligent decisions. Middle managers need to learn how to manage in the new technological environment because they will have the responsibility for making sure the use of the system is successful. End users need to learn CAM concepts and how to use specific computers, applications, and on-line services. Therefore, the education of employees across the organization becomes essential. Users and their managers assume more responsibility for the funding, justification, development, and use of CAM. The system department plays a coordinating, supportive, and standard-setting role as part of its responsibility to build and maintain the technical infrastructure for the system. The training should take place in three levels:[7]

* Executive Management Training
* System Management Training
* User Training

5.3.1 Executive Management Training

Top-level policy-setting executives must understand the nature and ramifications of information technology to make the proper decisions for their organizations. A good understanding of CAM technology, derived from a coordinated education program, will give executives the ability to make the informed decisions necessary to guide their companies in today's technology-driven world. Executives knowledge about computers and communication technologies will enable them to make wise decisions when allocating resources, planning, setting technological direction, and evaluating.

This training should also be attended by the system managers. The training should consist of a one day class in which a vendor representative or a third party consultant would explain how the CAM system will modify current business practices, and discuss the changes that must be effected to insure a successful implementation. More importantly, this class will establish realistic expectations on the part of management with respect to productivity improvements and make them aware of the typical start up problems that occur. This training will prove well worth the cost during the implementation process.

5.3.2 System Management Training

Systems Executives play an important role in the successful implementations of CAM. They can nurture or destroy a new system, consciously or unconsciously, by their support or resistance. Therefore, they need to become familiar with the risk and problems of new systems in their organization. They must make sure that their subordinates' jobs, health, and safety needs are met by the new system as part of managing the transition from the old to new.

This training can take place at the vendor or customer site and should be attended by the system manager and his chosen backup. It is better to have this training take place off-site so that the class will not be disturbed by on-going business interactions. If this training is done off-site, it should take place no more than one week before the installation. If the training is done on-site it should take place as soon as possible after the installation. The class will consist of 3 - 4 days of training on the following concepts:

Operating System
File Maintenance
Backup Procedure
Plotting Procedure
System Security

5.3.3 User Training

A number of factors contribute to the success of a system. A crucial factor is that the system meets the requirements of those who will use it in their day-to-day duties. In the past, users have been unable or unwilling to articulate their needs. Designers have sometimes produced systems that have been more oriented to using the latest technical development, or to serving the designer's ideas of managers' requirements, than to meeting the existing needs of the organization. The objective of the installation of a system must be to provide each user with the type of information that will be used most effectively; in circumstances confronting the individuals involved.

Again this training can take place on-site or off-site, and should be attended by the system users. If this training takes place off-site it should take place no more than one week before the installation, and it should be given on the same workstations as at the user site. If the training is done on-site, it should be performed as soon as possible after installation. The class will consist of 1 to 2 weeks of application training. It would be nice to send all of the users to be trained in one session, but this is usually not possible because it is necessary to automate on-going operations. If this is the case, it should not be a problem to have the vendor perform two training sessions. It takes approximately six months of experience with the software before one is able to adequately train others. [11] The author also cautions that training should not take place too early before the system is installed. If the users are not using the system within two weeks after the training session, they will have forgotten the majority of what they learned. Vendor support during the initial month of system use will be critical. As stated in the selection process, it is important to evaluate a vendors support services before selecting a system. It will be up to the system manager to make sure his users are provided with adequate support.

After the users have become proficient with the software it would be a good idea to assign a user to develop a customized training booklet for future users. This material will save much time, money, and effort when training a new user.

5.4 Standards and Procedures

One of the major responsibilities of the system management will be to establish and enforce standard practices and procedures to ensure effective system utilization. The following section discusses standards and procedures for the initial implementation and continued successful operation of the CAM system.

5.4.1 N/C Program Files Storage

A standard convention for naming and storing files must be established to manage the many files created on the CAM system. There can be as many as 15 N/C program files associated with a single part; and a good naming convention should allow a user to distinguish among these files to select the appropriate one. There are many possible conventions for naming files. The types of files associated with the CAM systems are discussed below.

5.4.1.1 Geometry File

The input to the CAM system is the finished part drawing or geometry file output by the computer aided design (CAD) system. This file should already have an assigned name from the engineering department. Depending on the naming convention being used by engineering, manufacturing, etc., either rename the part or leave it as is. For the sake of consistency, the manufacturing and engineering departments should try to establish a common naming convention.

5.4.1.2 Cutter Location Source File

The first file created on the CAM system is the cutter location source file. This file contains the post processor statements and motion commands usually in COMPACT or APT like format. This file is the result of user interaction with the CAM system on the specific geometry file. Once this file is complete, it is compiled by the post processor to produce the G-code file.

5.4.1.3 G-code File

The G-code file is the output of the post processor and is the second file created on the CAM system. This is the file that will be read into the machine tool. It is to be tested and edited for a production run to produce the desired part.

5.4.1.4 Production Program File

Rarely is a program completely correct the first time it is run on the machine. So the next step is to debug the program on the machine and optimize it for a production run. Once the program has been run, it is uploaded to the computer for temporary storage. This creates yet another file which must be uniquely identified, which is called the production program file.

5.4.1.5 Program Set-up Documentation File

This is a text file that contains the documentation that must be given to the machine operator in order to successfully run the program. This file is as important as the production program file since it contains the instructions to run the program on the machine tool.

A complex part can require five or more different set-ups each of which will require a separate cutter location source file, G-code file, and a production program file. The complex programs may also contain sub-programs nested within them. All of these programs will also require job set-up documentation which are essentially text files containing tooling, loading, and machine settings. Without a standard naming convention to uniquely name each of these files, the part program database will become an unrecognizable mess with programmers preferring to recreate a program rather than try to find it.

5.5 File Naming Convention

To be effective, a file naming convention for a CAM system must contain the following features:

- Base filename to associate the part program with the corresponding part number assigned by engineering.

-Operation designator to signify the operation for which the program is intended (front,back,side).

-Sub-program designator to indicate that a sub-program is required by the main program. This will also be used to differentiate among multiple sub-programs.

-File extension to differentiate among the file types discussed above.

There are many naming conventions which can be developed to accomplish the required objective. In the following paragraphs, an efficient methodology for assigning file names is developed. Each of the features mentioned above are discussed with respect to this methodology.

5.5.1 Base File Name

The purpose of this section of the file name is to associate the part program with the actual part design created by the engineering department. To maintain consistency, the manufacturing department should try to structure their naming convention after the engineering department's naming convention. The engineering department often uses part numbers for drawing file names. The manufacturing department should consider using a subset of the part number as the base file name to minimize the length of the file name. The typical base file name length is 5 to 8 characters.

5.5.2 Operation Designator

The operation designator is a single character within the program file name to signify the operation for which the program was created. As mentioned previously, main parts require more than one set-up on a machine to produce them. The operation designator will identify the operation that each program is intended for. A standard code to identify the separate operations should be developed by the system manager.

5.5.3 Sub-program Designator

The sub-program designator is a single character used to signify the use of sub-programs within the main program and differentiate between multiple sub-programs for the same main program. The system manager will also be required to develop a code for this purpose.

5.5.4 File Extension

The file extension will be used to distinguish among the many file types created on the CAM system (cutter location source file, G-code file, etc.). A simple three letter extension on the end of the file name will identify the individual file types. Again, file extension standards must be established by the system manager.

5.6 N/C Program Archiving Procedures

Once a standard naming convention has been established, the system manager must develop procedures for storing part programs. This is necessary to maintain the integrity of the part program database. Without standard procedures for file archiving, the computer database will become disorganized and overloaded with old programs. In addition, leaving many parts in on-line storage will decrease the performance of the computer and increase on-line storage cost. As the disk becomes overloaded the usual reaction is to purchase more disk storage. Often times what is really needed is a standard procedure for archiving old programs, deleting useless files, and maintaining only current work in on-line storage. The next section proposes a methodology to accomplish this task.

5.6.1 Database Management

The system manager should create a directory for each project that is assigned to the machine shop. All files that are associated with a particular project are placed in that directory. This is an easy way for the system manager to keep track of project files. An example of this file structure is depicted in figure 3.

After the project has been finished and the programs have been run, all of the cutter location source files and the production program files in the database structure directory should be archived to secondary storage. Secondary storage can be in the form of reeltape, cartridge, tape, or floppy disk depending on the system being used. All of the set-up documentation should be archived along with the part programs on a single tape or diskette labeled with the project name. The cutter location source file is stored along with the production program because it will be easier for the programmer to edit the CLSF file than the production G-code file when an ECO is issued on the part design. The programmer can also visually verify the CLSF file on the CAM system, where as menu systems cannot graphically portray a G-code file.

Once the files have been archived they should be deleted from on-line storage. It is very important that only one copy of each file be maintained and all others deleted to preserve the integrity of the database. A tape or diskette library should be kept in a secure place, preferably fire proof, insuring that the storage medium is not exposed to extreme temperatures, excessive dust, or magnetic fields. Some companies may also wish to keep a paper back-up file in storage. This file would contain the latest blueprint of the part, a punched paper tape of the program, and a copy of the set-up sheet.

5.6.2 File Modification Procedure

One of the powerful features of the computer is the ability to retrieve and modify existing files to reflect changes in product design. [9] However, this ability must be carefully controlled and monitored to preserve database integrity. File modification procedures must be established and enforced early in the implementation process. As part designs change so must the N/C programs and

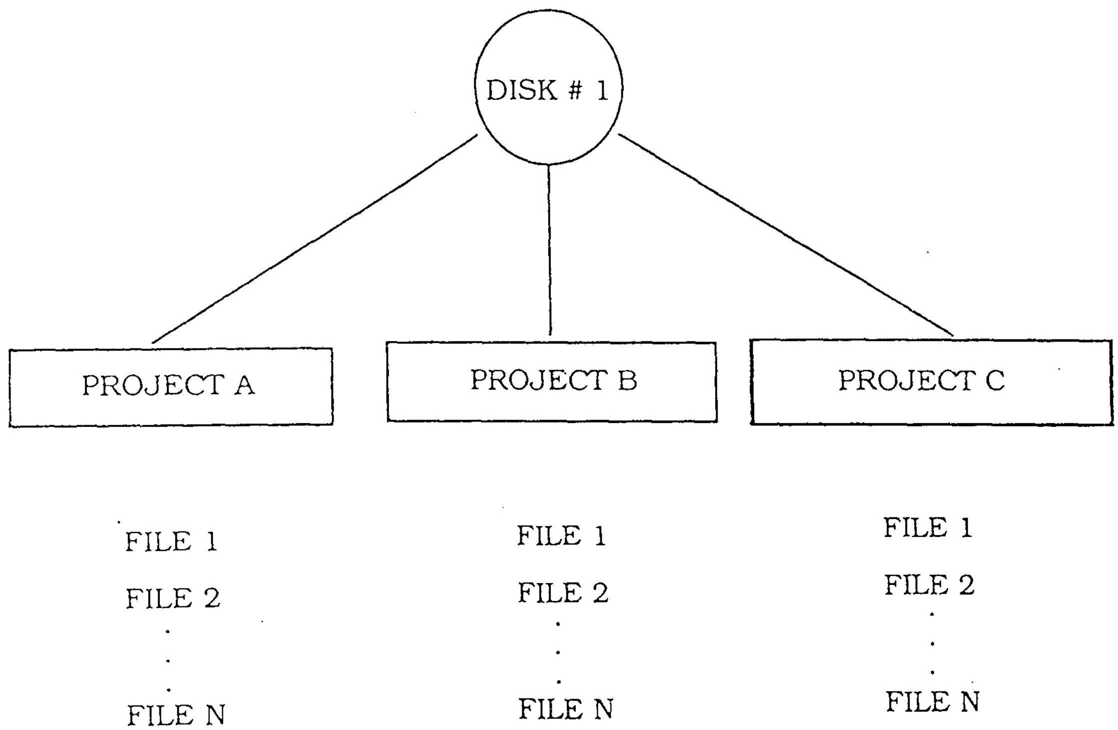

Figure 3 Database File Structure

the associated documentation required to produce the parts. The next section proposes a technique for N/C program revision control.

5.7 N/C Program Revision Control

It is very important for the machine shop to establish procedures to monitor and update part programs to reflect engineering change orders issued on existing part designs. By keeping N/C documentation current with engineering change order (ECO) levels, the machine shop will avoid the costly mistake of running a product program at the wrong revision level. ECO's procedures vary among companies, but in general when designs modification are approved by engineering, manufacturing is sent a notice and sometimes a copy of the modified drawing to update their files. If the modified drawing is not sent with the ECO, it is the responsibility of the shop foreman to request a copy from the drafting department. Once the modified drawing file is obtained, a programmer should be assigned the task of updating the corresponding part programs and set-up documentation. The procedure for updating the CAM database is described below.

5.7.1 Cutter Location Source File

The first line in all part program files should be a note stating the part number and revision level. The programmer must update the latest version of CLSF and modify it using the updated drawing file obtained from the drafting department. The programmer should also modify the revision indicator at the top of the file to correspond to the latest revision level.

5.7.2 G-code File

After the CLSF has been graphically verified on the CAM system, it should be post-processed to produce a new G-code file. Again this file should contain a note indicating the part number and revision level. This file will be downloaded to the machine tool for better productivity and optimization.

5.7.3 Production Program File

Once the G-code file has been debugged and optimized on the machine tool, it should be uploaded to the CAM system database to replace the old production program file. This production program file should be used to produce the actual product.

5.7.4 Program Set-up Documentation File

It is very important that the set-up documentation files be modified to reflect the changes in a program operation. The revision level on the program set-up sheet must also be modified to remain consistent with the part program. After all of these modifications have been made, the programmer must delete all old files so that only one set of program files exists for each part. The updated files can then be stored using the file archiving procedures described earlier. It is important to establish file maintenance procedures early in the implementation process. Database management is a tedious task; however, a poorly maintained database will lead to multitude of problems causing people to lose faith in the system capabilities. [7]

CHAPTER 6
INTEGRATION OF CAD AND CAM TECHNOLOGIES

Advancements in computer technology continue to have an impact on the manufacturing process and enhance the integration of individual "Islands of Automation" in computer aided design (CAD) and Production (CAP). The term, computer aided production, is used interchangeably with computer aided manufacturing. Even though there are many "Islands of Automation" in the production cycle, there are still walls between the communication of engineering and production functions. As a result, engineering continues to toss design information over the walls of production. In many cases, production receives inaccurate data that cannot be properly interpreted by production. This communication problem causes production problems, time delays, and poor project quality. Besides a lack of sharing, additional problems result from the walls between the two major functions. Typical problems are the following:

- Increased Human Errors
- Long Programming Time for Numerical Control
- Long Turn Around Time
- Decreased Productivity
- Reduced Producibility Information to Engineering

Such problems have promoted engineering and production to study methods and implementation strategies for computer assistance in integrating certain subsystems of the two functions. Thus, computer integration of these

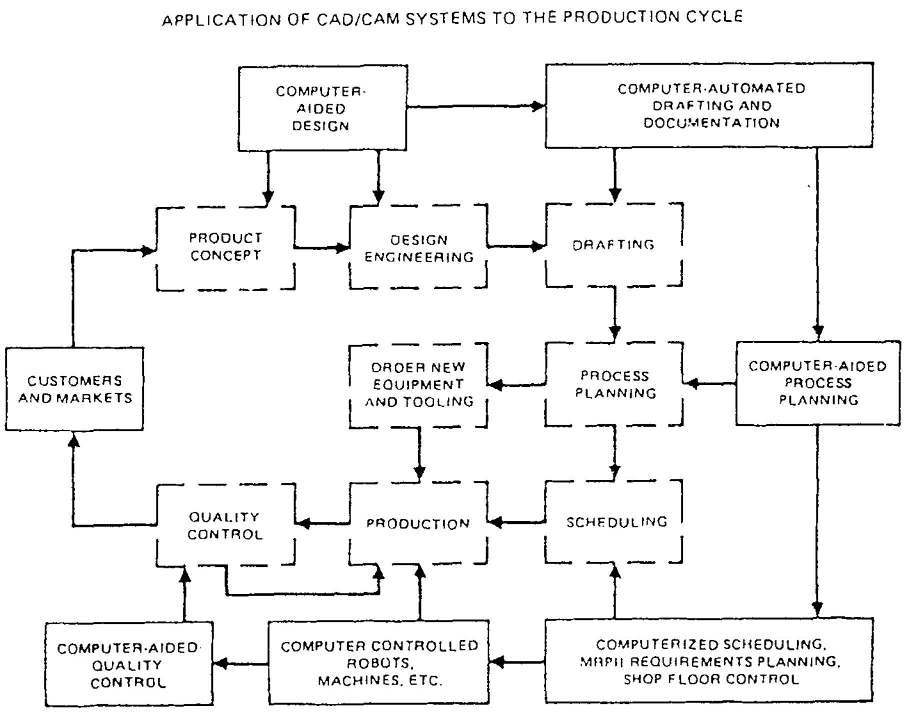

Figure 4 CAD/CAM Integration-Computer Assistance to Production Cycle

two functions brings into focus automated computer assistance in sharing data between operations in the production cycle as shown in figure 4.

Through cooperative efforts between the two functions, computer integration of subsystems of CAD and CAM begins to take place. The integration of CAD and CAM into the production process to improve productivity is referred to as CAD/CAM. Such systems store, retrieve, manipulate, and display graphic information all with unsurpassed speed and accuracy. Thus, more can be accomplished in a given time by engineers who are increasingly scarce and are a valuable resource. Product quality and yield are also improved, optimizing the use of energy, materials, and manufacturing personnel. New CAD/CAM technologies, including hardware and software concepts, appear continually in the market place as a logical result of ongoing evolutionary process in human thought, industry, and striving for manufacturing improvements. The majority of these technological improvements usually represent only small advances that can be implemented with relative ease by careful planning, support from management, and by simple addition, replacement, or modification of existing systems.

6.1 Integrated Computer Aided Manufacturing

The U.S. Air force program for integrated computer aided manufacturing was brought about by needs and pressures in state of the art technologies, economics, increasing human limitations, aerospace design and manufacturing complexity, computer developments, and competition from abroad. [10] This program may serve as a planning and implementation guide for computer integration techniques of CAD and CAM. It supports all areas of CAD/CAM technology. The integrated computer aided manufacturing (ICAM) is a long term effort that includes the establishment of modular subsystems, which are

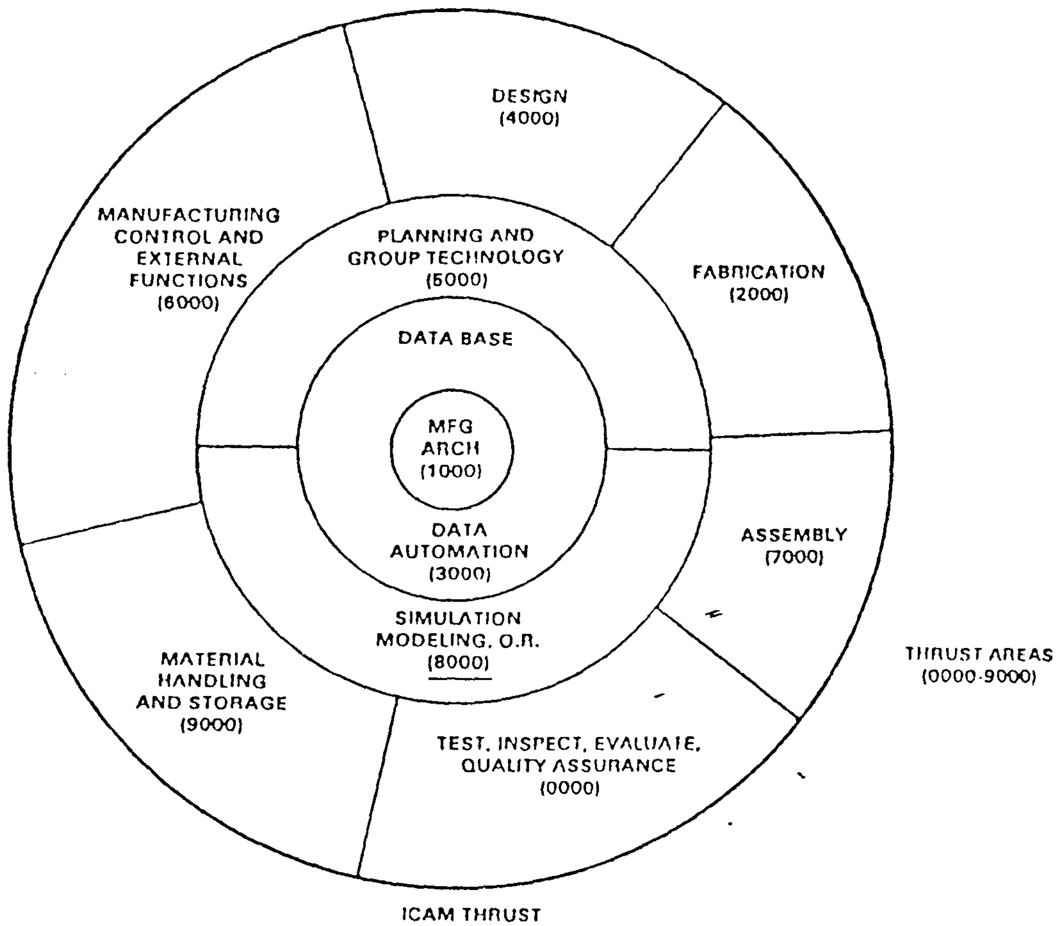

Figure 5 ICAM Program

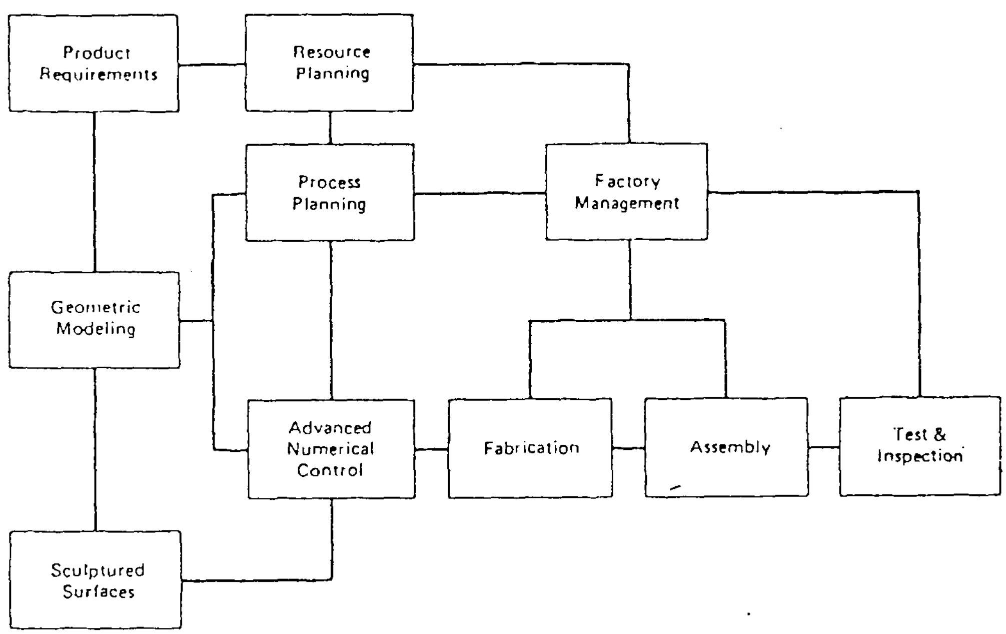

Figure 6 CAM-I Framework

designed to computer assist and integrate various phases of the design, fabrication, and distribution process, and their associated management hierarchy, according to a prioritized master plan. (figure 5) In essence the program provides a basic roadmap for integration of CAD and CAM where computer technology is applied to the design and production of an item in pursuit of a profit.

Data communication among the various CAD/CAM subsystems is accomplished through a shared access to a common database system. The CAD/CAM subsystems are referred to as computer integrated manufacturing subsystems (CIMS). A CIMS has the specifications and characteristics that allow it to be computer integrated in a CIMS environment. Computer Aided Manufacturing International, Inc. (CAM-I) developed a system framework for the integration of manufacturing functions through computerization. The framework shows the boundaries within which applications should be constrained and needed interfaces and interactions between them (figure 6). According to them, the main objectives of integration are the following:

- Define a system framework for CAD/CAM that is as independent as possible of present or predicted computer hardware and software.
- Describe an overall CAD/CAM system framework capable of simple orientation to an individual company.
- Provide a means for easy and efficient replacement or enhancement of individual applications systems.
- Provide a means whereby user may involve their own pace in the total CAD/CAM system through the use of a common database system.
- Provide a boundaries and guidelines for future development.

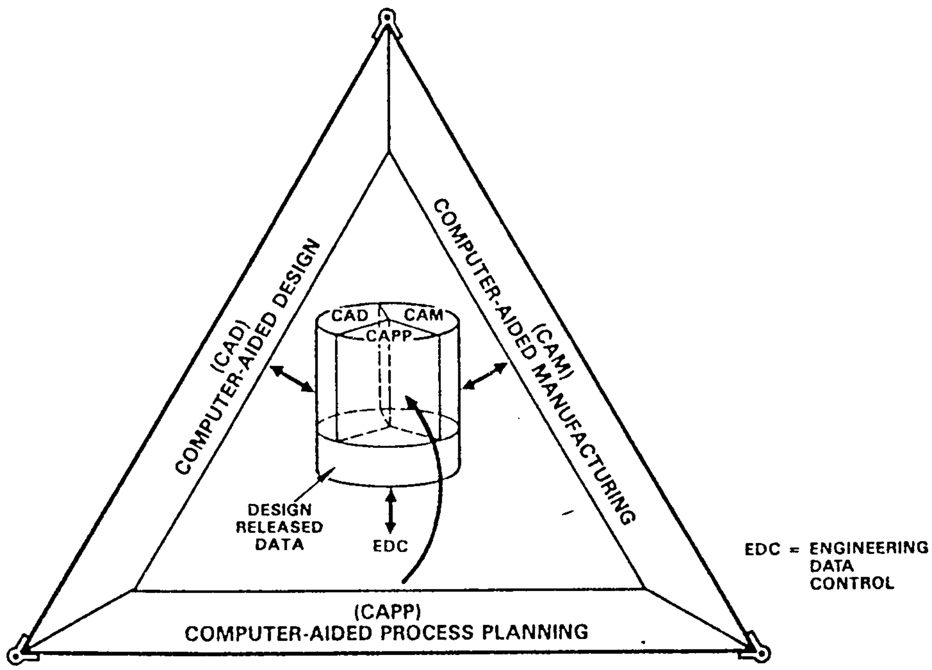

Figure 7 Big Three in Integration Process

6.2 The Big Three in Integration Process

As shown in figure 7, one role of the Big Three (CAD, CAPP, and CAM) is to co-generate a common database for product design. This database provides common data to the production process and is often referred to as the engineering released database(ERD). Engineering releases the data of the product model to engineering data control (EDC) when the product model meets the desired design requirements. Engineering data controls all changes made in the data of the product after it has been released by engineering and also protects the integrity of data.

Design, process planning, and producibility information are provided to the common database by CAD, CAPP, and CAM, respectively, when they are generating the product model. The data is further distributed to other production operations where values are added to the data to meet the requirements of the particular application. Figure 8 illustrates how group technology (GT) is used as a means of integrating design and manufacturing departments by providing a common database for design and manufacturing. This system can be implemented on its own, and at the same time, it can serve as a building block in a fully blown broad-based integrated system.

In an ideal integrated CAD/CAM environment, two systems are most important:

1. **Integrated CAD/CAM Database Systems**
2. **Communication Systems**

6.3 Integrated CAD/CAM Database Systems

An Integrated CAD/CAM database system is often referred to as the manufacturing database. It includes the product model data during the design

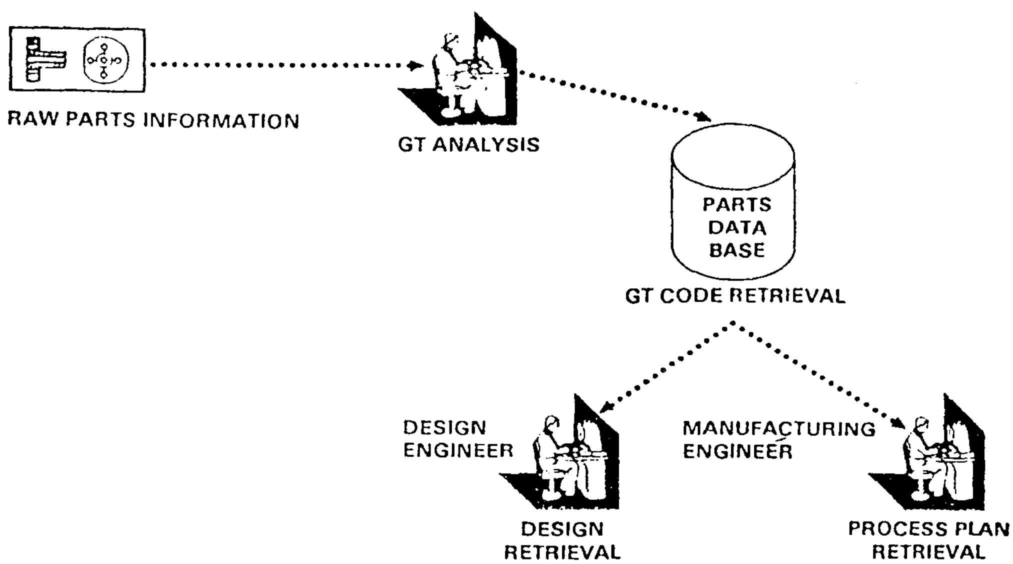

Figure 8 GT Based System in CAM Operation

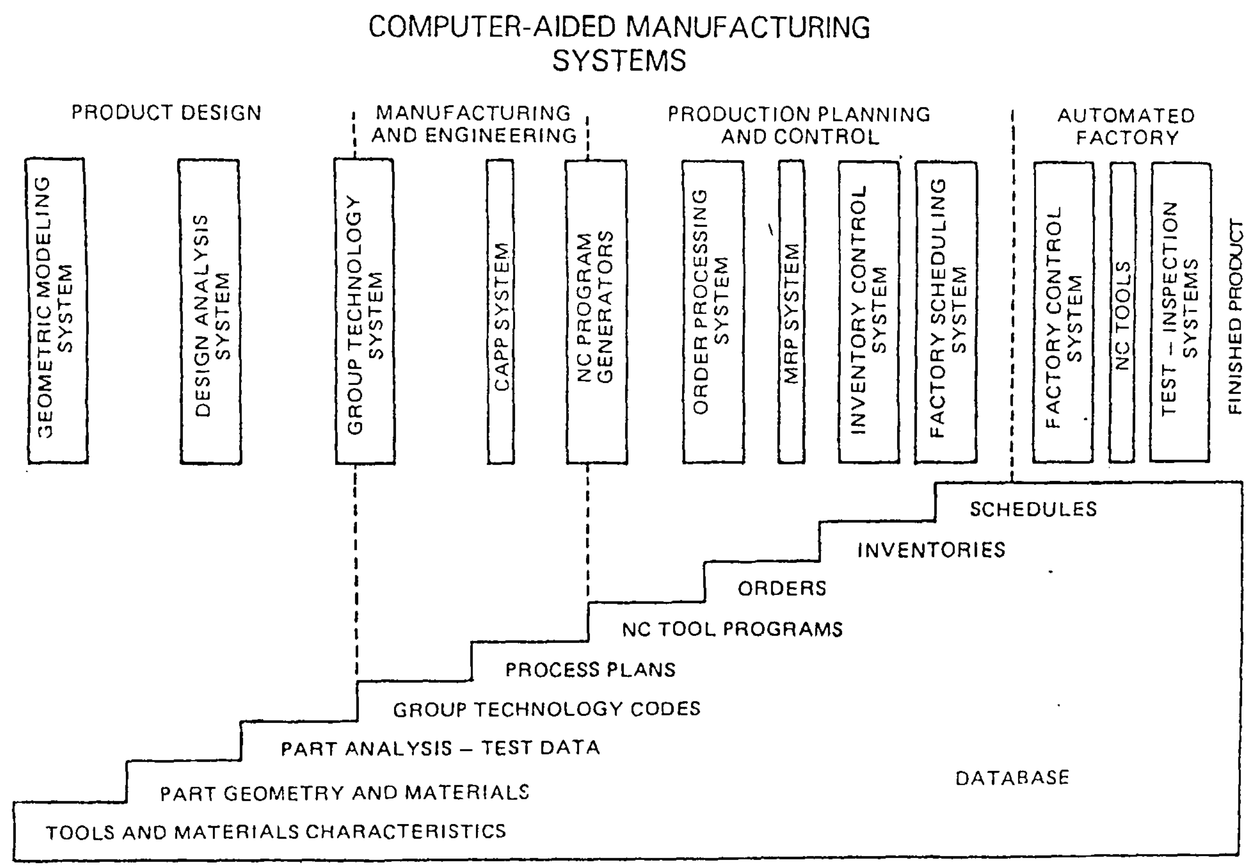

Figure 9 CAM System Database

phase and common data required by production planning, controls, processing, and shipping. Generally, much of the data used in the actual production are based on the product design data. A typical production of CAM's manufacturing database is illustrated in figure 9. In a manufacturing database, a designer generally creates a geometric model of the part on the screen. Additional data required to make the part are also processed and stored in the database. Typical data stored in manufacturing database relates to group technology, process plans, NC tool programs, inventories schedules, etc.

A manufacturing database system consists of subsystems such as a common database, distributed databases, data communication, database management, computers, parts dictionaries, and language translators. These subsystems work together to form a reliable, efficient, and productive database system. The development of a scheme for an integrated CAD/CAM database system is a long task. It requires a good understanding of the operations in the production cycle and a good knowledge of the future use of the database system. cause the database structure is the backbone of the CAD/CAM integration, it should be well analyzed, planned, and implemented. The subsystems of a manufacturing database system are described below:

- Common Database
- Distributed Databases
- Data Communication
- Database Management
- Computers and Database Applications
- Computers and Language Translators

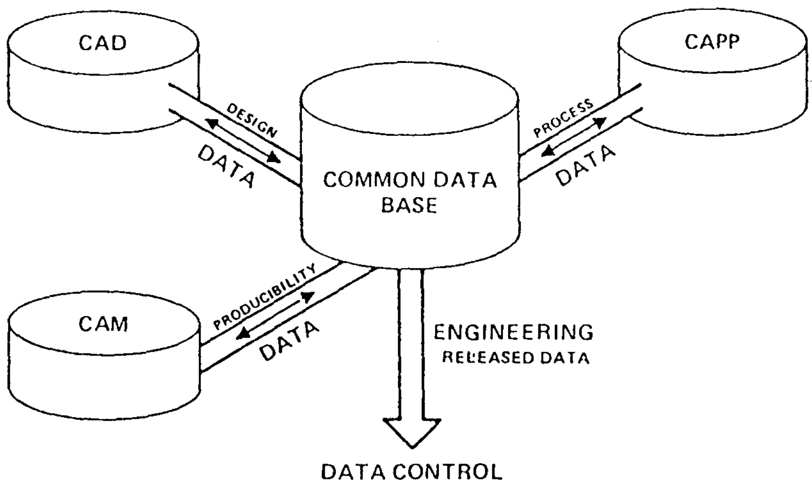

Figure 10 Common Database

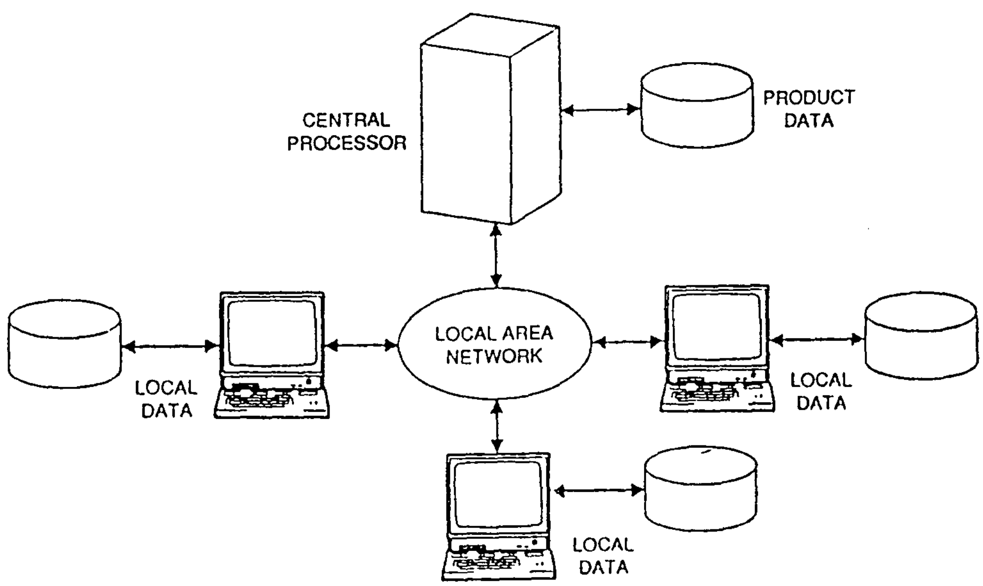

Figure 11 Distributed Database

6.3.1 Common Databases

A common database contains common product data that are shared among CAD, CAPP, and CAM. Figure 10 shows the relationship among the four databases in the subsystem. The CAD database contains part design data to record geometric models, bills of materials, drawings, GT codes, documentation, and test data. Data such as group technology codes, process plans, standards, machinability libraries, tooling, and speed/feed rate tables are stored in the CAPP database. The database of CAM contains data that specify the techniques to be used in making the part. It includes such data as NC programs, orders, inventories, schedules, processing equipment, and processing of material Under computer controls, the three databases interact and iterate with one another to generate the ERD, also referred to as the common database. This database contains the part or product model.

6.3.2 Distributed Databases

The common database is controlled by being signed off by the engineering department when the part or product model meets its desired requirements and is released to EDC. Data from the common database are controlled and distributed to other applications for their use. Typical application users are manufacturing resources planning (MRP II), Flexible manufacturing system(FMS), numerical control (NC), computer aided testing (CAT), and computer aided inspection(CAIN). Values are added to the common data to meet the requirements of the specific application. Data from the application areas are further distributed to applications at other levels for additional requirements.

A point of interest is that all data can be traced back to the common database. That is, the common database source may be viewed as a

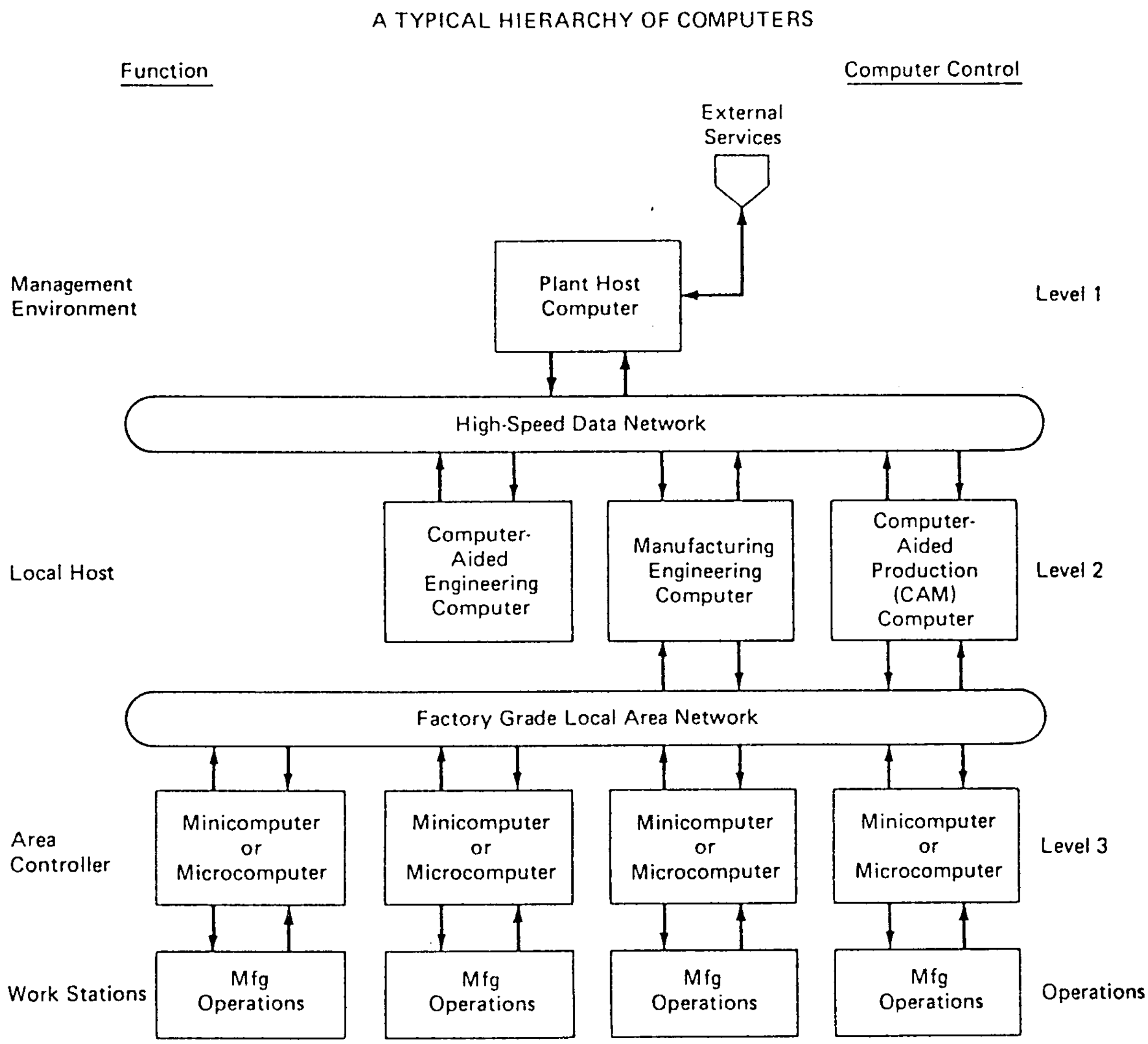

Figure 12 Levels of Communication

source of references or standards. The common database should be an intelligent database. An intelligent database will reflect any changes made in the stored data, and these changes will be reflected in the other databases in the system. For example, a change in a basic product model would be automatically carried to other applications associated with the model. Such as, manufacturing data would automatically change the NC tool path. All information is updated at the same time.

A basic key part of an integrated CAD/CAM database system is data communication. Communication links all databases together to form one integrated database system.

6.3.3 Data Communications

Database communication makes it possible to link distributed databases and computers into an integrated CAD/CAM database system. Database communication is a subset of the CAD/CAM communication system.

A database communication network eliminates "Islands of Automation". To the user, the distributed databases appear to be centralized. In this environment, with a good database communication network, a task may access information stored at any databases easily in the integrated CAD/CAM system. Such an integrated database permits production departments and applications to share information, which reduces redundant data in the enterprise and improves the total system's throughput. A key to solving the database communication problem is to access the up-to-date data as soon as it is stored in the integrated database system.

The importance of easy interfaces to database communication networks cannot be overemphasized. Ports, interfaces, protocols, and controls are required for application users, engineers and designers, programmers, operators, and the like who need access to the network. Standards supported by the International Standards Organization (ISO) should be used so that equipment from various manufacturers may be attached to the network.

6.3.4 Database Management Systems

A database system consists of many islands of databases that are interconnected electronically and distributed throughout the manufacturing facility. Each database is managed by its own database management system(DBMS) and is generally under the control of a local host computer. A DBMS is a special software package that provides an interface between application programs and stored data. It manages the access and storage of data on a storage medium . That is, a DBMS provides access to data in ways that account for more abstract structures, such as membership in sets having certain characteristics in common.

Typical features of a DBMS are the following:

- Build physical data structures to meet the information needs of an organization.
- Control data access and prohibit access by unauthorized users.
- Simplify system restoration in the event of a failure by providing checkpoint, recovery, and restart facilities.
- Let multiple users access and/or update information in the database to make informed decisions on file placement, blocking factors, chain usage, and so on.
- Automatically log before and after updating images of the database to aid in restoration if they are needed.

A DBMS plays an important role in the integrated database system. Collectively, DBMSs readily make available information on what is happening on the production floor so that the FMS will run efficiently.

6.3.5 Computers and Database Applications

A database is a rather abstract concept. Generally, it starts out as a "bit bucket" where there is relevant information about an enterprise's product to produce it. In an integrated manufacturing environment, however, it is a complete network composed of several components. In many cases, the products are composed of various subassemblies and component parts, and each product element has both engineering and production information associated with it. To organize and manage such a collection of information in the system, a relationship between the applications, databases, computers, and languages must be understood.

New CAD/CAM applications are popping up every day to support new and established CIMS through systems integration. Typical applications are flexible manufacturing(FMS), automatic assembly operations (AAO), computer aided testing(CAT), computer aided inspection (CAIN), experts systems (ES), and artificial intelligence (AI) systems. Applications are also being extended to intelligent robots, automated guided vehicles (AGV), and so on. These applications use data from the shared database to meet their requirements. The key to CAD/CAM integration is to use a common computer integrated database system from product development through delivery. Thus, the integrity of the basic product model is preserved as values are added to this basic foundation.

6.3.6 Computers and Language Translators

The integration of CAD/CAM requires many different types of equipment for communicating, for example, access data and control processes. The integration of the subsystems require several levels of communications, control computers, and language translators. Examples include computer numerical controls (CNC) for machining centers and lathes, programmable logical controllers (PLC) for assembly and material handling conveyors, robot controls for loading and unloading the AGVs that shuttle parts between machines and between multiple cells, and an automated storage/retrieval system(AS/RS) for storage of raw materials and finished goods.

A translator is a special program that changes data from one form of representation to another without significantly affecting the meaning. An example of a translation process is when a program written in high-level language is translated into the native language of the computer. Other components involved in machine-to-machine communications are look-up tables, code exchanges, dictionaries, and protocols.

6.4 Communication Systems

An integrated communication system is more than just a critical element in an integrated CAD/CAM facility. It links "Islands of Automation", computers, databases, and various support functions such a supervision, production control, quality control, and maintenance together.

The communication system is the key that unites diverse parts of a modern automated installation. Through its use in theory and in practice, the interaction of numerous discrete devices enhances each device's functionality. Communication also brings genuine automated status to the modern CAD/CAM industrial operation.

Factory communication helps to improve productivity by getting the right information to the right place at the right time. Real-time communication of events and parameter data among controllers allows automated coordination of the elements of a process. Timely communication of a product's parameters can alert plant personnel to problems and can aid in the selection of an appropriate and timely solution. Factory communication also sends management information from various plant floor controllers and improves the accuracy of production scheduling and resource planning.

Communication must be provided at all levels of the integrated CAD/CAM factory. The communication levels are shown in figure 12. As a result, the needs for information and control in the facility will be different at each level. There are two main levels of communication.

- **Management Communication**
- **Factory Communication**

6.4.1 Management Communication

At the top of the hierarchy structure, is the plant's host computer, which operates in a management environment. Communication for management information helps to support the overall operation of the business as well as the operation of the plant or process. The host computer communicates with and supports the CAE, CAPP, and CAM computers at level 2 which are referred to as local host computers. Management information must be communicated downward from the host to the local hosts (satellite computer) and management information must be sent back from the satellite host computer up to the plant's host. A satellite host computer is used to relieve a plant host of simple but time-consuming operations such as compiling, editing, and controlling input and output devices. The satellite computer is no longer isolated from the plant host. They must work cooperatively in conjunction with computers and controllers at lower levels to achieve productivity enhancements through integrated plant-wide production controls.

6.4.2 Factory Communication

Production information is communicated from local host computers (level 2) to area controllers at level 3 and onto workstations. Direction of production information is based on input from several functional areas. Effective communication supports the interaction of major departments and production processes. Factory communication also supports synchronization of departments, control systems, and production schedules.

A second level of local area network(LAN) using manufacturing automation protocol(MAP) is at the shop floor level and links area controllers at Level 3 with local host computers at Level 2. This level of communication is referred to as a factory-grade LAN. In some cases, this LAN is a cheaper enhanced performance option of MAP known as MAP/proway. It uses carrier-band technology instead of broadband; and it streamlines the use of the ISO model by removing the middle layers.

6.5 Planning and Implementation of Communication System

6.5.1 Planning

An integrated communications system must be carefully planned at all levels with the company's goals in mind. Successful automation is a gradual process, and a plant's evolution toward integrated communication can be likened to the building of a pyramid. Automation starts when controls are interfaced to the machine and process equipment. Increased production rates place greater demand for response times in the milliseconds.

Machinery and processes respond to commands from the station-level controls. Therefore, access to plant-flow data is necessary for supervisory monitoring and control, and it must be formatted for easy understanding by plant personnel. It must be available in real time to depict plant floor conditions accurately. As stations multiply, the call level comes into play, coordinating their functions to allow integrated monitoring and control. Control messages should have priority over information messages to ensure the safety and reliability of the control system, yet maintain the required access to real-time data to support decisions.

Devices on the center level coordinate multiple cells for scheduling, production, and management information. At the top of the pyramid, the plant level, management directs planning, execution, and control of plant operations. A key factory communication issue is information management within and among manufacturing and process areas. Typical questions that may be asked for this level are: What is the right information for plant floor coordination? Where should it be and when? How should it be acted on?

6.5.2 Implementation

Implementing an integrated communication system that addresses the planning issues we have discussed is not an easy task. An approach to an implementation solution places the issues into six functional areas:

1. **Distributed Control:** for integrating devices on the plant-floor level within rigid response times while still enabling upward communication to coordinate the entire process.

2. **Monitoring:** for gathering uptime and downtime information, alarm histories, trending parameters, and other data in nonreal-time environment.

3. **Data Acquisition:** for using the network to provide access to an on-line database related to the manufacture of the specific product. (Parts counts, parts rejected, and other quality and production data are included in this database.)

4. **Supervisory Control:** for supplying actionable information to higher levels and returning the appropriate response. (An alarm may notify an operator that something is out of tolerance, and it may request a specific command. The operator response completes the supervisory control process.)

5. **Program Support:** for using the communication system to upload, download, and store programs(transferring very large files, creating high-capacity but less time-critical demands on the communication system).

6. **Management Information:** for gathering large amounts of preprocessed information from lower levels to facilitate batch transfer to the plant computer.

6.6 Standards to Facilitate the Integration of CAD and CAM

Establishing communication practices and procedures for data transfers between engineering and manufacturing is necessary to derive the maximum benefits from the CAM system. [11] These procedures would include the release of part designs to manufacturing for production as well as engineering change order notices for design modification. The computer can be used to enhance the flow of information between engineering and manufacturing, making it more efficient and error free. The following section proposes a methodology for establishing standards to effectively interface CAD and CAM.

6.6.1 CAD File Formatting Standards

Many companies have invested in CAD systems solely for the purpose of automating the drafting department. In these situations where the main objective is plot creations, there usually is no file formatting standards for data transfer. With the implementation of the CAM system, there is now a need to electronically transfer information between the two disciplines. One of the benefits of establishing the CAD to CAM link is that geometric data can be passed directly from the CAD system to the CAM system for part program creation. However, the part programmers will only use portions of the geometry files created by the drafting department, specifically the geometry associated with each view of the part. The other data associated with the part; such as, dimensions, notes, drawing border, etc. are not needed in the geometry file for the creation of part programs and should not be transferred to the CAM system database.

To effectively interface the two systems, standards must be established to facilitate this data transfer. The objective of these standards is to minimize the data manipulation required to input the geometry files to the CAM system. Establishing these standards will require a cooperative effort by the system managers of CAD and CAM systems. The following paragraph describes some of the standards that should be enacted.

6.6.2 Layering Standards

The majority of CAD systems available today have the ability to break a geometry file into many separate layers. This capability can be used to the advantage of engineering and manufacturing by making large files much easier to view and manipulate. Layers can be compared to foils on an overhead projector in that they can be viewed collectively or selectively depending on what the user is trying to accomplish. For example, a user may place all of the part geometry on layer 1 and all of the dimensions on layer 2. It is now possible to view both layers together or individually if the user only wants to see the geometry. By establishing standard CAD drawing procedures, the system manager can have drawings formatted by the user with minimal effort on the users part. Formatting the drawings as they are created will save time and effort when the drawings have to be manipulated for the use on the CAM system.

6.6.3 Database Integrity

In addition to organizing the files into layers for file manipulation, standard drawing practices should also be established to maintain the integrity of the CAD database. As CAD/CAM systems are implemented, paper communication between the engineering and manufacturing departments will be replaced by electronic communication. The manufacturing department will be working directly from the electronic drawing files created by the engineering department. Drawing standards and checking procedures must be established to insure the integrity of drawings in the CAD database before they are transferred to the CAM system. Typical standards would require that drawings be submitted to the machine shop at a scale of 1:1 with all dimensions accurate to 5 decimal places.

6.6.4 Production Release Practices

As mentioned previously, the implementation of the CAM system will change the manner in which the engineering and manufacturing departments communicate. To cope with this change, the practices for releasing designs to the manufacturing department must be modified. Data transfer procedures must be established to provide an accurate, efficient, and timely flow of information from the engineering department to the manufacturing department. These procedures will determine the contents of the design release package, along with when and how it will be released to the manufacturing department. A typical release package will contain design drawings, a bill of material, and work order. The way in which this information will be transferred depends on the particular computer configuration. If the systems are tied together on the network, the data can be sent directly to the CAM system. Without a network, the data will have to be placed on a secondary storage device such as a diskette or a tape and loaded onto the CAM system.

6.6.5 N/C Program Documentation Standards

When releasing part programs to machine operators it is important that the program documentation be clear, complete, up-to-date, and in a consistent format. Using manual programming methods it is more difficult for the shop foreman to maintain standards among many programmers. Machine operators would have to decipher the varying program documentation that they receive from the different programmers. This documentation can be hard to read or incomplete. With the use of the CAM system, this information will become an easier task. The computer will reduce the effort required to create and manipulate program documentation while allowing the system manager to establish standard document formats.

Standard text files can be created on the system for the programmer to call up and fill in the necessary information. The file can then be

Sample format file printed for use by the operator. This will maintain consistent document formats among programmers. The end result will be more legible and consistent which will be easier for the machine operators to understand.

6.6.6 Old Program Conversion

Prior to the advent of magnetic medium storage devices, N/C part programs were stored in G-code format on punched paper tape. These programs were fed in the machine through a tape reader interfaced to the machine. The question will arise as to how and when to convert these programs to computer storage. The best way to approach this problem is to convert old programs as they are used. For example, if an old program is called out for a production run, after the job is complete, the production program can be uploaded to the computer for storage. The set-up documentation should also be revised at this time to the standardized format on the computer. If an old program must be modified, it should be reprogrammed on the CAM system and the old program should be discarded. This is a much more cost-effective method of program conversion than assigning an individual to a full-time task of converting old programs.

6.6.7 Initial Project Selection

The first project to be completed on the new system should be carefully selected because the outcome of this project will have a lasting effect on managements confidence in the systems ability. The project selected should not be overly complex or require new production techniques. Projects that are already behind schedule should be avoided. This is the first chance to show off the new system within the company and the opportunity should not be missed.

CHAPTER 7
EVALUATING SYSTEM PERFORMANCE

The subject of evaluation of computer aided manufacturing systems and productivity associated with this technology has been elusive. Productivity measurement is of great concern to many users of CAD/CAM. It is not uncommon to hear such questions as: How do we evaluate the performance of these systems? What impact have these systems made on our company or corporation? How do we measure productivity or CAD/CAM systems?

The application of computers to conventional manufacturing methods can provide benefits that include improved productivity and quality control, operating flexibility, and reduced direct labor. To be able to measure these benefits, procedures must be established to track and measure the system's performance. Tracking the system's performance in a verifiable manner is necessary to compare the actual performance with the company's initial projections and to correct the system's inefficiencies. The following section proposes a methodology for monitoring the system's use to ensure maximum performance.

7.1 Scheduling System Use

By allowing system usage on an "as needed basis" the system manager will be unable to track down the user or system performance. A scheduling system must be established to ensure that individuals are assigned on a daily basis to the projects that are most useful to the company. [2] In this way the system manager can track the progress of the project and be able to identify inefficiencies in the system's use. The department manager should be responsible for scheduling users based on the projects assigned to them.

7.2 User Log

Once the users have begun a regular schedule of the system's use, the system manager must provide them with a means for generating feedback on the system's performance. This can be accomplished by keeping a user log. In this log the user will record the time spent on the system, the project worked on, and any problems that occurred during the session. This can also be used to point out system bugs to the software vendor.

7.3 User Support Group

For large system installations with more than ten full-time users it will prove worthwhile to form a user support group. This group will be responsible for catering the needs of the system users, acting as a liaison between the users and the system vendor. The users will come to the user support group with software and hardware problems and the support group will be responsible for solving these problems. By representing many users in this fashion it will be easier for the vendor to support the system.

7.4 Comparing System Performance to Conventional Methods

When evaluating system performance it is important not to focus only on direct labor savings. Indirect benefits; such as improved product quality, decreased N/C program prove-out time, reduced fixture design time, and increased machine utilization, should also be considered. In most cases, procedures for monitoring these variables have already been implemented. Establishing performance measures to determine the actual gains achieved with CAM is difficult. It is felt that the best way to evaluate system performance is to track the new production cycle time using the data collection methods described above in conjunction with previously established methods for tracking shop efficiency and product quality. The total production cycle time should include programming time, fixture design time, machine run time, and any rework required. This data can then be compared with the data recorded from manual methods. This comparison will require that accurate and verifiable data collection methods be established.

It will take 6 to 12 months before the users become proficient with the new system. During this time period it is important for the system manager to monitor their progress. If some of the users seem to be lagging behind they may need more training or more system time. When the users become frustrated with the system, they will revert back to manual methods which spells disaster for the system implementation. By carefully monitoring user progress, this problem can be avoided.

7.5 Auditing the CAM Implementation

It is necessary to carry out a CAM system audit as, inevitably, changes in the production environment and the overall company environment will lead to differences between what was planned and what is actually implemented. Over time, these changes can lead to a situation that is significantly different from that originally planned. [7]

The aim of auditing CAM is to ensure that maximum benefits are being obtained from the investment in CAM and, if they are not, to determine a course of corrective action. The audit must define the 'current situation of CAM' relative to original objectives and current requirements. The 'current situation of CAM' covers the complete range of activities associated with the implementation of CAM. It is not sufficient to limit the audit to the use of CAM. Other activities that need to be reviewed include objectives, organization, plans, impact of CAM on the company, and so on.

The required frequency of major audits will vary from company to company. The time between successive audits depends on the actual state of CAM implementation and use. It may be suitable to carry out the first major audit about three years after installation of the system, with further major audits being carried out at intervals of between four and six years. The amount of time required for such an audit will also vary from company to company. For a company with four workstations it could be from 15 to 30 man-days. The investment is significant, thus the company will not want to carry out such audits too frequently, and will need to ensure that when one is carried out, it is as effective and thorough as possible.

It is difficult for those members of the company involved in using or supporting the CAM system to carry out the audit. This is partly because they are too close to take a dispassionate view and they will not have enough time. In a very large corporation, there may be CAM auditors in a staff position. In general, companies will make use of an external consultant who will be able to take an independent, informed view of the use of the CAM system within the company.

The first step in the audit is to gather information. The type of information needed and the way in which it should be collected are described below. Once the information has been collected from various sources, it will be analyzed and a conclusion will be drawn. Next, results need to be put in a form in which they can be communicated to top management. It will then be possible to decide on the future course of action. The major steps involving in the CAM audit procedures are:

- Information Gathering
- The Management View of CAM

- The CAM Service Organization View of CAM
- The User View of CAM
- Detailed System Performance and Problems
- Use of CAM Relative to Competitors
- Effect of Changes in the Environment
- Analysis
- Redefinition of Objectives and Plans

7.5.1 Information Gathering

The information gathering process is principally composed of three activities:

Interviewing
Consulting Documentation
Observation of System in Use

7.5.1.1 Interviewing

It will be necessary to interview people involved with CAM at all levels of the company. Top management will be interviewed to identify the corporate impact of the use of CAM. Middle management will be interviewed to identify the impact at their level. Managers in other departments not using CAM should be interviewed to find out if the use of CAM is affecting them. Details of achievements of CAM on actual projects can be obtained from project managers. Members of the CAM service organization should also be interviewed.

7.5.1.2 Consulting Documentation

There should be several sources of documentation available to assist the CAM auditor to develop a clear picture. There should be documents describing the original objectives of the use of CAM. Committee meeting reports can be referred to, giving a chronological overview of successes and problems. Project documentation can be referred to, showing how much CAM has been used, on which projects, by whom, at what level, and so on. It may even provide enough data for calculations of productivity improvements. The reporting documentation which has a complete record of the system use will be an excellent source of information. The quantity and quality of documentation associated with the use and support of CAM will have to be investigated.

7.5.1.3 Observation of System Use

Finally, a great deal will be learned just by watching the users and the CAM team at work for a few hours. The strengths and weaknesses of both is apparent to an experienced auditor, who has seen equivalent activities in many similar companies.

7.5.2 The Management View of CAM

The information that the auditor is looking for when interviewing management does not relate directly to the use of the system. It is much more concerned with the impact on the use of the CAM system in the company. Management should be asked to describe this both in general terms and in specific terms; for example, as it relates to relationships with clients, or to the development or modification of the products. It is also important to find out whether management feels that the results of implementing CAM are in line with the original objectives. If they are not, it will be interesting to see when, why, and how the changes occurred. It may well be that current objectives are no longer the same as the original ones, in which case the underlying reasons need to be brought to light. Management should be asked on the following:

Organizational Structure
Impact on Other Departments
View on Cost and Benefits

7.5.2.1 Organizational Structure

Top managers, such as the CAM Director, should be asked to describe the CAM's organizational structure, in particular as it concerns reporting relationships involving the CAM manager. Any changes made to the company's organization as a result of CAM needs to be identified and explained. For example, these could include changes in responsibilities between design engineers and manufacturing engineers, or an increase in the number of electronic data processing (EDP) specialists reporting to departments other than the EDP department. It may also include changing departmental boundaries, and changing the goals of middle management.

7.5.2.2 Impact on Other Departments

The impact of CAM on those departments that do not actually use it needs to be investigated. Some questions to ask are: How has CAM affected the purchasing function? How has CAM affected the manufacturing planning fountain? Have attempts been made to integrate CAM with other systems? Has CAM been of use in sales and marketing?

7.5.2.3 View on Cost and Benefits

Perhaps most importantly of all, management views on the costs and benefits of CAM has to be brought to light. Information on the real costs should be made available. This would include the cost of activities such as training, maintenance, support, management involvement, and documentation. (Many activities of this type are often conveniently forgotten when a calculation is made on the cost of CAM). The benefits will probably be of different types and at different levels. They need to be described and, if possible, quantified. Top management may see the benefits very much on the business level; for example, CAM helped to bring a product to the market earlier than expected. Middle management may have a slightly different view; for example, less parts being reworked per year because of better quality design resulting from the use of CAM. Project managers, in turn, will have yet another view. This may be the easiest to quantify, since it may be directly linked to the amount of time and money saved by using CAM on particular projects.

7.5.3 The CAM Service Organization View of CAM

Development of the system, associated people, and other resources need to be described. The description should include the dates and costs of developments such as increases in the number of workstations and growth in the CAM team. An organization chart of the team should be supplied, along with details of the functions of each member.

The training courses given to the CAM team, as well as the users, should be listed, attempting to find out how they perceive the suitability and success rate of the courses. The increase (or decrease) in the number of users trained in CAM and the number actually using CAM in a given year should be noted, along with the percentage of time for which each user actually uses the system.

The number of potential users not yet trained to use CAM should also be discovered.

The CAM manager should be asked whether the CAM team is of sufficient size and quality. Such questions are: Is it of the planned size? Have team members resigned? If so, for what reasons? Are all the necessary abilities available in the team; for example, is there a data management specialist? Is there a communications specialist? If certain skills are lacking, for what reason(s)?

The planned resources and budgets can be found by referring to the original documents. It may be that they were grossly underestimated or overestimated. It may be that in subsequent years there has been major differences between planned and actual resources and budgets. If so, it may not be possible to give credence to those planned for the future.

The CAM manager should also explain, in fairly general terms, the way in which the system and its use has been developed, and is planned to be developed in the future. This would cover interfaces built between CAM and other systems in the company, the way in which data is managed, the way in which projects are managed, and any special software that has been produced.

7.5.4 The User View of CAM

The users should be asked on the following subjects:

* Which applications are used with the CAM system. Such questions include: Is it only used for drafting, or also for design, NC programming, and so on? For which projects and products have these applications been used? When was the first use made for each application? Has an application been abandoned because the system was found to be unsuitable?

* The frequency of the use of the functions: This is to show that some functions are not used often, perhaps because training has been inadequate.

* A description of the training given: Includes the number of people trained on each course, an opinion to the suitability of courses with respect to the work being carried out, and suggestions for improvements.

* Number of models created and modified with CAM: To calculate to what extent data is being reused, both within an application and between applications.

* Comment on the ease of use of the CAM system and the quality of the associated documentation,(both that of the vendor and that produced in-house): Describing, from their point of view, the benefits and cost of the system.

7.5.5 Detailed System Performance and Problems

This part of the audit is focused on the CAM system itself, its use, its support, its operation, its management, its environment, and so on. The points to be noted are:

* Nearly all of the data required must be directly available. If not, it may indicate poor recording procedures.

* The description of the system: A list of installed hardware and software, CAM applications software, and the revision levels of the software.

* The availability of the system: Amount of time available for the users, undergoing maintenance, unavailability to users because of training or testing requirements, just not working, system failures, or repair times.

* Response times of the system to the functions used most often: Number of hours worked at each workstation, the type of work carried out at each terminal, and the way the system is used throughout a typical day.

* The general environment of the system and the workstations: Includes noise levels, temperature levels, etc.
* Plans for expansion of the system and any limiting factors for expansion.
* The throughput of the system and any bottlenecks.
* The current organization of the system: System management procedures, maintenance and operational procedures, data management, data security and data communications procedures, standards in use, the contents of data libraries, and their frequency of use.

7.5.6 Use of CAM Relative to Competitors

A comparison of the company's own use of CAM with that of its competitors is obviously very useful. If the competitor is using different CAM systems and using them in a different way, then top management will immediately want to know why. The type of information that the auditor needs to gather about the use of CAM by the company's competitors includes the type of the system used, the applications area for which they are used, the number of users, and so on. It may even be possible to find their systems in the areas in which they have most success, and the type of associated costs and benefits. The information thus gathered may show the company to be ahead (or behind) of its competitors. In either case, questions need to be asked as to what can be learned from the way in which competitors are using their system.

7.5.7 Effect of Changes in the Environment

Top management may well be wondering what CAM will be looking like in five years time, and how it will affect the company's organization and other systems in the company. Another source of questions concerning future development of the system stems from the continually changing technological environment and market.

Top management itself probably has the best view of the way in which customers requirements will change, and the way in which this will influence products and the behavior of competitors. The "pure" CAM part of the environment includes the availability of improvements to the CAM hardware, software, systems, and applications. Questions to ask are: What will be the effect of the increased availability of workstations? When will solid modeling techniques be more usable for drafting? Should the company expect to be using CAM on a mainframe computer or on distributed workstations connected by communications network? Which database technology will be most suitable for long-term CAM use.

Then there is the question of the way in which changes in associated engineering systems may effect CAM. And what about CIM? Should the company concentrate on getting CAM to work as efficiently as possible without taking too much account of other computer-based systems in the company, or should it try to integrate CAM to all these other systems even if that reduces the efficiency of the CAM system?

7.5.8 Analysis

Once all the information has been gathered, the next step is to analyze it with a view to redefining, if necessary, the CAM objectives and action plan. Since many people in the company will have been interviewed, a good overall view of the effect of CAM on the company should now be available. The different views of CAM given by different people need to be checked for consistency. Although the views of past and current events can be expected to be dissimilar, future plans and objectives should concord.

The first point to concentrate on the analysis is the objectives. The original objectives should be compared with the ensuing plans and use of CAM. The reasons for any incompatibilities need to be understood. Only then will it be possible to redefine objectives that can realistically be met. The major benefits of CAM as described by top management should be compared to those which were expected, and also to those that have been quantified at the project management level. Only thus is it possible to build up a solid base from which further advances can be made of the resource that will be required if such benefits are to occur.

By analyzing the results of the use of CAM in the company, the use of CAM by competitors, and expected changes in the environment, it is possible to identify activities in the company to which CAM should be applied. One particular area where the external auditor's views should be taken into account concerns the apparent strengths and weaknesses of the CAM installation. It may be clear to an outsider that the system is not being used to the limits of its potential, or that users are not being trained properly. Major areas where improvements are needed should be identified. These may include missing system usage procedures, lack of data management, bottlenecks obstructing better system throughput, and so on.

7.5.9 Redefinition of Objectives and Plans

From a clear picture of the existing situation, top management can redefine long-term objectives and middle management can adjust medium-term and short-term plans. Top management will be most interested in knowing if CAM has met its original objectives, and what impact it has had on the company's operations. With this knowledge at hand, it will be possible to redefine objectives. It may be decided; for example, to apply CAM to new activities in the company, to expand the CAM system, or to increase the number of users on CAM.

The major bottlenecks that have limited the throughput of the system need to be addressed, and solutions need to be found to remove or bypass them. This may require recruiting extra staff, purchasing new equipments, or developing interfaces between the CAM system and other systems in the company.

Top management will also have to address any questions that may arise concerning the organizational structure. Introduction of a new technology, such as CAM often causes new stresses and strains that result in cracks appearing in the organization. The results of the audit may well be one of the first and most tangible indications on the effect of CAM on the organization and on the organizational changes that management has made.

Before defining original CAM objectives and plans, it was necessary to go through a process of increased understanding and knowledge of CAM. The audit is somewhat a similar process. It provides a "total picture" which serves as the basis for defining CAM objectives and plans. Since these relate to all sorts of matters, including organization, size of system, CAM team size, training, use of CAM and so on, it is clear that the "total picture" really needs to give a complete picture on the effect of CAM. Therefore, if a company decides on an audit on the CAM implementation, then it must carry out a "total audit". There is little point in auditing the use of the CAM system without; for example, investigating its effect on the organization, on project management, on the quality of new products, or the acceptance rate of new proposals.

Just as, originally, the definition of CAM objectives and plans by top management was the first step in a long process involving middle managers and users, and eventually leading to everyday use of CAM. So the redefinition of CAM objectives resulting from the CAM audit opens up a new chapter in the use of CAM within the company. It should help to improve the effectiveness of the existing systems, and answer short-term questions about upgrading or replacing the system. It should lead to organizational changes that will increase the overall engineering efficiency. Most importantly though, it should lead to actions that will further improve the quality, use, and flow of engineering information within the company.

CHAPTER 8
DESIGN AND APPLICATION OF CAM SYSTEM FOR SHAFT MANUFACTURING

This chapter describes designing of an educational computer aided manufacturing (CAM) system for shaft manufacturing. The system could easily be altered for industrial use as well. This system is a complex system which can retrieve information from its databases in order to evaluate its operations and machine performance. The design methodology divides the design process into stages and solves different problems at different stages with proper tools and techniques.[14]

8.1 Background

To provide a background for the manufacturing process, the general structure is shown below:

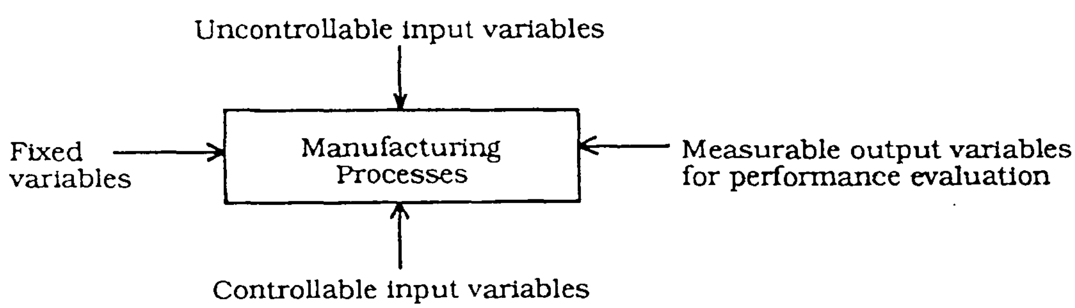

Figure 13 Structure of Manufacturing Processes

CAM can be applicable to the selection of feasible processes for producing specific machined shapes. This particular CAM process consists of using two sets of information:

Set 1: Information characterizing the parameters of the surface to be machined (Shaft drawings in this particular application).

Set 2 : Information about the processes, which can produce such surfaces as well as machines used in the processes.

A CAM package with a well-organized database can support this application by matching the two sets and efficiently generating a set of alternatives which contains those processes capable of meeting the parameter values in Set 1 and Set 2. The CAM system would then proceed to evaluate the economics of each potential process based on requirements such as volume, tooling costs, plant capacity, machine load, etc. Figure 14 shows the CAM data flow.

The information in Set 1 and Set 2 is stored in databases to facilitate the implementation of the CAM system. Figure 15 shows the role of databases in a general CAM configuration.

The manufacturing engineer enters the information about a product through a keyboard, disk workstation, or any other input/output device. The CAM system then uses the product information to pull out the processing information(defined in set 2) and required parameters (defined in set 1) from the technical database. The CAM system matches all the given parameters and generates the following for each alternative:

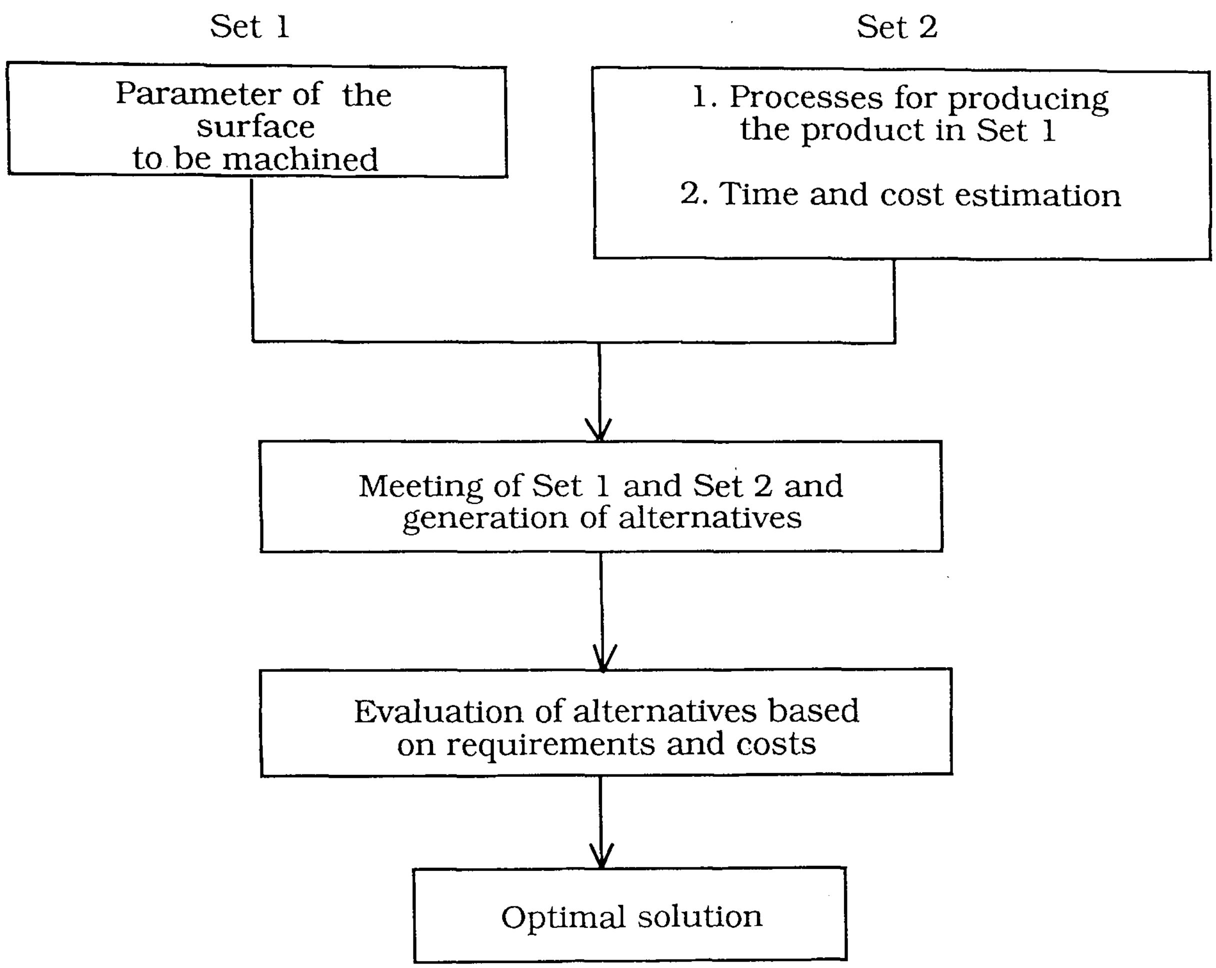

Figure 14 General CAM Data Flow

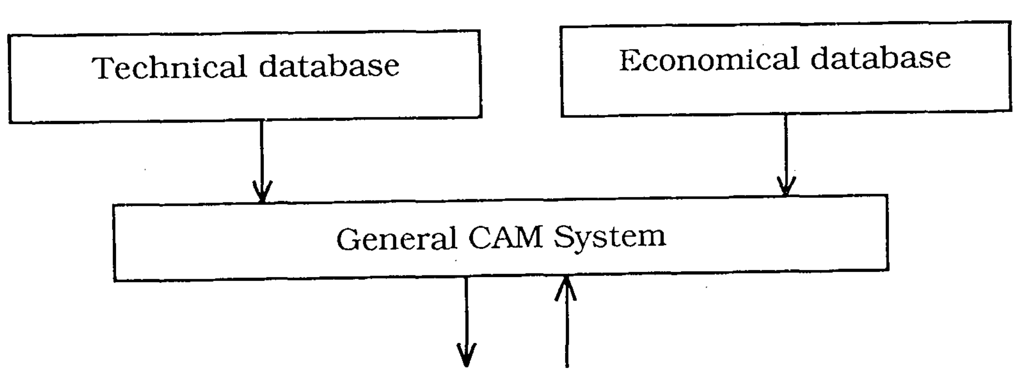

Figure 15 CAM Database Configuration

-Selection of Process

-Selection of Sequence of Manufacturing

-Selection Machines and Tooling

The CAM system analyzes all the alternatives from an economic point of view. This analysis is based on volume requirements and costs by using information stored in the economics database. After completion of the economic analysis, the system will select the optimum alternative for producing that product. The ultimate objective of the analysis is to:

-Minimize the Production Cost Per Piece

-Maximize the Production Rate

-Maximize the Profit

In addition to the above objectives, a well organized CAM should consider:

-Quality Optimization

-Process-yield Minimization

-Least Squares-error Minimization

Generally, the components of the manufacturing databases are very large. They contain information about the various considerations in manufacturing such as inventory, data, forecasting data, quality assurance, product history, purchase orders, customer orders, etc.

This section only discusses the technical data component. The technical database for shaft manufacturing CAM system contains the following information in Set 1 and Set 2:

I. Set 1

1. Requirements

   A. Number of Parts in Each Product
   B. Number of Products
   C. Clearance Plans
   D. Surface Finish
   E. Work Materials
   F. Accuracy

2. Engineering Dimensions

   A. Weights
   B. Sizes

3. Engineering Data

   A. Classification
   B. Standards
   C. Revisions

II. Set 2

1. Manufacturing Processes

   A. Turning
   B. Drilling
   C. Grinding

D. Planning

E. Slotting

F. Broaching

G. Shaping

H. Threading

I. Milling

2. Controllable Input Variables
(Adjust during the operation)

A. Temperature

B. Speed

C. Feed

3. Uncontrollable Input Variable

A. Tool Sharpness

B. Work-material Hardness and Geometry

4. Fixed Variables
(between operations)

A. Set-up Time

5. Measurable Output Variables

A. Power and Force

B. Temperature

C. Vibration

D. Flow Rate

E. Voltage

6. Performance Evaluation Variables

A. Economics of the Process

B. Quality of the Products

7. Pre-Planned Control

A. Program Control

B. Predetermined Operation Steps

C. Sequencing Control

8. Available Equipment

A. Machine Feed and Speed Rate

B. Tool Retract and Entry Modes

C. Tool Geometry Information

D. Coolants and Lubricants

E. Rough Cut Distribution

F. Tool Path Display

G. Cutting Side

8.2 Analysis

The analysis stage analyzes the technical data in a CAM environment for the functional requirements. The data describing the parameters of manufacturing the products are interrelated in a complex manner. The organization of such data plays an important role in understanding these intricate relationships of parameters and assists in constructing a CAM system.

The CAM system developed here must have the database of shafts and typical environment needs for shaft manufacturing. For example, in order to produce the shaft we need information like material of bar stock, machines needed, operation requirements, etc.

8.3 O-R Data Model

The Object-Relationship (O-R) data model is used to organize the information which should be stored in the technical database. The O-R model is based on a perception of a real system which consists of a set of basic objects and relationships among the objects. An object is described by a set of attributes. A set consists of the same type of objects. Objects may be either:

-Concrete, such as a machine

-Abstract, such as an operation

A relationship is an association among several objects. For example, we may define a relationship which associates machine "Swiss Turn" with operation "turning". The relationship between two sets may be many-to-many, one-to-many, many-to-one, or one-to-one. Figure 16 shows the Object-Relationship diagram with a set of machines and a set of operations.

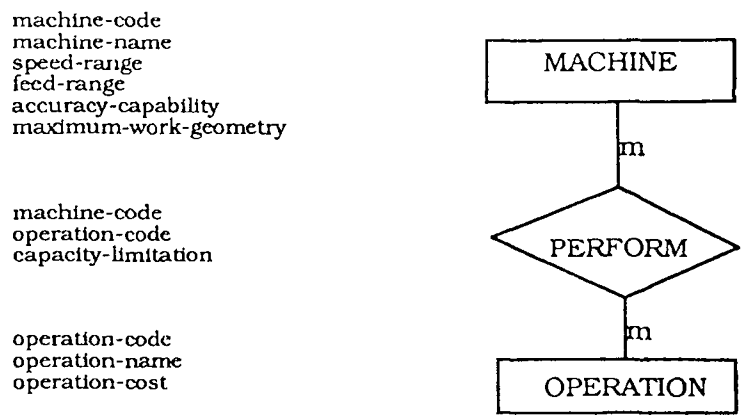

Figure 16 Object Relationship Diagram

8.4 Database Specification

Database specification serves as the input to technical design; therefore, this specification has to express user requirement in a form appropriate for technical design. Since, most commercial DBMS's store data as a set of records, the logical records structure is used to represent the enterprise model. The next step is to construct the database on a commercial DBMS. This includes:

1. Selection of DBMS
2. Methods to Store All the Required Data on Hardware Devices
3. The Database Structure Which Will Enable the Data To Be Accessed By Application Programs

The types of database includes relational, network, and hierarchical. The network DBMS is ideal for a CAM application in that a one-to-

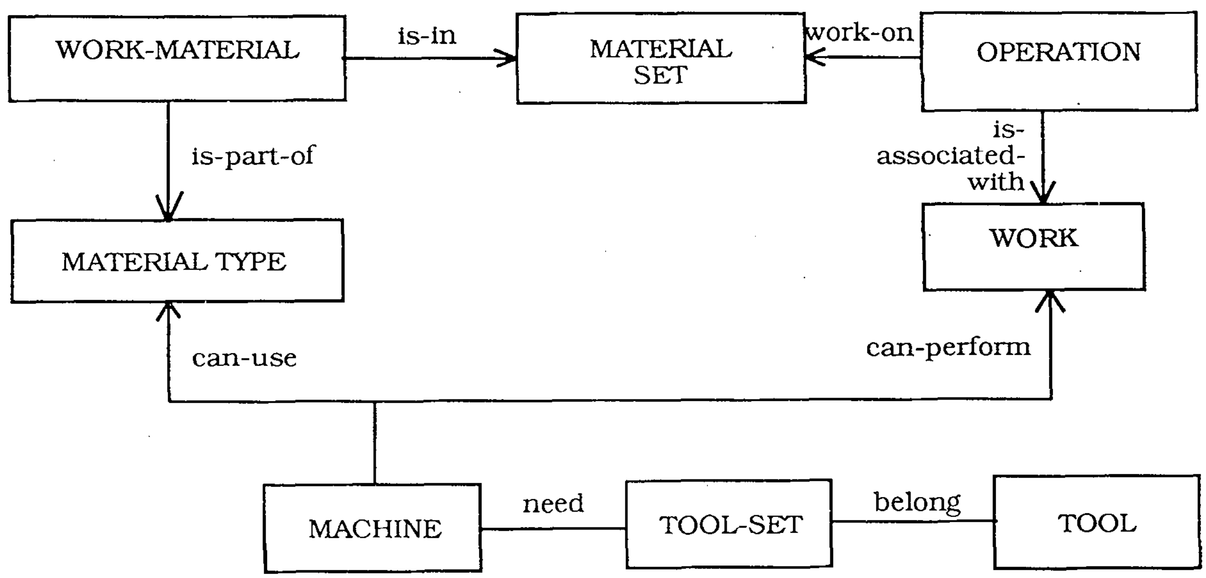

Figure 17 Overall CAM Network Structure

many relationship can be processed efficiently. Figure 17 shows the overall CAM network structure diagram.

8.5 Application Development for Shaft Manufacturing System

According to the above procedure, a CAM system is developed for shaft manufacturing. This system model is intended to demonstrate the concepts and functionality of computer aided manufacturing systems. The system is; however, a functional software package that may be adapted for use in small or midsize companies interested in computer aided manufacturing. If a database already exists within a company for manufacturing of basic components like shafts, bearings, cams, gears, etc., this system can be used for design changes, engineering changes, and process planning procedures. For analysis purposes, we will use the design and database of shaft manufacturing system developed by the Manufacturing Department of Allied Signal Aerospace Company, Eatontown, NJ. Following are stages of the methodology for implementing a CAM system into a shaft manufacturing system:

1. Constructing the Shaft Database
2. Developing the New Design and Processes to Facilitate the CAM System (Engineering Design and Methods Work)
3. Designing and Implementing the Software
4. Purchasing the Equipments and Hardware

8.5.1 Constructing the Shaft Database

Any CAM system cannot work without proper database and database management systems. Before implementing the CAM system, manufacturers should have a complete database of the parts which are to be manufactured by that system. In our case it will be a shaft database. The typical database includes:

Part number: A GT based classification and coding system can be developed to assign the proper partnumbers. This means coding of parts on the basis of similarities in their design and manufacturing attributes. GT based coding is useful to reduce set-up time, engineering and manufacturing changes, generic routing development, etc. The database in the Appendix shows a typical database for shafts, and a GT based coding system where each digit of the part number has a proper significance.

Details and Dimensions: Details like stock diameter and hardness are important in shaft manufacturing. In the advanced CAM system database, part drawings can be retrieved by each operator on their individual terminals. In that case, dimensions are on the drawings itself and do not need to be specified in the part database. Details also includes the number of teeth on the splines, pitch, material removal, etc. (Appendix)

8.5.2 Developing the New Design and Processes

The use of CAM has radically changed the design process as well as the resulting design. Using techniques on CAD, such as solid modelling, finite element methods, and dynamic simulation, the designer can design the strength of the structure to match precisely the expected operating load. The engineering department can develop complex and innovative designs with closer tolerances which were impractical by conventional manufacturing systems. Figure 18 and 19 shows the shaft design before and after the implementing the shaft design of CAM for the drive shafts. This results into the smaller bar stock size, lesser material removal, closer tolerances, etc.

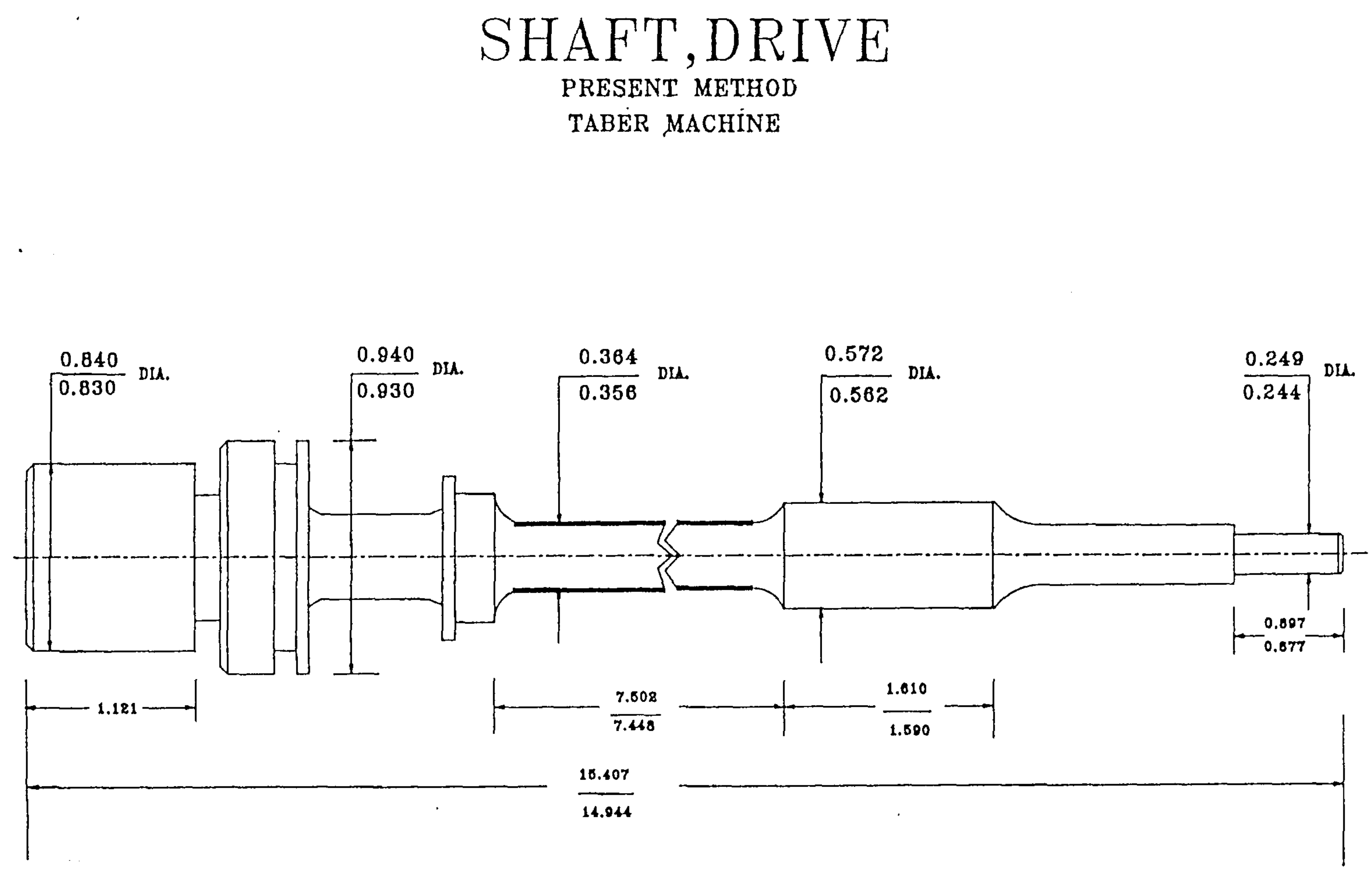

Figure 18 Shaft Design-Present Method

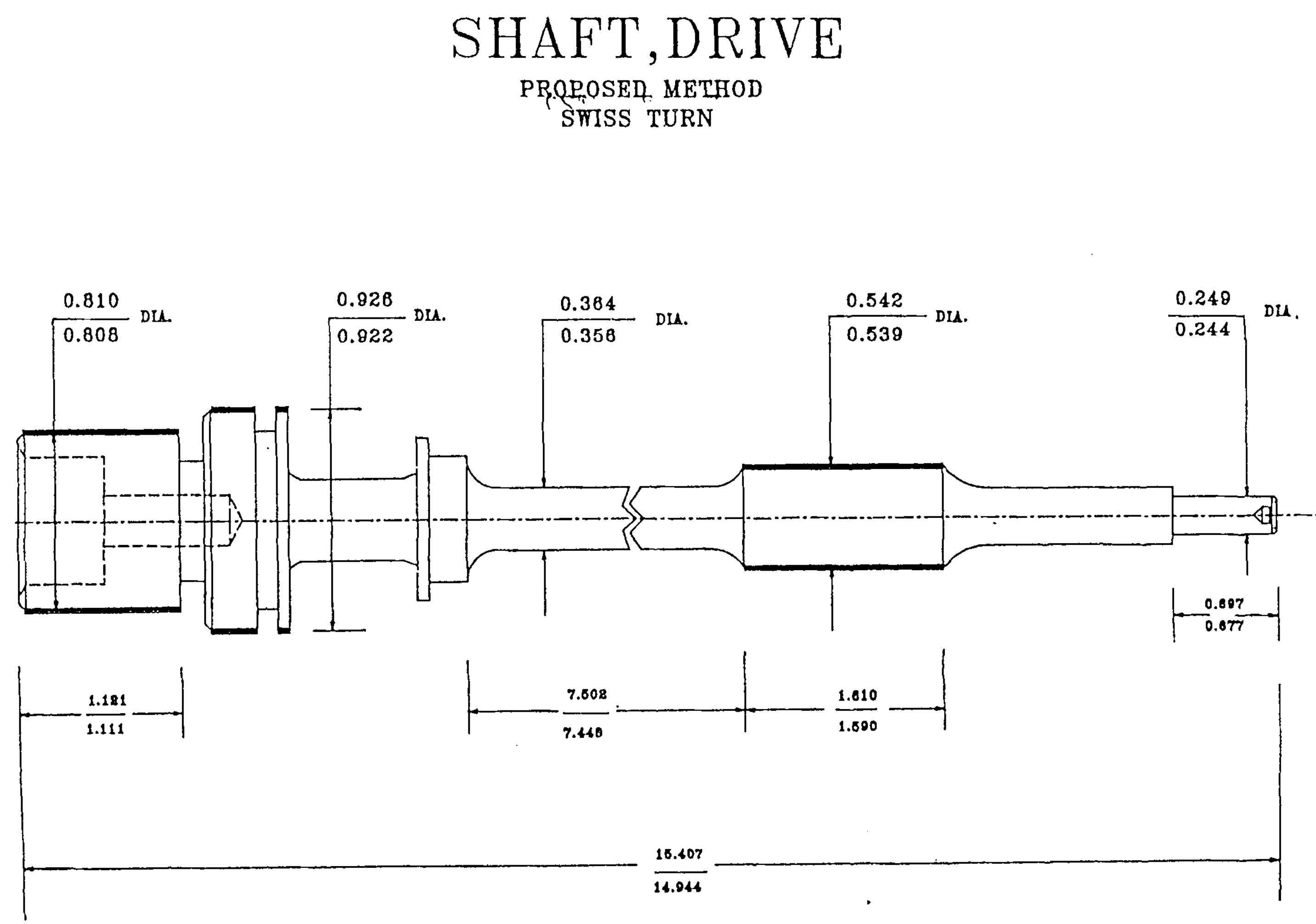

Figure 19 Shaft Design-Proposed Method

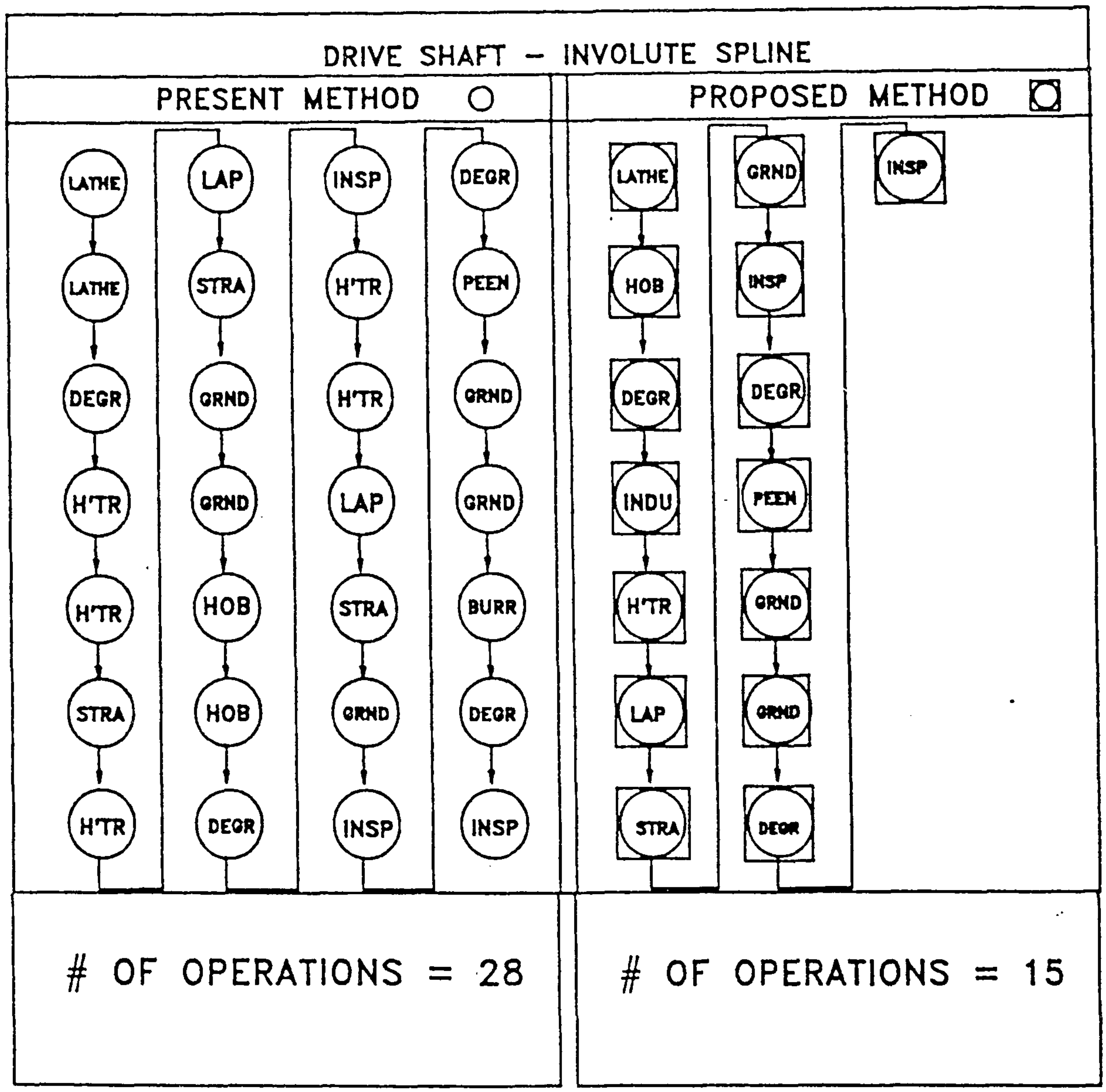

Figure 20 Changes in Manufacturing Method

The new design also results into new processes. The inventions and new technology made it possible to perform different manufacturing processes on the same machine and at the same time. For example, CNC swiss turn machines can turn the one end of shaft and at the same time drill the other end. The manufacturing department has to make new process plans for the CAM system. Process planning is the phase of manufacturing in the production cycle in which product designs are translated into the process required to produce the product. Process planning is responsible for the general flow of information from design engineering to the factory floor. Figure 20 shows the changes in the manufacturing method after implementing the CAM system. This results into new factory layout, less number of process, less material handling, smooth flow of material, less throughput time, less in-process inventory, and so on. The new process sheet will be transferred by the computer system and each operator can have up-to-date information of the product in the process.

8.5.3 Design and Operation of the CAM Software

This customized CAM system is designed in the software package Quatro Pro 3.0, which is a spreadsheet package similar to Lotus 1-2-3 and Excel. CAM is designed using the macro commands allocated by the Quatro Pro package which can be altered to operate in other spreadsheet packages.

Macro's are written in much the same way as a program would be written in BASIC. That is by following logical programming operations and conforming your ideas to the common limitations set out by the software. This program is designed to be as user-friendly as possible, so that people with limited computer knowledge can generate processes with relative ease.

Using special macro commands, custom menus are displayed to the user who in turn makes the proper selection from the menu. Messages are

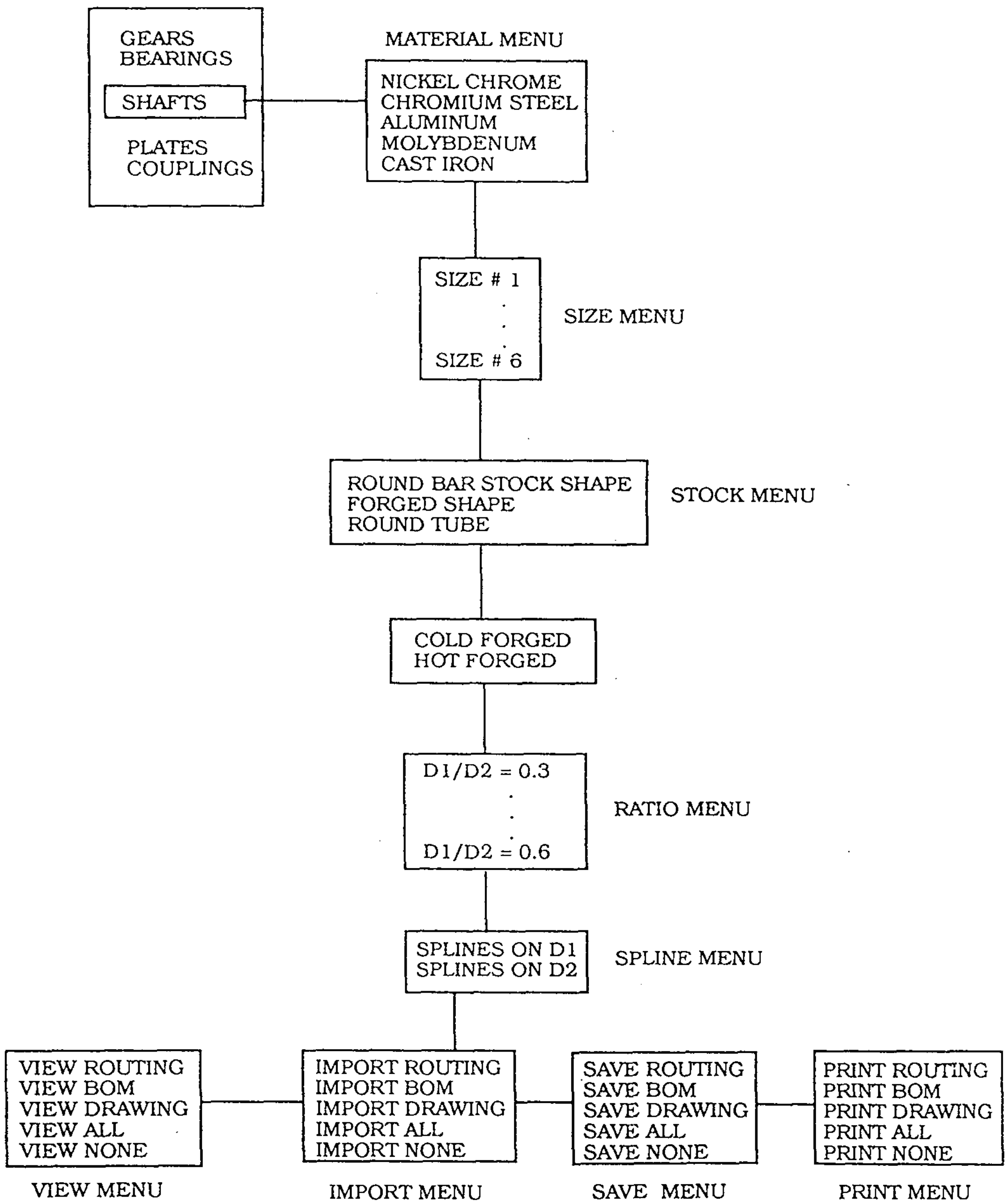

Figure 21 Schematic View of CAM Program

displayed to the user throughout the process to help guide the user. The selection the user makes will generate the part code number. This code number will be used to search a database of existing route sheets, bill of material, and drawings of a particular part number. If the code number does not exist in the system, the system will allow the user to select the nearest code number in the family, make the necessary changes, and save the new route sheet, and drawing to the system. Figure 21 shows the schematic view of the program.

8.5.4 Equipment Selection

It is necessary to purchase new equipment to facilitate the CAM program. Equipment selection is a critical factor in the success of the CAM system. After analyzing the procedures, the manufacturing manager should ask for a quotation from vendors of CNC machine tools. In the shaft manufacturing system the main machine is the lathe. The decision should be based on the machine capacity, size limitations, power, flexibility, controller type and its compatibility with existing CAM software, number of tools, and set-up time. The functional comparison sheet should be developed and vendors should be asked for all the functional requirements. The swiss turn machine selection sheet is shown in figure 22. Once we finish the functional requirement, an expert's help is needed. They should be asked for technical requirements and advanced developments. Training is also an important consideration in the equipment selection. The vendors should be asked for in-house and outside operator's training. At last, the user's opinion should be taken on the selection of the machine.

SWISS TURN / ATTRIBUTES	CITIZEN E 32 SELECTED	KMX SYS. KMX 26 OUT	MAZAK MULTI 420 OUT	STAR KNC 32 OUT	TSUGAMI NP32 OUT	MAZAK 15A MS OUT	14/12/90
MAX. DIA. STD.	1.26 "	1 "	2.0 "	1.26 "	1.260 "	1.375 "	MAX. DIA. STD.
MAX. DIA. SPECIAL	1.29 "			1.29 "	1.29 "		MAX. DIA. SPECIAL
MAX. LENGTH	12.6 "	6.0 "	7.08 "	12.2 "	8.28 "	18.9 "	MAX. LENGTH
MAIN SPINDLE HP	10	10	20	10	10	20	MAIN SPINDLE HP
MAIN SPINDLE RPM	6000	3000	3600	6000	4500	4500	MAIN SPINDLE RPM
RAPID TRAVERS SPEED IPM Xn/Zn	472 / 630	394	472 / 945	394 / 472	315 / 315	709 / 709	RAPID TRAVERS SPEED IPM Xn/Zn
SUB-SPINDLE HP	2		3	2	2	7.5	SUB-SPINDLE HP
SUB-SPINDLE RPM	5000		2500	5000	3000	4500	SUB-SPINDLE RPM
# OF TURRETS	2	2	2	2	2	1	# OF TURRETS
TOTAL # OF TOOLS	20 40 WITH SP.TOOLHOLDER	12	24	20 + 8 3 AXIS TOOL HOLDER	12 ROTORY ON REAR TURRET	12	TOTAL # OF TOOLS
TOOL SIZE TURNING	0.75 " sq. x 3.5 "	0.625 " sq.	0.75 " sq. x 5.0 "	0.625 " sq. x 3.0 "	0.625 " sq. x 3.15 "	0.75 " sq.	TOOL SIZE TURNING
TOOL SIZE DRILLING	.393 "	1.0 "	1.25 "	0.9 "	1.0 "	1.25 "	TOOL SIZE DRILLING
TURRET AXIS CAPABILITY TOTAL/SIMULTANEOUS	6 / 3	3 / 3	6 / 3	4 / 3	5 / 4	6 / 3	TURRET AXIS CAPABILITY TOTAL/SIMULTANEOUS
CONTROLLER TYPE	CINCON SYS III		MAZATROL CAM T-6	FANUC OTT	FANUC CONTROL	MAZATROL T-32	CONTROLLER TYPE
SUBMITTED SAMPLE PARTS	YES	NO	YES	YES	NO .	NO	SUBMITTED SAMPLE PARTS
POSITION ACCURACY	0.00004 "		0.00004 "	X +/- .00004 Y +/- .00004	0.00035 "	0.00004 "	POSITION ACCURACY
REPEATABILITY	0.00004 "	0.0002 "	0.00004 "	0.00004 "	0.000040 "	0.00004 "	REPETABILITY
INDEX TIME / STATION	0.2/STATION		0.7/STATION	1 SEC CHIP TO CHIP	2 SEC. CHIP TO CHIP	0.4/STATION	INDEX TIME /STATION
BASE CONSTRUCTION	CAST IRON			CAST IRON	CAST IRON		BASE CONSTRUCTION
DOUBLE CHUCKING	YES	NO		YES	YES	YES	DOUBLE CHUCKING
↓ OPTIONS ↓	↓	↓	↓	↓		↓	
CHIP CONVEYOR	OPTIONAL		OPTIONAL	OPTIONAL	OPTIONAL	STANDARD	CHIP CONVEYOR
OPERATOR TRAINING	2 W/OPER,1 W/PROG. INHOUSE/SCHEDUALE			2 W OFF SITE OR INHOUSE	2 W/OPER.,SCHEDUALE NC INSTRUCTION SCHOOL		OPERATOR TRAINING
WARRANTY MACH/CNTL	1 YEAR/1 YEAR			1Yr./2Yr.	1Yr. /2Yr.		WARRANTY MACH/CNTL
SERVICE CONTRACT	AVAILABLE PARTS & LABOR			AVAILABLE 1Yr AT A TIME	AVAILABLE		SERVICE CONTRACT
TOOL PRESETTER	OPTIONAL			OPTIONAL	OPTIONAL		TOOL PRESETTER
PARTS CONVEYOR	OPTIONAL		OPTIONAL	OPTIONAL	OPTIONAL	OPTIONAL	PARTS CONVEUOR
POST PROCESSER	OPTIONAL			OPTIONAL OFF MACHINE	OPTIONAL		POST PROCESSER
NOTES:		CAN'T MACHINE PART OF REQUIRED LENGTH	NOT A TRUE SWISSTURN MACHINE	CITIZEN HAS A BETTER CONTROLLER		CAN'T FURNISH MACHINE IN REQUIRED TIME	
	CENTERLESS GROUND MATERIAL REQ.		20,000 INVESTMENT FOR TEST RUN	CENTERLESS GROUND MATERIAL REQ.	CENTERLESS GROUND MATERIAL REQ.		

Figure 22 Machine Selection Chart

8.6 CAM System Benefits

The objective of CAM is to improve the service level of the manufacturing engineering department. Utilization of planning an engineer's time can be increased typically on the order of 60 %, with substantial improvements in the level of service provided. The impact of this can considerably affect shop floor performance due to:

- Release of Engineers From Clerical Routines for Method Improvements and Cost Reduction Exercises.
- Improved Level of Detail Available for Manufacturing Instructions.
- Consistency in Development of Operation Times Over a Wide Product Range.
- Acceptability of Planned Targets By Shop Floor Operation and Supervision.
- Speed of Response of Engineering Changes.
- Accurate Estimates For Comparison With Shop Floor Achievements.
- Reduced Pro-production Lead Times.

8.7 Possible Future Work

This CAM program can be developed for large manufacturing facilities. The same program with a substantial database system can be used for manufacturing of gears, bearings, cams, and plates. This database should include the following:

* Group Technology Based Coding Systems
* N/C Program Generation
* Conversion of CAD Files
* Interface Programs With Actual Machines

CHAPTER 9
CONCLUSION

The thesis has proposed a methodology to implement the CAM system in a production environment. The main problems with the CAM implementation are the communication gap between different departments and training of management to accommodate the new system. The problem can be eliminated using proper selection, implementation, integration, and evaluation of the system. The design of the CAM system was dealt with the creation of a database according to the product.

The selection of the system was based on, which areas to be automated in the organization. This decision can be made by performing AS-IS-Analysis and Need-To-Be Analysis on the factory environment. A CIM planning system is proposed using different management teams. The management team has to develop a specific evaluation criteria, find the vendors that can fulfill the identified automation needs, and meet the basic criteria established in the CIM plan.

The implementation of the selected CAM system was dealt with problems like system management, site selection, training, and establishing standards and procedures for acomputerized system. The training is needed throughout the organization from top executives to the end users. A theory is developed to establish new standards and procedures for the CAM system. The theory discussed about problems on file naming, archiving procedures, and revision control of the new programs.

Through cooperative efforts between the engineering and manufacturing departments, computer integration of CAD and CAM has begun to take place. Integration of CAD and CAM can solve many communication problems existing in the CIM environment. This integration can be done by using an integrated database system, and planning and implementation of a communication system.

Evaluation and auditing of the CAM system, is associated with productivity measurement. Productivity measurement was discussed by two methods-comparing the system performance to conventional method and comparing the system with existing systems of the same kind at other companies.

Finally, this thesis proposed the design criteria for the CAM system and, a CAM program is developed for the shaft manufacturing. The program deals with computer aided process planning of the shaft. The use of the program can save efforts and money invested in the process planning. Operation of the program is simple and user-friendly.

APPENDIX

FILE: C:\PDX\VAULT\DRVSHFTS

December 28, 1990

DRIVE SHAFTS

PART#:	1532300-2	STOCK DIA.:	1.312	LOHARD:	34	A-TEETH:	24.000	B-TEETH:	12.000	D:	7.244	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	1.267	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	20/40	E:	1.031	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	1.200	B-PITCH DIA:	.600	F:	.906		
ATTRIBUTE:	D		.045	LENGTH:	9.432								
PART#:	1532300-3	STOCK DIA.:	1.312	LOHARD:	34	A-TEETH:	24.000	B-TEETH:	12.000	D:	7.244	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	1.267	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	20/40	E:	1.031	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	1.200	B-PITCH DIA:	.600	F:	.906		
ATTRIBUTE:	D		.045	LENGTH:	9.432								
PART#:	1532582	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	12.000	B-TEETH:	12.000	D:	10.500	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.687	HIHARD:	38	A-PITCH:	24/48	B-PITCH:	32/64	E:	.718	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.600	B-PITCH DIA:	.375	F:	1.625		
ATTRIBUTE:	D		.251	LENGTH:	12.750								
PART#:	1532633	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D:	10.884	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	32/64	E:	.756	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.375	F:	1.625		
ATTRIBUTE:	D		.071	LENGTH:	13.134								
PART#:	1532943	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	12.000	B-TEETH:	11.000	D:	8.341	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.650	HIHARD:	38	A-PITCH:	20/40	B-PITCH:	24/48	E:	.750	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.600	B-PITCH DIA:	.458	F:	1.125		
ATTRIBUTE:	D		.288	LENGTH:	10.341								

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PART#: 1534530	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D: 10.437	G:	0.000
DESCRIP.: SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E: .781	H:	0.000
CLASS: SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F: .750		
ATTRIBUTE: D		.071	LENGTH:	12.125							

PART#: 1534979	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D: 9.828	G:	0.000
DESCRIP.: SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E: 1.262	H:	0.000
CLASS: SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F: .750		
ATTRIBUTE: D		.071	LENGTH:	11.327							

PART#: 1536185	STOCK DIA.:	1.312	LOHARD:	34	A-TEETH:	24.000	B-TEETH:	12.000	D: 9.701	G:	0.000
DESCRIP.: SHAFT,DRIV	- MAX OD:	1.267	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	20/40	E: 1.031	H:	0.000
CLASS: SHAFT		=========			A-PITCH DIA:	1.200	B-PITCH DIA:	.600	F: .656		
ATTRIBUTE: D		.045	LENGTH:	11.451							

PART#: 1536779	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D: 7.776	G:	0.000
DESCRIP.: SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	32/64	E: 1.141	H:	0.000
CLASS: SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.375	F: .500		
ATTRIBUTE: D		.071	LENGTH:	8.641							

PART#: 1537494	STOCK DIA.:	1.312	LOHARD:	34	A-TEETH:	24.000	B-TEETH:	12.000	D: 7.679	G:	0.000
DESCRIP.: SHAFT,DRIV	- MAX OD:	1.267	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	20/40	E: 1.500	H:	0.000
CLASS: SHAFT		=========			A-PITCH DIA:	1.200	B-PITCH DIA:	.600	F: .750		
ATTRIBUTE: D		.045	LENGTH:	9.867							

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DRIVE SHAFTS

PART#:	1543715	STOCK DIA.:	1.312	LOHARD:	34	A-TEETH:	24.000	B-TEETH:	12.000	D:	9.705	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	1.270	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	20/40	E:	1.031	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	1.200	B-PITCH DIA:	.600	F:	.656		
ATTRIBUTE:	D		.042	LENGTH:	11.455								
PART#:	1544392	STOCK DIA.:		LOHARD:		A-TEETH:		B-TEETH:		D:		G:	
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.704	HIHARD:		A-PITCH:		B-PITCH:		E:		H:	
CLASS:	SHAFT		=========			A-PITCH DIA:		B-PITCH DIA:		F:			
ATTRIBUTE:	D			LENGTH:	6.719								
PART#:	1544466	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D:	11.193	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E:	.661	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	1.750		
ATTRIBUTE:	D		.071	LENGTH:	12.755								
PART#:	1545961	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D:	11.565	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E:	1.375	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	1.750		
ATTRIBUTE:	D		.071	LENGTH:	13.125								
PART#:	1546588-1	STOCK DIA.:	.938	LOHARD:	48	A-TEETH:	16.000	B-TEETH:	12.000	D:	10.952	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	52	A-PITCH:	20/30	B-PITCH:	24/48	E:	.874	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	2.188		
ATTRIBUTE:	D		.071	LENGTH:	12.686								

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December 28, 1990 DRIVE SHAFTS

PART#:	1546725-1	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	11.000	D:	13.831	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E:	1.000	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.458	F:	1.063		
ATTRIBUTE:	D		.071	LENGTH:	15.465								
PART#:	1547196-1	STOCK DIA.:	.938	LOHARD:	28	A-TEETH:	16.000	B-TEETH:	12.000	D:	7.128	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.876	HIHARD:	32	A-PITCH:	20/30	B-PITCH:	20/40	E:	.756	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.600	F:	.875		
ATTRIBUTE:	D		.062	LENGTH:	7.691								
PART#:	1548118-1	STOCK DIA.:	.938	LOHARD:	28	A-TEETH:	16.000	B-TEETH:	12.000	D:	11.187	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	32	A-PITCH:	20/30	B-PITCH:	24/48	E:	1.375	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	1.625		
ATTRIBUTE:	D		.071	LENGTH:	13.187								
PART#:	1548876	STOCK DIA.:	1.000	LOHARD:	34	A-TEETH:	11.000	B-TEETH:	12.000	D:	1.000	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.922	HIHARD:	38	A-PITCH:	24/48	B-PITCH:	20/30	E:	10.227	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.460	B-PITCH DIA:	.800	F:	1.625		
ATTRIBUTE:	D		.078	LENGTH:	12.251								
PART#:	1549640-1	STOCK DIA.:	.938	LOHARD:	44	A-TEETH:	16.000	B-TEETH:	12.000	D:	14.833	G:	10.083
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	48	A-PITCH:	20/30	B-PITCH:	24/48	E:	.880	H:	.312
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	.750		
ATTRIBUTE:	D		.071	LENGTH:	15.536								

FILE: C:\PDX\VAULT\DRVSHFTS

December 28, 1990 DRIVE SHAFTS

PART#:	1580307-1	STOCK DIA.:	.938	LOHARD:	28	A-TEETH:	16.000	B-TEETH:	12.000	D:	9.523	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	48	A-PITCH:	20/30	B-PITCH:	24/48	E:	.780	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	.750		
ATTRIBUTE:	D		.071	LENGTH:	11.022								

PART#:	1580499-1	STOCK DIA.:	.938	LOHARD:	28	A-TEETH:	16.000	B-TEETH:	12.000	D:	10.413	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	50	A-PITCH:	20/30	B-PITCH:	24/48	E:	.780	H:	0.000
CLASS:	SHAFT		=========			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	.750		
ATTRIBUTE:	D		.071	LENGTH:	11.022								

PART#:	1581241-1	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D:	11.407	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E:	1.375	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	1.625		
ATTRIBUTE:	O		.071	LENGTH:	12.094								

PART#:	1581466-1	STOCK DIA.:	1.000	LOHARD:	28	A-TEETH:	6.000	B-TEETH:	12.000	D:	12.682	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.937	HIHARD:	50	A-PITCH:	AUTO	B-PITCH:	20/40	E:	.156	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.865	B-PITCH DIA:	.600	F:	1.300		
ATTRIBUTE:	D		.063	LENGTH:	13.372								

PART#:	1581901-1	STOCK DIA.:	.938	LOHARD:	28	A-TEETH:	16.000	B-TEETH:	12.000	D:	8.562	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	32	A-PITCH:	20/30	B-PITCH:	32/64	E:	1.015	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.800	B-PITCH DIA:	.375	F:	.937		
ATTRIBUTE:	D		.071	LENGTH:	9.827								

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DRIVE SHAFTS

PART#:	1538375	STOCK DIA.:	.938	LOHARD:	28	A-TEETH:	16.000	B-TEETH:	12.000	D:	9.701	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.875	HIHARD:	32	A-PITCH:	20/30	B-PITCH:	20/40	E:	1.000	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.800	B-PITCH DIA:	.600	F:	.656		
ATTRIBUTE:	D		.063	LENGTH:	11.451								
PART#:	1538782	STOCK DIA.:	1.312	LOHARD:	47	A-TEETH:	24.000	B-TEETH:	12.000	D:	12.075	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	1.267	HIHARD:	50	A-PITCH:	20/30	B-PITCH:	20/40	E:	1.000	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	1.200	B-PITCH DIA:	.600	F:	.875		
ATTRIBUTE:	D		.045	LENGTH:	13.575								
PART#:	1539169-1	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	12.000	B-TEETH:	12.000	D:	8.062	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.750	HIHARD:	38	A-PITCH:	20/40	B-PITCH:	24/48	E:	.626	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.600	B-PITCH DIA:	.500	F:	1.625		
ATTRIBUTE:	D		.188	LENGTH:	10.061								
PART#:	1541612	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D:	9.523	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E:	.780	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	.750		
ATTRIBUTE:	D		.071	LENGTH:	11.022								
PART#:	1543438	STOCK DIA.:	.938	LOHARD:	34	A-TEETH:	16.000	B-TEETH:	12.000	D:	9.942	G:	0.000
DESCRIP.:	SHAFT,DRIV	- MAX OD:	.867	HIHARD:	38	A-PITCH:	20/30	B-PITCH:	24/48	E:	.688	H:	0.000
CLASS:	SHAFT		*********			A-PITCH DIA:	.800	B-PITCH DIA:	.500	F:	2.250		
ATTRIBUTE:	D		.071	LENGTH:	11.583								

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