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A structured methodology for the evaluation and selection of turnkey CAD/CAM systems.

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A STRUCTURED METHODOLOGY FOR THE EVALUATION AND SELECTION OF TURNKEY CAD/CAM SYSTEMS

by

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in

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CERTIFICATE OF APPROVAL

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

10 Dec. 1984
(date)

Professor in Charge

Chairman of Department

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ABSTRACT

The objective of this thesis is to develop a computer based methodology for the evaluation and selection of computer-aided design and computer-aided manufacturing (CAD/CAM) systems. Literature in the field indicates that traditionally, turnkey systems have, for the most part, been evaluated and selected based on specific departmental needs or corporate mandates. Requirements for these systems ranged from increased throughput for detailed designs to the ability to expeditiously generate numerical control (NC) machine tool tapes. This narrow focused approach to purchasing and implementing CAD/CAM systems has subsequently led to stand-alone islands of automation within the business structure. This thesis, however, develops an integrated systems approach that promotes and facilitates computer integrated manufacturing (CIM). The uniqueness of the methodology developed in this thesis is that it provides the user with a selection process that is timely and efficient and yet gives consideration to the technologies required to implement CIM.

The structured system selection methodology is centered around the approach to developing,

evaluating and selecting a CAD/CAM system that will allow a CIM strategy to become a reality. Initially, this approach requires a thorough understanding and analysis of the process that will be automated by CAD/CAM. This analysis is then expanded to include the integration of CAD/CAM into the overall business function. Finally, the computer methodology is applied to a case study whereby the criteria to achieve CIM are weighted and categorized based on perceived needs and company objectives.

Chapter 1 INTRODUCTION

In the broadest of terms, CAD/CAM systems provide computer aided assistance in all design and manufacturing functions. Specifically, CAD/CAM furnishes the tools to access, create, modify and analyze an integrated product data base. The tools are rapidly becoming mandatory, particularly in the area of design productivity where increases of 3:1 are common.[4]

CAD/CAM technologies have the capability to provide many other important benefits including reductions in total time required to bring a product to the marketplace, reduced inventory via parts and process standardization and the sharing of common data between manufacturing and engineering. Engineering analysis tools can also provide the capability of continued superior part performance and decreased weight.

Integration of these CAD/CAM technologies is vital to realizing the full potential of any system installation. The objective of the area or department charged with the responsibility of evaluating and selecting a CAD/CAM system is to identify and incorporate specific CAD/CAM technologies into all applicable design and manufacturing functions. The ultimate goal should be to interface these technologies into appropriate business and manufacturing planning systems, achieving a Computer Integrated Manufacturing environment (CIM).

This thesis will describe a computer based methodology that can be used for the evaluation and selection of turn-key CAD/CAM systems. A case study will also be presented in which the qualifications of the CAD/CAM department members will be addressed as well as the definition of the user investigative organizations. The result of this thesis will therefore be to develop a logical and systematic approach for the selection and implementation of an appropriate CAD/CAM system.

Chapter 2 PROBLEM DEFINITION

Despite the rapidly growing interest in computer-aided design and computer-aided manufacturing (CAD/CAM), methods for evaluating and selecting these systems remain elusive. The potential customer is faced with a decision to choose among hardware and software products supplying a wide spectrum of capabilities. The problem, therefore, is to first identify and categorize these modern technologies and then create a structured methodology that allows the prospective buyer to uniformly evaluate turnkey CAD/CAM vendor offerings.

There is, however, no simple answer as to how to evaluate and select a CAD/CAM system. The trend is for companies to focus the evaluation process around a specific localized requirement or mandate. The majority of the systems selected using this specific procedure are evaluated on their ability to generate either design drawings or numerical control (NC) machine tool tapes. CAD/CAM systems purchased with these limited criteria normally fulfill the original user's needs but seldom allow for growth or system enhancement. The challenge is then to provide a methodology that evaluates

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CAD/CAM systems based on overall corporate business needs while at the same time provides for integration into a comprehensive computer integrated manufacturing (CIM) strategy.

Chapter 3 BACKGROUND

This chapter gives a background of the organization that was examined as part of the case study for this thesis. The organization of the company, its products, and the groups that were surveyed to develop the information flow diagrams are described below.

The company is a heavy duty truck manufacturer that produces trucks for the American as well as foreign markets. Although considered a transportation industry, truck manufacturing is different from automotive manufacturing in that the final delivered product is completely customer specified. This allows the customer a great deal of freedom in deciding what features he wants on his truck but this unrestricted options form of marketing creates the need for additional special engineering and manufacturing support.

3.1 Engineering.

At a high level, characteristic project and work flow through engineering would be as follows: (Figures 3.1 and 3.2).

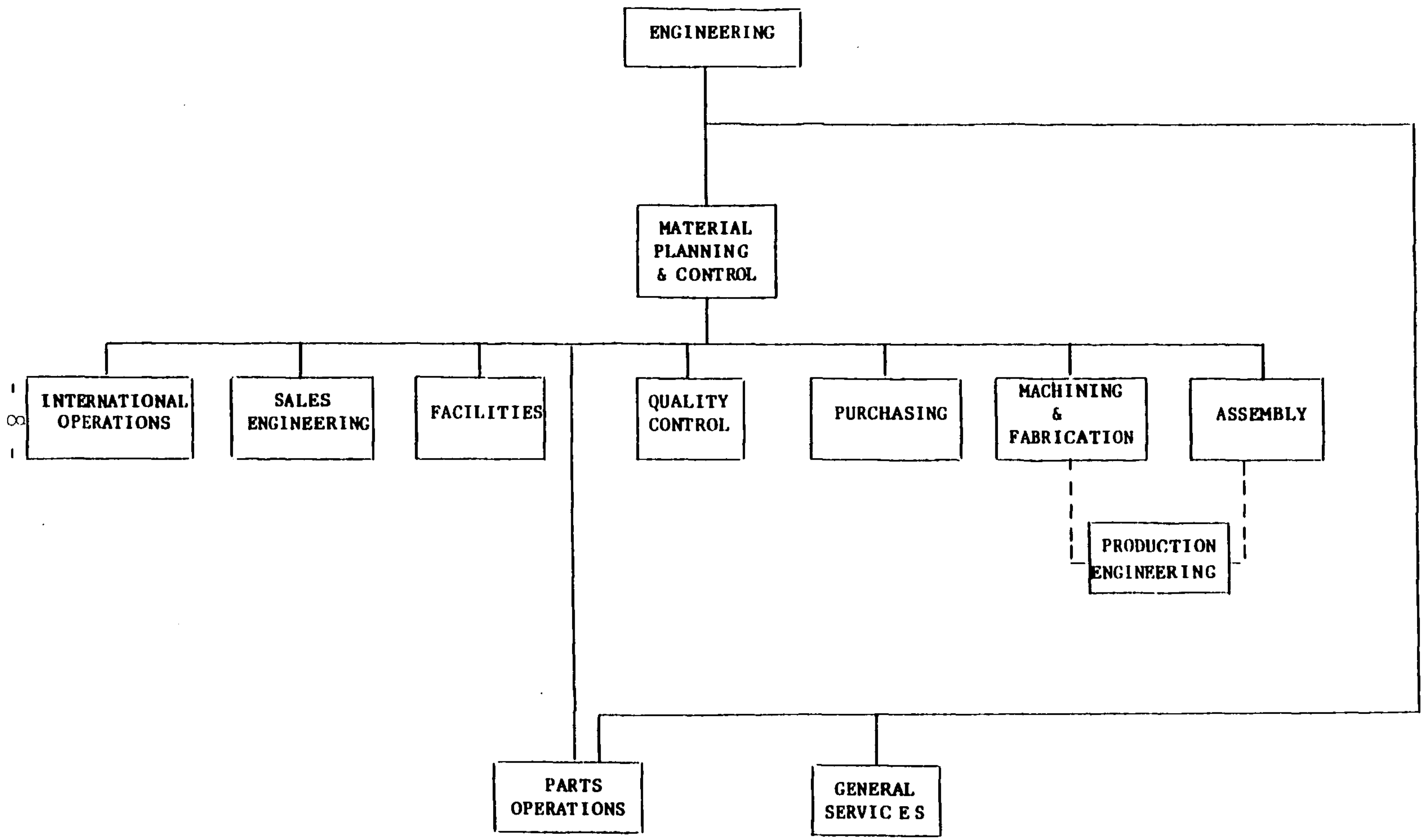

Figure 3.1 Functional Schema of Corporate Operations

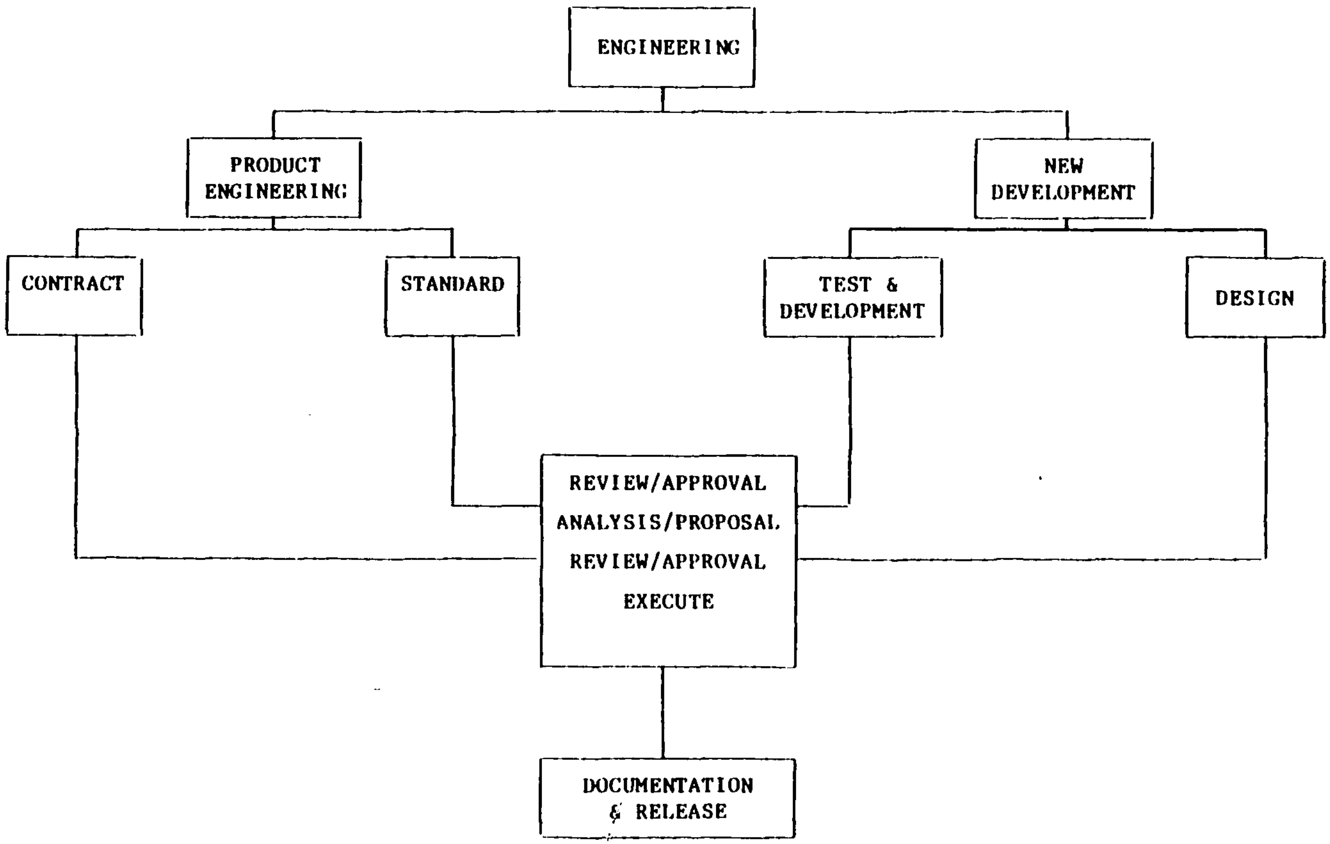

Figure 3.2 Functional Schema of Engineering Information

A need for a new product is determined by top management with basic requirements being passed on to the engineering division. The product development group develops broad recommendations, renderings, specifications for management approval. Upon approval, design layouts will be prepared. From those layouts prototype components will be designed and manufactured for test within the engineering development laboratory.

Prototype testing results will determine any necessary design changes, which will again result in a prototype test. This cycle will be repeated as deemed necessary to arrive at an optimum design.

At a point in time after the new product has been implemented into production, the responsibility for the product is transferred to product engineering for ongoing enhancements and maintenance. With reference to the "special customer" responsibilities, it is noted that approximately 85% of all orders received require some degree of "contract" engineering.

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The need to create or revise engineering drawings can originate from various areas. While the reasons for creating or revising drawings vary, the method used to initiate most activity is either the request for design change (RDC) or general sales order (GSO) which relates to special engineering requirements. These documents are reviewed and approved by engineering. Each approved project is then assigned to the appropriate design supervisor who in turn assigns the project to the appropriate drafting supervisor.

The various steps outlined below (design, layout and detail) are not always required, but are dependent on the scope and complexity of the project. For purposes of this thesis, all three (3) phases will be covered.

1. Design Drawings. Where the complexity of the project demands, conceptual design configurations will be developed. These drawings may take the form of simple hand sketches or may be formal engineering drawings or artist renderings. The documents will carry the information required to convey basic design concepts. The designer will normally

interface with design management and a project engineer. Once the concepts have been approved the related sketches and drawings are passed to the layout function.

2. Layout Drawings. The layout drawing is basically used to determine space availability for new or revised components. These documents carry sufficient information in the form of dimensions and notes to allow complete detailing of components. Layouts may or may not be assigned part numbers. Similiarly, not all layouts would be retained in engineering drawing files. Following required approval, all layout drawings and design sketches are passed on to the detailing function.

3. Detail Drawings. Detail drawings include all necessary information required to manufacture the component. This includes part outline, dimensions, views and sections, notes and appropriate specific-ations. Revision history is also recorded. These drawings may be utilized as a source of information in preparing manufacturing processes or on the manufacturing floor as a direct source of

machining and fabrication information.

Arrangement drawings are part of the detailing function. These drawings carry all pictorial and dimensional information as well as notes required to facilitate the assembly of two or more components. These drawings also carry revision history information. It is during this process that certain information required for other engineering activities is extracted or developed. This includes the creation of a rough bill of materials listing based on arrangement and assembly drawing content and creating a "new part versus old" comparison listing for engineering change and release notice requirements. All arrangement and assembly and detail drawings, when completed, are then checked for accuracy and adherence to engineering and manufacturing standards.

The checked drawings are then reviewed by appropriate design management and,following their approval, sent to the engineering reproduction department for copying and distribution via the engineering change notice (ECN) procedures. Original drawings are retained within the reproduction department files.

3.2 Manufacturing.

Dissemination and use of engineering information within the manufacturing areas vary from one plant to the next. For purposes of this thesis, a schematic of the work flow is provided. (Figures 3.3 and 3.4). In general, however, engineering information is transmitted to the manufacturing and assembly areas in the form of new part announcements, drawings, engineering change notices and other related or supplemental documentation.

Within manufacturing this information is used in the performance of the following primary tasks:

1. Preparation of Machining, Fabrication and Heat Treating Processes. When a part drawing is released to manufacturing, the first activity that occurs is the determination of the manufacturability of the part using existing equipment. As is the case with the introduction of a new model vehicle an advanced planning section will make the necessary capacity studies to determine if additional equipment or facilities is required. This same group is also responsible to investigate new and inno-

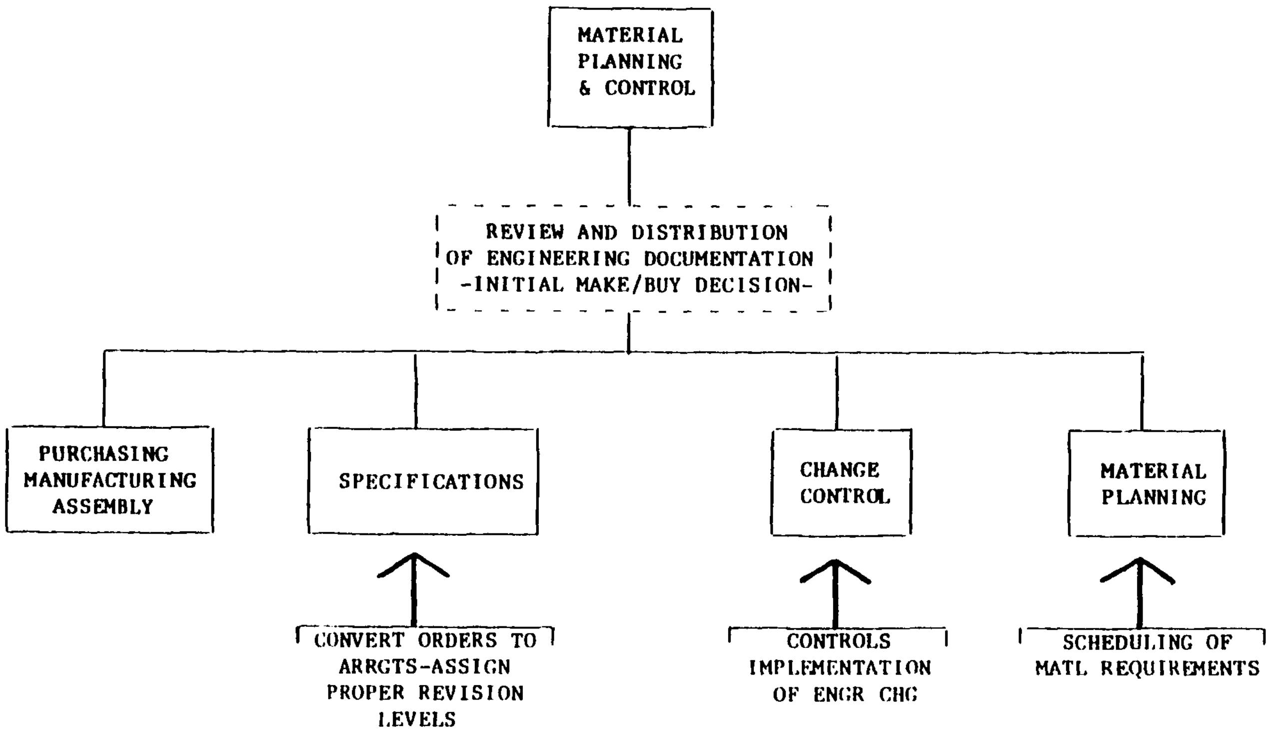
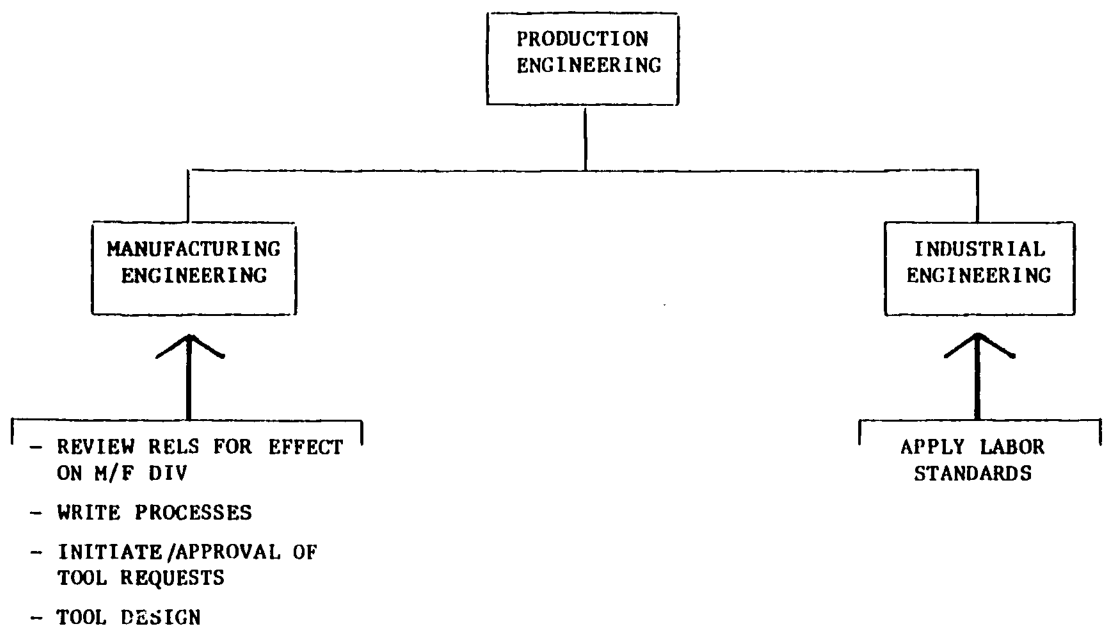


Figure 3.3 Functional Schema of Material Planning and Control Information



<u>Figure 3.4</u> Functional Schema of Production Engineering Information

vative processes and technologies.

2. Tool, Fixture and Gage Design. All tools, fixtures and gages are logged by assignment of a commodity code number. Should the manufacturing engineer not have the proper tooling, a tool request form is issued to the tool design section. The tool design section in turn instructs the tool designer to develop the fixturing for the manufacturing process.

3. Purchase and Manufacture of the Above. This is commonly referred to as the make or buy decision. Based on a financial analysis, a part is determined to be economically feasible to be manufactured by the company or made by an outside vendor. With this procedure, quotes, processes and long term business strategies are utilized as part of the decision process.

4. Preparation of Part Routing and Labor Standards. Based on the equipment and tooling available, the manufacturing engineer develops the process whereby the product is transformed from raw material into

a saleable commodity. Each step in the process is assigned to a specific location and machine within the factory. The methods entailed to perform the work for each step are meticulously calculated by the industrial engineer. The cost of the part is derived by the accounting department from information written on the routing sheet.

5. Preparation of Numerical Control (NC) Programs. The process routing sheet and part print are given to the NC department for further processing. Numerical control can be defined as a "form of programmable automation in which the process is controlled by numbers, letters and symbols."[24] The development of the letters, symbols and numbers to drive a computer controlled machine tool is the responsibility of the NC programmer.

Chapter 4 LITERATURE SEARCH

The purchase of CAD/CAM systems is on the increase. According to a report issued by International Technology Marketing (ITA)[1] 26.8% of aerospace companies use CAD/CAM with nearly 75% of those presently not using this technology planning to purchase systems within the next few years. The architectural engineering companies place second with 12.3% of the companies surveyed using CAD/CAM. Motor vehicle and machine tool manufacturers have the least utilization of CAD/CAM with 8.6% and 8.7% respectively. The report also indicated that of the 681 companies surveyed more than 42% will purchase new CAD/CAM systems within the next year. But, perhaps the most significant statistic is that of the 594 companies currently not using CAD/CAM, 34% plan to purchase a system within the year and 59% anticipate CAD/CAM purchases within the next two years.

To the novice, the task of evaluating the available hardware and software within the CAD/CAM marketplace is awesome. Studies [16] have estimated that six new CAD/CAM technology vendors are added each month to the already overwhelming potential number of suppliers to be analyzed. McMillan stated it succintly:

> "Years ago, when CAD/CAM systems were first developed, the selection process was simple. There were perhaps one or two crude systems from which to select. Today, the variety and complexity of available systems make such simple selection almost impossible." [21]

As previously stated, competition drives many companies to evaluate and select turn-key CAD/CAM systems. Knox,[15] however, prescribes a checklist of points that can be used by a company to see if they will be successful in the implementation of CAD/CAM.

1. Recognition of Productivity Problems. According to Green,[8] one of the ways to meet the overall cry throughout the country for increased productivity is through the use of CAD/CAM systems. Carter[4] suggests that productivity increases of 3:1 to 4:1 with system paybacks in a one to two year period are common. Groover and Zimmers[10] state that productivity improvement is dependent on the complexity of the engineering drawing, the level of detail in the drawing and the repetitiveness and symmetry

in the design. Productivity will increase as each of these factors increases.

Today most managers and top executives are willing to purchase CAD/CAM systems largely on faith. Michael Packer and Zella Kahn,[23] both of MIT, have conducted research for the Productivity Research Program which will carefully analyze how a number of firms are implementing CAD/CAM. This study hopes to guage both tangible benefits of CAD systems such as shorter project and design flexibility and such intangibles as creativity and design uniqueness. In order to provide credibility to the productivity ratios, the study will collect data from a large number of manual and CAD designs and use statistical methods to compare them. This technique, the authors say, will allow them to objectively evaluate how each facet of design complexity contributes to the actual time needed to complete a design job. In addition, they will be able to objectively calculate the effect of CAD systems on both design and overall project time.

Some of the preliminary data of this study has indicated a few emerging trends which will be significant to the group responsible for the selection of a CAD/CAM system. First, (1) CAD assisted designers do not seem to perform much better than manual designers in some of the intangible aspects of effectiveness. However, (2) CAD groups seem to have poorer teamwork than manual design teams. This may lead, say the authors, to a problem in transfering knowledge from experienced designers to younger engineers working on the CAD system.

The significance of the preliminary results of the research by Packer and Kahn is that it supports some of the basic premises of this thesis, That is,CAD/CAM technology cannot be evaluated until the processes that will be automated are first understood. (1) and (2) in the previous paragraph indicate that it is important to know whether the company that is being examined will use the technology for creating new designs and only new designs or if the company's main design function is to modify existing designs.

The psychological element associated with the implementation of this technology cannot be underestimated. To overcome the loss of teamwork, Edwards[6] proposes that the designers be adequately informed and educated in the use and capabilities of the CAD/CAM system. This educational process is not static and must be continued long after the system is installed.

2. Involved Management. Hess[12] feels that the first step to getting started in CAD/CAM is to maintain full top management and support. However, the introduction of this technology within a corporation will involve changes to the management procedures and structure as are denoted in Table 4.1. Chasen stated "management by conventional procedures will give you worse than conventional results."[18] This need for innovative management will put pressure on all levels of management and will specifically require the CAD/CAM evaluation task force to constantly update upper management as to the progress of the project.

3. Fifty Percent Parts Designed Internally. The state of the art indicates that it would be less than prudent in selecting a two-dimensional drafting system. However, the design drawing is still the medium of communication between engineering and manufacturing. Therefore, if the 50%

Table 4.1 <u>Examples of Management Implications</u>

1. Organization
2. Management participation policy
3. Decision making
4. Management style
5. Educational policies for management and other personnel
6. Selection and training of personnel
7. Systems impact on those not responsible for managing the systems
8. Psychological impact at all levels
9. Need to manage change
10. Need to plan and manage technology transfer
11. Closer ties between industry and teaching institutions
12. Cost control systems
13. Capital investment (major changes in decision making criteria)
14. Reduced differentiation between stock and custom products
15. More new products, shorter lead times
16. Potential for customization of mass produced products
17. Market refocus (more, smaller markets)
18. Plant locations (probably closer to points of distribution)
19. Acquisitions, small vs. large companies
20. Quality, warranty, service, spares provisioning, litigation
21. Sales, opportunities, communications, relationships with customers
22. Purchasing and vendor relationships

parts designed internally is met, the CAD/CAM system must have adequate drafting capabilities.

4. Integrated System Design. Hess[12] again states that, according to his company's experience, a company planning or implementing CAD/CAM technology must accept the fact that one integrated database must be installed. Ingersoll Milling Machine took on this responsibility and redesigned and rewrote all their application system software to achieve the integrated database concept.

5. Willingness to Analyze the Present. One of the basic fundamentals in evaluating CAD/CAM systems is to first understand the operations the system will effect. Knox[15] states that a task force be established to gather all the information. Groover and Zimmers[10] expand the analysis to contain a strategy that will include future needs of the corporation. The case study in this thesis deals with a department which in turn established an investigative committee to provide the necessary information. Briggs promotes criteria necessary in selecting a CAD/CAM system. He states:

> "A team concept, which combines designers and computer experts, has proven beneficial. Designers generally are not computer-oriented, nor are software programmers always applicationally perceptive. Working together, designers and programmers must decide what tasks can be accomplished effectively by the system,and what type of user interface is required for each interactive command. If this phase is done thoroughly, evaluation of vendor specifications will be meaningful and useful; vendor demonstrations can be benchmarked and assessed more accurately; and vendor qualifications will become very apparent."2

The selection and evaluation of a CAD/CAM system is quite different from selecting a general purpose computer. McMillan[21] attributes this to the fact that techniques of man and computer interaction set CAD/CAM apart. This is supported in a paper on getting started in computer integrated manufacturing by Hess in that the approach to evaluating turn-key systems must be user driven.

In order to establish an effective CAD/CAM system Marks[19] contends that at least four components should be present:

1. Product. Clear product objectiveness must be set and communicated throughout the organization. Engineering should be making plans to upgrade their

skills and procedures to match the new technologies.

2. Tools. Users should be involved in the up-front selection process. Also, the human factor such as ergonomics and user-friendly software must be taken into account. The engineering process must be understood before the necessary CAD/CAM tools can be evaluated.

3. Process. The design process should be measured effectively before trying to establish its efficiency. A pilot project should be developed that exploits a learning curve process rather than trying to automate everything at once.

4. People. Although almost half of the general public know how to use computers[11] many times the new tools and methods associated with this technology threaten people. The use of educational programs with hands-on experience will alleviate some of the fear. An investment in people is as important as the investment in the hardware and software.

A methodology by James McDonald and Warren Hastings called the CAD/CAM Audit[20] involves a seven step process. The seven steps are:

1. Feasibility study
2. Needs analysis
3. Cost and benefit analysis
4. Systems architecture design
5. System specifications
6. Benchmarking and selection
7. Implementation and start-up

This seven step procedure for justification, specification and selection of CAD/CAM technology has, according to its authors, been refined and verified over the past several years. This particular methodology assumed that a suitable product is available from a turnkey CAD/CAM vendor. However, the methodology is applicable even if such a system does not presently exist. The overall objective of the CAD/CAM Audit is to allow a company to define its technology requirements, determine which pieces can be purchased off the shelf from vendors, gather information of the costs and benefits of each step, and finally devise an implementation plan for system installation.

Chapter 5 DEVELOPMENT METHODOLOGY

The introduction of the computer into the design and manufacturing cycle (CAD/CAM) will revolutionize manufacturing companies and has been called the equivalent of a "second industrial revolution." A company's ability to remain competitive in the coming years depends in large part on its capacity to apply this computer technology to its operations. Integration of CAD/CAM into the business structure will require a comprehensive plan and implementation procedure as well as restructuring of various functions and accountabilities.

With respect to the primary areas addressed by CAD/CAM technologies, namely the design and engineering activities, and process planning functions, there appears to be no viable alternatives. While manpower can be used to meet increased workloads in these areas, this alternative will not provide increases in the degree of efficiency. As stated previously, the tools provided via CAD/CAM technologies are rapidly becoming accepted as mandatory relative to increasing productivity in the design and development of most manufactured products.

Increases in productivity in all design and manufacturing processes are considered to be critical to the continued profitability of most manufacturing concerns. Therefore, a decision not to investigate and implement the appropriate CAD/CAM technologies will have a measureable and negative impact on the growth and survival of many American companies.[28]

The investigation of CAD/CAM systems requires an analysis of the flow of engineering information throughout the corporation. Once this flow is established, the group responsible to evaluate turnkey systems can begin to apply the various CAD/CAM technologies to the activities occurring within each department of the company. An analysis of the work flow as discussed in the background section of this thesis reveals that specific departmental functions can be enhanced through the application of particular computer based technologies.

5.1 Design Engineering.

Design drafting and documentation can be greatly facilitated through the use of interactive computer graphics. Each engineering work station must have the ability to view drawings and models stored in the database. Not everyone, however, will need the ability to edit, create or dynamically move models. Only those who require this capability will have this feature within their workstation. Computer-aided engineering (CAE) is the use of computer tools to improve the decision making by product planners, designers and engineers.[19] The CAE system will include finite element analysis, kinematics and mass properties. Information generated will subsequently reduce the product development cycle. In addition, a CAE system should include electronic mail and word processing which would improve communications between the project members in a design team.[3] Program development aids must include compilers for Fortran, Basic and Pascal.

Another emerging technology which will aid the designer in retrieving existing part models is Group Technology. With this software package, each newly created design will be associated with a specific code that can be easily accessed and retrieved at a later date. Each part print will be coded on specific design criteria. Codes do not replace part numbers but enhance part characterstored in the database. Not everyone, however, will need the ability to edit, create or dynamically move models. Only those who require this capability will have this feature within their workstation. Computer-aided engineering (CAE) is the use of computer tools to improve the decision making by product planners, designers and engineers.[19] The CAE system will include finite element analysis, kinematics and mass properties. Information generated will subsequently reduce the product development cycle. In addition, a CAE system should include electronic mail and word processing which would improve communications between the project members in a design team.[3] Program development aids must include compilers for Fortran, Basic and Pascal.

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5.2 Manufacturing Engineering.

The use of interactive graphics as a CAD/CAM technology has many applications within manufacturing. Part geometry is obtained from the CAD database and is used to create NC programs. Toolpaths can be dynamically displayed and used for verification in part prototype proveout. Graphics is also used for plant layout whereby the engineer can simulate the placement of equipment and material to optimize work cell design in the plant. Robotics design and placement can be emulated on graphic workstations. Being able to simulate the robot's motion and placement can greatly aid in the final equipment installation.

Computer-aided engineering analysis tools can be used in manufacturing to increase the productivity of tool and fixture design. Through the use of finite element analysis the tool designer will be able to minimize the design iteration and thereby improve the fixture development cycle time. These same analysis tools will allow the manufacturing engineer to determine piece part deflection due to material cutting pressures.

Group technology for manufacturing is defined as:

> "The analysis of similarly collected parts or assemblies using similar form, shape, function, or operation, such that they may be manufactured in a similar manner utilizing identical tooling or machine tools. Two distinct methods exist: (1) Collection by type is defined as a technique utilized for similar parts using uniform data such as processes, material size, tools and weight. (2) Collection by group is defined as a technique where a selected group of parts have similar operations which may be combined and performed in a specialized machine shop or machine."[15]

This software package can be used to generate process plans and time standards in addition to the analysis feature which expedites work cell design. Tools and fixtures can be coded and later accessed by a tool designer as part of the design retrieval aspects of Group Technology.

Having applied the technologies associating CAD/CAM to the various functions within design and manufacturing, it is now necessary to develop the categories required to evaluate turnkey CAD/CAM systems. They are:

1. Graphics
2. Database and database manager
3. Command language
4. Hardware and product line
5. Communications and networking
6. Service and software support
7. Vendor experience
8. Training and documentation
9. Engineering analysis and special application
10. Bill of material
11. System recovery methods
12. Numerical control
13. Group technology
14. Scanning interface
15. Environment
16. Miscellaneous

For the purpose of clarity, the above categories will be called "vendor considerations." Having evaluated eighteen CAD/CAM vendors, it is the writer's opinion that each vendor offers software that includes or interfaces to some or all of the above categories.

5.3 Vendor Considerations

1. Graphics. Graphics is perhaps the most important category under the vendor considerations list and includes 3-D wire frame modeling, solids modeling and surfacing.

Three (3)-D wire frame modeling is a technology developed during the early 1970's. It is a relatively easy system to use that provides the ability to show the basic part shape as if it were made of wire mesh. The method of creating and editing geometry involves the use of points, lines, circles, arcs and splines. Geometry can be created using point to point construction, construction lines or the designer can reference existing geometry to create new geometry. Hidden line removal techniques can involve the designer in a time consuming task if the only method to remove hidden lines from an isometric view was to manually select and remove the desired line. Some vendors claim they have automatic hidden line removal for 3-D wire frame modeling but none of these systems were demonstrated to the writer. It is also important to be able to control the display of hidden line (display hidden line on the model as dotted or dashed lines.)

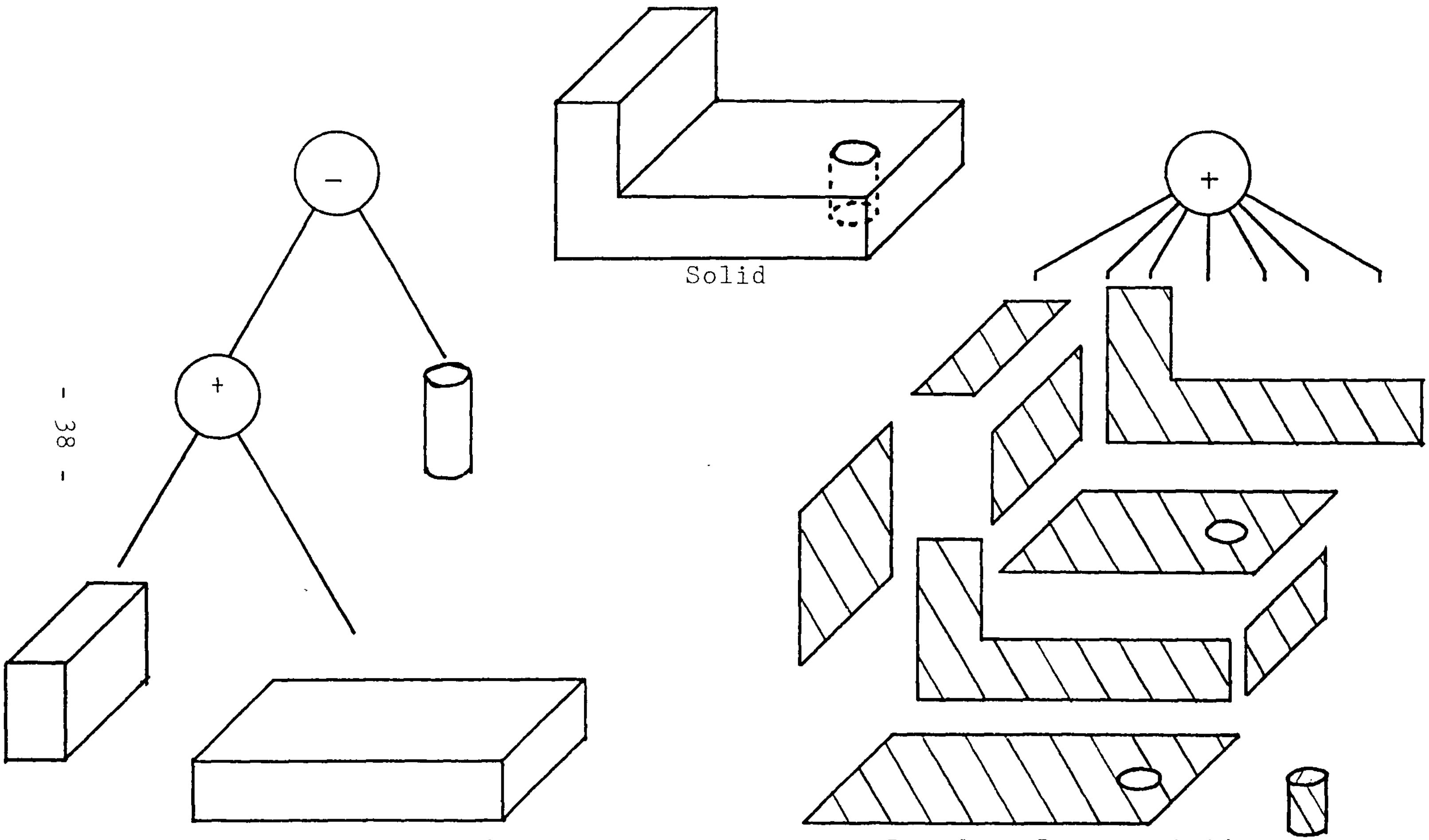
Cross hatching is a form of geometry visualization where the designer can select a pattern of line segments or symbols to place on the drawing. The ease of creating cross hatching designs and the control of the size and density of the pattern is important.

"Sectioning" is the ability to slice the 3-D wire frame model with a plane (or planes). Some CAD/CAM systems will represent a section cut only as a series of points in space and consequently make the view difficult to visualize. Sectional properties such as area, perimeter and moment of inertia are required by the designer to determine assembly clearances.

The types of model views available to the designer as well as the number of simultaneously displayable views is another consideration under 3-D wire frame modeling. Orthogondal views pertain to the standard drafting practice of top, front and side views of the production part. Isometric, perspective and flying eye views are each special ways of looking at the 3-D wire model. In the isometric view all features of the design remain dimensionally equal whereas in perspective and flying eye views the model becomes dimensionally distorted. The ability to manipulate these views can be accomplished within the design terminal (hardware) or within the host computer (software).

Solids modeling was developed in the late 1970's and into the 1980's. True surface and edge definitions are inherent in the CAD part model. With solids modeling any well-defined geometrical property of any represented solid can be calculated automatically.[24]

Constructive Solid Geometry (CSG) involves the use of "primitives" to create a model. Boolean operators are used to add, subtract and intersect primitive shapes such as a cube, sphere, cylinder and torus. With this technique the number of primitives available for use is critical. Boundary Representation (B-Rep), on the other hand, uses a collection of faces and edges described by surface equations. (See Figure 5.1). The major benefit of these methods is the ability to generate mass properties (e.g. mass volume and moment/polar moment of inertia). Visualization in solids modeling is greatly enhanced through the use of color shading and automatic hidden line removal. This ability to develop and change



Constructive Solid Geometry Representation

Boundary Representation

Figure 5.1 Graphic Comparison of CSG and Boundary Representation colors and the light source greatly impedes the performance of some CAD/CAM systems. Sectioning is similar to 3-D wire modeling except with solids modeling the designer should be able to use a contoured surface to section a solid model. This ability is particularly useful in die design. View manipulation is also the same as 3-D wire frame except in the case of solids modeling it is more critical that pan, zoom and rotate functions be performed locally in the users terminal. It was the writer's experience that software view manipulation was unacceptable due to the amount of time required to perform those operations by the host computer.

Surfacing can be thought of as a special form of 3-D wire frame technology. With this technique, the designer describes complex geometrical designs such as an automobile fender or an aircraft fuselage. Points are input into the computer in X, Y and Z values and algorithims perform operations on those points to develop a mathematically representable surface. The Bezier and B-Spline algorithms are the two most popular in use by turnkey CAD/CAM vendors. In general, Bezier surfaces differ from B-Spline in that the displacement of a single point on the object's surface will affect the entire Bezier surface.[25] Surface filleting, intersecting and offsetting are important methods of creating and editing surfaces. Designers also require the ability to develop draft angles onto surfaces especially when creating casting or forging designs. Color shading as well as the ability to control the "mesh" density of the surface aids in better surface visualization. Sectioning and sectional properties include the means to determine the surface area as well as being able to project an entity onto the surface. Unwrapping or flattening a surface is a requirement for manufacturing as well as being able to drive a curve over a surface. NC programming requires the means to display a ball nosed end mill generating a specific 3-D surface.

From a systems standpoint the potential user may want the ability to convert from 3-D wire frame to solids and surface to solid. Conversion from solids to 3-D wire is mandatory. However, with present technology the ability to make a drafting document directly from a solids model is virtually non-existent, although this feature will be required in future systems.

A turnkey CAD/CAM system should provide both semi-automatic and automatic dimensioning capabilities. In the semi-automatic mode the user will be able to locate or define the text at a chosen position on the drawing. In the automatic mode, the system will dimension geometric entities selected by the user, thus providing automatic generation of dimension lines, arrowheads and dimension labels. All dimensioning must follow ANSI standard Y14.5. The designer will want to use horizontal, vertical, angular, parallel, radial and diametral dimensioning capabilities. The ability to dimension complex surfaces and isometric views is also valuable but is not available on many turnkey CAD/CAM systems. Conversions from Metric to English and English to Metric dimensions as well as the ability to dual dimension a design is considered mandatory.

"Tolerancing" is the amount of variation permitted in the size of a part or the location of points or surfaces. The user should be able to set global values for mini-max as well as plus-minus tolerances. These tolerance values will apply to all dimensions including linear, angular and circular dimensions. A CAD/CAM user will also need to create geometric tolerancing symbols and selectively change tolerances when required.

A design symbols library will include but not be limited to symbols for concentricity, parallelism and perpendicularity. Again, the user will require the ability to selectively create new symbols and line weights. When evaluating a CAD/CAM system it is important to note the number of text fonts, line types, arrowhead types and line weights that are offered by the turnkey CAD/CAM vendor.

"Layering" in CAD/CAM system is very much like taking clear sheets of acetate and placing them on top of each other. For example, the geometry of the part may be on layer (1) in the system; dimensions and notes on layer (5); and the NC toolpath on layer (20). The ability to selectively turn layers on and off is provided by all vendors. However, the number of layers available varies greatly and must be noted by the investigative team.

Limited word processing capabilities is also a consideration. Many times a designer will need the ability to change text on a drawing without changing the geometry. Without some type of text editing system the user will be required to delete all text and enter all notes as if he were creating the design from the beginning.

The amount of "associativity" that is required by a turnkey CAD/CAM system depends on the amount of revisions and changes that are generated by the engineering department. Company policies vary from little to no concern about design revision to elaborate procedures that track and monitor each part change throughout the product life cycle. Associativity within a CAD/CAM database occurs on a number of levels. The first is the associativity between geometry and dimension. A user should have the option to create associative or non-associative dimensions through the use of a single command. Associative dimensioning implies that the geometry is directly related to the dimension. A change in geometry therefore implies that the dimension will be updated. Although this capability is not uncommon the reverse of this capability was only demonstrated in a very few systems. The updating should also be immediate or deferred depending on the operator's decision.

View to view associativity implies the ability to change geometry in one view of the model and have that change automatically reflected in all views. For example, it may be convenient for the user to add a hole in the top view of a design. All other views of that part should be updated to reflect that change. Included with this associativity is the requirement to construct geometry using multiple views of the model. This implies that at any given instant all views of the design are active including any magnified view of a small portion of the model.

The third area of associativity is model to drawing. A number of CAD/CAM systems have two modes of operation - modeling and drawing. Modeling mode indicates that the user is creating a computer generated geometrical representation of a design. Drawing mode is when the system operator extracts a representation or view from the model. This view can then be used for documentation and dimensioning purposes. Associativity from model to drawing requires that the drawing be updated (either automatically or user controlled) when the model is changed.

A degree of integration from CAD to CAM is required for the fourth level of associativity. A number of turnkey CAD/CAM vendors market the ability to directly and automatically generate an NC program from the CAD generated model. Associativity from CAD to NC necessitates the updating of the related NC information after the part design has been changed. The type of information that needs updating would include the NC toolpath as well as the NC program (both source and machine code).

The final area of associativity is the most difficult and requires a database structure to be part of the CAD/CAM system. Most companies contemplating the use of mechanical CAD/CAM have a hierarchical approach to manufacturing a product. That is, components are used in sub-assemblies; sub-assemblies are combined with other sub-assemblies or components and are called assemblies; and finally, assemblies are combined with other assemblies, subassemblies and components to form the product. Under this operating scheme, the user of turnkey CAD/CAM system will create sub-assemblies by calling up geometry of specific components and merging them into a single file. In this manner, individual part geometry may be duplicated many times in numerous subassemblies and assemblies throughout the CAD database. Associativity between model and assembly entails the ability of having the computer system determine and selectively update all assemblies that use a design that has subsequently been changed.

2. Data Base/Date Base Manager. It is interesting to note that the majority of turnkey CAD/CAM vendors will refer to their methodology of managing data as a database. Traditionally, emphasis is placed on the type of data that is contained within a file and not the relationships between files. System software which comprises the routines for interactive graphics is differentiated from the application data which includes specific part geometry and information. The conventional CAD/CAM database (a file management system) allows the transparent interaction of the system software with a specific application file. However, the relationships between the actual part files is left to the user to determine and implement. (Traditionally, this

remains a manual task). This section will, therefore, depart from a description of the traditional CAD/CAM database and will focus on the need to establish a more integrated approach to CAD/CAM databases.

When evaluating turnkey CAD/CAM systems it is important to understand the structure that controls the information within the CAD/CAM database. The structure of databases can be defined as hierarchical, networked or relational. Hierarchical structures associate data in a tree-like fashion. A hierarchical database requires that the connections between files be established at the start and remain fixed for the life of the database. Although the creation of a new file of information within a hierarchical database is a fairly simple matter, the time required to search for a piece of information grows exponentially with the size of the database.

The networked database reduces the amount of time required for an information search by establishing information relationships through connectivity of data. The user can then relate any file with any other file. Although networked databases allow for faster searches than hierarchical databases, the ability to alter relationships within the database can become a tedius task.

Relational database structure can be best explained in terms of lists. Consider the database to be an assortment of lists of data with the relationships between these lists being established, changed and updated easily. The amount of time required to search a relational database is dependent on how well the lists are connected (related) as well as the size of the lists. The choice of the type of database structure to use to control a CAD/CAM system is based more on availability than capability.

Today, within most companies, the administration of engineering information is specific and, for the most part, well established. Engineering projects are monitored for status and content. Original drawings are maintained and accessed through some kind of log-in, log-out procedure. When evaluating CAD/CAM it is important for the potential customer to be aware of the turnkey vendor's offering in this area of drawing management.

As the size of the CAD/CAM database increases and is distributed over a hierarchy of computers, it is important that the database manager track the location of a part model. This database management software must also store the part status (current, non-current and terminated) and the tape location of a design after it has been stored off-line. The system must track revision history as well as design access history. This information can be recorded by date, person and reason for revision or access. All designs residing within the CAD/CAM database will require well defined user protection. Engineering users will have the right to create and edit designs. Manufacturing will need to access and view engineering models but will not have the ability to change the design. Manufacturing will, however, have the right to create and edit NC tapes and machine tool processes.

If the frequency of design changes is a problem, then revision control must be considered. It is conceivable that four different drawing revisions may be active at the same time - engineering with the most updated copy (revision 4), planning and material control with revision 3, manufacturing with an even older version (revision 2) and the actual production floor copy would be revision 1.

Although the decision as to what department will require a specific revision will derive from another computer system, the CAD/CAM database must store and locate upon demand the appropriate design revision level.

The existence of a database as part of the CAD/CAM system allows for a more flexible method of storing sub-assemblies and assemblies. As the user is developing the sub-assembly the database manager will create a pointer within the sub-assembly file that traces back to the component part geometry. The actual file of the sub-assembly, therefore, does not contain geometry but merely points back to the component parts. When the assembly is accessed by a user, the database is searched and the model is constructed.

3. Command Language. When evaluating turnkey CAD/CAM systems it is important to note the system software language as well as the macro (parametric) programming language. Earlier CAD/CAM systems were written in assembler language. Although this language provided good response time, the ability to modify and enhance the graphic system software

was greatly reduced due to the unwieldiness of the language. The Macro or user language should be available in various levels and modes. This allows for difference in individual preferences in style and method of inputting information into the system. Menu choices for the user should be provided. The user will also want to define menu options as well as turn off the menus when desired. Another area to be considered is the ability of the terminal to buffer command inputs.

4. Hardware and Product Line. This section deals with the interaction between the user and the CAD/CAM system (ergonomics). When evaluating the turn-key system it is important to be aware of the features available to the customer in the area of hardware.

Cursor control can be accomodated by one or a combination of the following items:

1. Light pen - a device that resembles the shape of a pen and is used to detect the presence or absence of light displayed on a refresh type CRT (Cathode Ray Tube).
2. Keyboard - a standard alpha-numeric

computer input device.

3. Joystick - a toggling device (stick) that can be moved in any direction causing the cursor to move in the corresponding direction.

4. Ball - similiar to joystick, except instead of exerting pressure on a rod the user rotates a ball to cause the cursor to move on the screen.

5. Mouse - similiar to the ball except the ball is mounted in a holding device that is positioned on a flat surface. Movement of the mouse corresponds to movement of the cursor.

6. Electronic tablet and stylus - an electronically sensitive panel is activated through the use of a pen-like stylus. This method allows for both commands and free-style geometry to be input into the system.

7. Thumb wheels - the cursor is positioned by having the user selectively rotate a knurled wheel. Two wheels are provided: one for horizontal movement and the

other for vertical movement.

The ability to see the commands as they are issued to the system is many times as important as being able to visualize the graphic results of those commands. A number of systems provide separate screens to display textual information. The size and placement of those separate CRT's becomes an item to be evaluated and rated as part of the CAD/CAM selection process. On those systems that do not provide a separate display, it is important to note the location of the text as well as the control of the amount of lines displayed on the screen. Some CAD/CAM implementations allow only three lines of text to be displayed whereas other systems allow the user to select if he/she wants text display and how many lines will be visible at a time.

The following is a listing of the present technology used to display computer graphics:

1. Vector refresh - the image on the screen is regenerated many times a second due to the limited ability of the phosphor elements to retain their brightness. This type of display allows for animation

but is unwieldly when the screen is densely filled due to image flickering.

2. Storage tube - Unlike the vector refresh, the storage tube retains the projected images and does not flicker when displaying very detailed drawings. The disadvantage is that storage tube technology does not allow for selective erasure and upon editing requires an entire screen redraw.

3. Raster scan - This is the most widely used display technology available. The raster scan screen uses pixels to display the graphic information and the amount of pixels used in the horizontal and vertical axis is called the resolution. Until recent developments in technology (dithering and anti-aliasing) raster scan terminals were known for the "stair steps" effect of displaying diagonal lines.

A major push for using raster scan technology is the use of color. At least one vendor in the market today no longer sells monochrome terminals. For a more detailed explanation see Groover and Zimmers.[10]

When considering the overall work station configuration the amount of user friendliness must be judged. Things to be considered here are as follows: Is the work station adaptable to both left-handed and right-handed operators? Does the work station appear to be a piece of office equipment and will it fit on top of a desk? If the CAD/CAM vendor supplies a desk as part of the terminal is the work space adequate?

Another area to be considered is if the terminal has local intelligence or if the CAD/CAM terminal is a stand-alone work station. An intelligent terminal is one which allows for local execution of a finite set of graphic commands. A stand-alone work station is a separate processor that allows the user to function apart from a host computer environment.

The signifigance of stand-alone and intelligent terminals is that the amount of data being transmitted to and from a host computer is reduced thereby increasing the response time to the user. Increased user response time equates to increased productivity.

A high speed plotter using wet ink or ball-point pens must be able to accomodate a drawing surface large enough to plot "E" (34 inches by 60 inches) size drawings. An electrostatic plotter must also be capable of making an "E" size drawing but must operate at a speed of 360 lines per minute as well. A hard copy unit (monochrome and color) must be provided to allow the users to acquire a fast print of what is displayed on the screen. The prospective customer will also need to question the vendor on the availability of Computer Output Microfilm (COM) and RGB (red, green, blue) interface.

5. Communications Networking. As a company develops and implements Computer Integrated Manufacturing (CIM) the ability to network CAD/CAM information through the corporation becomes critical. Turnkey CAD/CAM systems must be able to emulate the standard HASP-RJE interactive protocols IMB [14] (3270,3780, SNA Gateway) as well as Honeywell[13] (GRTS), CDC [5] (VT 200) and Univac[27](1004) interfaces must be provided. User productivity, especially when using solids modeling, is enhanced when the vendor supplies a 56

kilobaud data transmission rate between workstation and host. Demonstrations of 9,600 baud workstation to host communication were painfully slow, particularly in displaying color shaded images. Therefore, communication speeds, whether between workstation and host computer or from host to host within a local area network (LAN) becomes a major issue of consideration for the evaluation of CAD/CAM systems. Data interchange over a long distance through a dial-up link must also be provided. (Appendix A)

When considering networking, the maximum distance between nodes as well as the number of work stations allowed per ring or CPU must be evaluated. These figures vary greatly from vendor to vendor. It is the author's belief that as hardware prices decrease, each design workstation becomes more intelligent and ultimately becomes a stand-alone graphics processor . The effect on system performance of networking these workstations together must be demonstrated and documented.

6. Service and Software Support. Under normal agreements the turnkey CAD/CAM vendor will be responsible to provide software updates as they

become available and correct software "bugs" and errors as they are discovered. A maximum response time for service should be quoted as part of the system as well as penalties for not complying with the response time requirement. Also, ask the vendor if on-site support will be available when the system warrants such support. On-line toll-free telephone assistance o n a wide range of system problems is also required.

User groups can be a major source of information. Contact with a specific vendor's user group will provide an insight into the system deficiencies not normally uncovered during a cursory evaluation. Contact with the user group after installation will provide the ability for additional problem solving and interaction.

First pass evaluation of turnkey CAD/CAM systems will require costs for the following items:

1. Hardware
2. Software
3. Installation
4. Training
5. Service and Maintenance

Obviously, as the project progresses and the amount of vendors narrow, the amount of details requiring prices will significantly increase.

7. Vendor Experience. The turnkey CAD/CAM vendor will have had to demonstrate a committment to customer satisfaction. Acquiring information on the number of years experience and financial strength of the company will provide some insight into the potential vendor's ability. The CAD/CAM vendor should also provide the number of system installed customers and installation data such as the size of the system, number of terminals and number of years in use. Information concerning the total number of employees as well as the amount of employees developing new software and maintaining existing software must be made available. If possible, a contact should be made with an existing user. Valuable information regarding vendor credibility can be obtained through this type of contact.

8. Training and Documentation. The result of training will be that users will be able to fully utilize the system for maximum productivity in a minimum period of time. Intensive courses taught

by experienced full-time CAD/CAM instructors must be available at the vendor's facility as well as on site at the customer's company. If the training is held at a vendor's facility, the proximity of that facility will be important for the evaluation. Each course offered must be a mix of classroom and laboratory sessions supplemented with concise and understandable instruction manuals as well as system manuals. Courses should be offered for each level of operation, staff and manager. A good example of this would be as the system grows a company will want to provide their own CAD/CAM training staff. The vendor should provide a class to train the trainer.

9. Engineering Analysis and Special Application. The Finite Element Modeling (FEM) package of the CAD/CAM system should be able to generate finite element models for general purpose analysis programs such as NASTRAN, STRUDL, SAP, ANYSYS and SUPERB.[14] Models will be created by directly assessing geometry from the CAD database. The FEM package provided by the CAD/CAM vendor must be integrated into the CAD software so that the FEM package will be able

to use the same computational, manipulation and display benefits of the system.

As well as providing a complete library of standard elements, the FEM package will allow the user to define non-standard elements. Both automatic and semi-automatic two and three dimensional mesh generation must be supported. Material and property descriptions, single point constraints and loads are affixed to the model as part of the mesh generating process before formating to specific application codes. The system should allow the user to verify the finite element model using all the standard display capabilities.

As previously stated the turnkey CAD/CAM system must support a FEM package that will generate FEM meshes both automatically and semi-automatically. In either case, the numbering of grid points must be user definable or automatic. When considering automatic mesh generators, the system should be able to generate meshes for 3-D curves including B-spline, bezier, or ruled surfaces. This mode must also provide the user the ability to check for and selectively delete coincident nodes. In the semi-automatic node, the user will want to create a FEM mesh arbitrarily within a 3-D region. The system will be able to semi-automatically move, copy and mirror major elements to form a complete finite element model. The FEM package must also allow a user the ability to define the first and last elements (whether linear, parabolic or cubic iso-parametric beams) and have the system interpolate the remaining elements. Dynamics, including kinetics and mechanisms, must also be supported by the turnkey CAD/CAM vendor.

Some other special applications include:

1. Piping and routing - The ability to take CAD generated geometry and establish an interference-free piping network.
2. Printed circuit board design - this includes the ability to generate final printed circuit boards, drawings and associated documentation.
3. Facilities and space management - this includes features for plant layout.
4. Technical publication - A great cost benefit can be derived from using CAD geometry for the development of service publications.

10. Bill of Material. A bill of material represents the documentation of a design that engineering uses to communicate information to other disciplines and departments within a company.[15] The bill of material for a specific product is a detailed listing of all the parts, sub-assemblies and assemblies that are utilized in the manufacture of that product. A turnkey CAD/CAM system should have the ability to assign bill of material attributes to detailed parts. These attributes shall include but not be limited to items such as name, weight, part number and revision level. As the user is creating the product structure these attributes will be accumulated at higher levels. The CAD/CAM system must then have the ability to extract these non-graphic attributes associated with a model or drawing. This extract procedure must be user definable and at the same time allow the user to format the information in a form usable by another system. This file will then be networked into the company's business planning computer.

11. System Recovery Methods. Virtually all CAD/CAM systems provide a method of saving information

during a terminal session. This back up procedure can be manual (user initiated) or automatic. In the automatic mode the commands issued during a workstation session can be saved every few minutes or can be saved after the completion of a specific number of tasks. The automatic methods of saving commands has an obvious advantage over the user initiated file saving routine. In the event of a power failure all commands and graphic instructions issued after the last file save are lost. If the save procedure is time or task dependent the user will be able to restore the CAD/CAM file to a known position. However, if the save procedure is left to the descretion of the operator, more times than not,a significant amount of work will be lost.

Another method of guaranteeing system restorability after a power failure is through the use of journaling. With journaling a separate file contains the textual commands issued during a session. This file is started as soon as the user signs onto the CAD/CAM system and is stored and updated each time a new graphic command is issued, thereby insuring that no work is lost in the event of a system failure. Also, closer inspection of the journal file yields a productivity tool. For example, many times a designer during the course of creating a part model will pursue a development path that results in an unacceptable design. Instead of creating an entirely new model, the designer can simply edit the journal file and delete the area that produced the negative results.

Another area of concern in system recovery is the method of backing up and restoring the CAD/CAM system. Since the CAD/CAM system is a computer system, it will require periodic system dumps onto magnetic tape to provide security in the event of a system failure. During the evaluation process, the CAD/CAM vendor should be asked to detail the procedure as well as the amount of time that is required to back up the system. This is important in that as some CAD/CAM systems are being backed up onto tape no one is allowed to use the system. Most companies, however, circumvent this lost productivity problem by performing system back ups on a non-used shift (3rd) or weekends. Nevertheless, this is a procedure that must be documented and evaluated in reference to CAD/CAM system performance.

12. Numerical Control. The numerical control packages of turnkey CAD/CAM systems contain the ability for the user to develop NC information such as toolpaths, set up data and NC machine code. This manufacturing tool must support two through five axis machining operations as well as punching, milling, drilling, turning, electro-discharge machining and flame cutting. The system must support a dynamic 3-D visualization of the NC toolpath as well as the ability to recognize and pass over a slot or depression that is too narrow for the tool being used. APT (ADAPT or UNIAPT) or COMPACT II[14] source will be generated and post-processed to provide an NC machine language file that will subsequently be used for direct numerical control (DNC) or numerical control tape generation. As was the case for the FEM package, the NC applications package must be integrated and use the same fundamental graphics capabilities of the turnkey CAD/CAM system.

13. Group Technology. Design proliferation and redundancy is a major problem facing all manufacturers today. Engineers and designers daily create new parts to solve new problems. The coding

and classification of parts by group technology allows for parts to be grouped on the basis of similiar attributes and then assigns a code to each part. Codes do not replace the part numbers but enhance part characteristics retrieval.

The codes are not unique and when they are not, this represents a similarity and acts as a signal to the engineer or designer that even though the parts are from different families and look different , they may in fact be interchangeable. If they are interchangeable one (or more) of the designs may be terminated. In the case of a new design, this has eliminated the need for a new part.

This same coding scheme is used in manufacturing to classify and retrieve part process plans. The manufacturing engineer codes parts for particular process functions. These codes are then later used for manufacturing analysis to determine optimal factory machine cell groupings. Analysis of this type allows for efficiencies in machine set up, in-process inventories and standardized process plans.

Industry studies[22] reveal that the average cost to develop a new design is $800. The manufacturing preparation costs range between $2000 and $12,000. The life time cost of the part can be as high as $200,000 including engineering, manufacturing, tooling, manuals, service and inventory carrying charges. If these figures are correct, it will not take many eliminated designs to pay for an investment in group technology as part of the integrated CAD/CAM system.

14. Scanning Interface. An important factor in CAD/CAM effectivity is the time required to create a CAD database. One of the possible breakthrough technologies to aid this process is scanning. These computer-based optical systems read an existing drawing (much the same as OCR systems do for bank checks) to create a CAD file. At this point most scanning companies can quickly read the part print but cannot adequately create a coherent CAD file. The picture can be captured but not the intelligence inherent in the dimensioning, lettering (notes), dashed lines and curved lines of the drawing. This shortcoming limits the ability to create a database of part models for analysis and manufacturing processing.

15. Environment. This section varies the smallest from vendor to vendor. The turnkey CAD/CAM vendor must be the ultimate person responsible for the correct installation, interconnection and satisfactory operation of equipment and software. This means that air conditioning and electrical requirements must be known and installed well in advance of the system's shipping date. Most systems will operate in the $40^{\circ}F$ to $80^{\circ}F$ ambient temperature range with 49% to 80% relative humidity. The electrical requirements are for 120-240 VAC $\pm$ 10% with a clean reliable power source, free of voltage dips or large spikes. Since the equipment will be operated in an office environment the noise levels must be acceptable in that environment. Lighting is also an issue. Earlier CAD/CAM systems required that the equipment be placed in a specially lighted room. The potential customer should observe the lighting in the room where the vendor demonstrates his equipment.

16. Miscellaneous. This section can be covered by having the CAD/CAM vendor answer two questions:

1. Does the system support the Initial

Graphics Exchange Specification (IGES)?

2. Are the total capabilities of the system interfaced or integrated?

This concludes the discussion of the items to be considered when evaluating computer-aided design and computer-aided manufacturing systems.

Chapter 6 CASE STUDY

Today, most companies recognize the signifigant impact that technology is having on the functions associated with mechanical design and manufacturing. To address the relationship of computer-aided design/computer-aided manufacturing (CAD/CAM) most companies will establish a steering committee or task force. This project group is normally charged with the responsibilities of investigating the state of the art of CAD/CAM systems and then preparing a summary analysis of how this technology can be applied to increased efficiencies in design development and production. This section will examine a case study of how a major east coast truck manufacturer developed the strategy for selection and implementation of an appropriate CAD/CAM system.

Early in 1983, an executive CAD/CAM committee consisted of the Executive Vice-President of Manufacturing, Senior Vice-President of Engineering and the Vice-President of Information Resources Management. In April of that year, this committee established a CAD/CAM department to develop detailed recommendations and specifications for the selection and implementation of a corporate computer integrated design and manufacturing system. The writer of this thesis was given the responsibility of managing this challenging assignment.

The first item to be accomplished was to establish a statement of purpose and then develop the qualifications for staffing this newly created department. Since the CAD/CAM project crosses three distinct functions within the corporation, three people were chosen to become part of this department - one from engineering, manufacturing, and management information systems. The following is a statement of purpose followed by the qualifications of the personnel within the department.

6.1 CAD/CAM Department Specifications

The basic function of the CAD/CAM department is to define the application of CAD/CAM through a product life cycle and apply the advanced technologies associated with computer integrated design and manufacturing to that cycle. (The product life cycle is defined in this thesis as all the necessary steps and functions required to design, test, and manufacture the company's product.) Development of the application of CAD/CAM to the product life cycle will require an analysis of the relationships between the design, manufacturing, and MIS functions. This analysis will establish a blueprint for the future restructuring of accountabilities within the organization.

The project will be product oriented and will extend in scope from design concept through final assembly. It will be the department's responsibility to insure the establishment of a comprehensive product model database. (Appendix B). This database will be bounded by and may provide or receive information from financial systems, customer order entry systems, production planning and control systems, purchasing systems and marketing systems.

The major accountabilities for the manufacturing representative are:

1. Establish a product life cycle for the manufacturing function.
2. Determine the relationship of manufacturing to engineering and MIS.
3. Become familiar with current CAD/CAM systems and apply that knowledge to the development of a new product life cycle.

4. Develop and implement an integrated CAD/CAM system within the corporation.

5. Determine and document all new functions, relationships and accountabilities established within the CAD/CAM project.

The skills and knowledge level for the manufacturing representative are:

1. Thorough knowledge of manufacturing functions within all divisions.

2. Familiarity of manufacturing function as it relates to other organizations within the company.

3. Possess mature administrative and managerial skills, such as good organizer, accepts challenges, works as part of the team.

The major accountabilities for the design engineering representative are:

1. Establish a product life cycle for engineering functions.

2. Determine the relationship of engineering to manufacturing and MIS.

3. Become familiar with current CAD/CAM systems and apply knowledge of CAD/CAM

system to the product life cycle.

4. Develop and implement an integrated CAD/CAM system within the corporation.

5. Determine and document the new functions, relationships and accountabilities within the CAD/CAM project.

The skills and knowledge level for the design engineer representative are:

1. Thorough knowledge of engineering function within all divisions.

2. Familiarity of the engineering function to other functions within the company.

3. Possess mature administrative and managerial skills, such as being a good organizer, being able to accept challenge and working as part of a team.

The major accountabilities for the management information systems (MIS) representative are:

1. Define the interface between existing systems and the design and manufacturing functions.

2. Become knowledgeable with current CAD/CAM systems and aid in applying that technology to the development of a new

product life cycle.

3. Develop and implement an integrated CAD/CAM system within the corporation.

4. Document all new functions, relationships and accountabilities established within the CAD/CAM project.

The skills and knowledge level for the management information systems representative are:

1. Thorough knowledge of MIS functions within all divisions.

2. Familiarity of scientific computer hardware and software.

3. Possess mature administrative and managerial skills, that is, being a good organizer, being able to accept a challenge and working as part of a team.

In order to understand the relationship between all the various functions within the corporation, an investigative team was established to provide information to the CAD/CAM department. This team was charged with the responsibility of charting the flow of information as it was developed and passed through their particular division or department. The members were chosen from the following departments: management information systems (all divisions), accounting, material planning, quality assurance and control, advanced planning and manufacturing, international operations, design analysis engineers, product development and test engineering and product engineering (all divisions).

Having become knowledgeable on how the company performs its business, the department then began investigating available CAD/CAM technology, both from the vendor and user viewpoints. Considerable time was devoted to understanding how the company's operation could be applied to the available technology. A total of twenty-six CAD/CAM technology vendors were researched to various levels. (Table 6.1) Also, twelve CAD/CAM user companies were visited or spoken to in an effort to obtain information relating to satisfaction with various systems, selection methods and implementation techniques. Tables 6.2 through 6.8 summarize those functions and activities that would benefit through the application of various CAD/CAM related techniques.

Table 6.1 . <u>Vendors and Users Surveyed During CAD/CAM Evaluation Process</u>

A. <u>CAD/CAM Systems</u>

Apollo Computer, Inc.
Applicon
Auto-Trol Technology Corporation
Computervision
Control Data Corporation (CDC)
Digital Equipment Corporation (DEC)
General Electric (CAE and Calma)
Gould, Inc. (S.E.L.)
Graphics Technology Corporation (Graftek)
Information Displays, Inc.
Intergraph, Inc.
International Business Macnines (IBM)
Harris Corporation
Manufacturing Consulting Services, Inc.
Manufacturing Data Systems, Inc.
Matra Datavision
McConnell Douglas Automation Company (McAuto)
Prime Computer

B. <u>Data Capture Systems/Automatic Digitizers (Scanning)</u>

ANA Tech
Broomall Industries, Inc.
Metagraphics, Inc.
Scitex
Skantek

C. <u>Coding and Classification (Group Technology)</u>

Bringham Young University
Logan and Associates
Organization of Industrial Research

D. <u>CAD/CAM Users</u>

Air Products and Chemicals
Allis Chalmers Fluid Products Company
Chrysler Corporation (two divisions)
Cummins Engine Company
Deere & Company
Ingersoll Milling
Landis Tool Company

Table 6.1 , continued.

McDonnel Douglass Aircraft
Renault Vehicules Indistriels
Rockwell International Corporation
Storage Technology Corporation
Westinghouse Electric Corporation

ENGINEERING APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- DESIGN DRAFTING	- INTERACTIVE COMPUTER GRAPHICS	- PRODUCTIVITY INCREASE (3.1) - DESIGN STANDARDIZATION - IMPROVED METHOD OF CREATING ASSEMBLY/ ARRANGEMENT DRAWINGS (EXPLODED ISO DRAWINGS) - MAXIMIZE CREATIVE POTENTIAL
- DOCUMENTATION		- INHERENT CREATION OF FORMALIZED PARTS UNIT LIST & CHANGE WRITING INFORMATION
- DESIGN RETRIEVAL	- GROUP TECHNOLOGY (CODING & CLASSIFICATION)	- AUTOMATED DESIGN RETRIEVAL - LIMITS DESIGN REDUNDANCY

- ANALYSIS	- COMPUTER AIDED ENGINEERING	- MINIMIZE DESIGN ITERATIONS & IMPROVE DESIGN DEVELOPMENT CYCLE
		  - FINITE ELEMENT ANALYSIS
		  - KINEMATICS
		  - MASS PROPERTIES
		  - ETC.
		- QUALITY OF ENGINEERING

- INFORMATION MANAGEMENT	- DATA BASE MANAGEMENT SYSTEM	- INFORMATION ACCESS & CONTROL - PROJECT CONTROL (POTENTIAL FOR USE AS A BASIS FOR ENGINEERING ADMINISTRATION SYSTEM)
- VENDOR COMMUNICATIONS	- DIGITAL DRAWING FILES	- TRANSFER OF DRAWINGS TO AND FROM VENDOR ELECTRONICALLY

Table 6.2 Application of Technology to Engineering

MATERIAL PLANNING AND CONTROL APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- DESIGN RETRIEVAL (DETAILS/ASSEMBLIES/ ARRANGEMENTS)	- GROUP TECHNOLOGY	- AUTOMATED DESIGN RETRIEVAL - ASSIST IN INITIAL MAKE/BUY DECISION
- DRAWING ACCESS	- COMPUTER GRAPHICS (DISPLAY TERMINALS)	- IMMEDIATE ACCESS TO DRAWINGS - ELIMINATION OF PAPER PRINTS & APERTURE CARDS

Table 6.3 Application of Technology to Material Planning and Control

PRODUCTION ENGINEERING APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- PICTORIAL PROCESS PLANNING & ANALYSIS	- GROUP TECHNOLOGY (CODING & CLASSIFICATION)	- AUTOMATED PROCESS PLANNING (INCLUDES UTILIZATION OF EXISTING ENGINEERING GEOMETRY)
	- INTERACTIVE COMPUTER GRAPHICS	- REDUCED WIP (OPTIMIZED MATERIAL FLOW; WORK CELL ANALYSIS) - AUTOMATED PROCESS PLAN RETRIEVAL - STANDARDIZED PROCESS PLANS - LIMITS PROCESS PLAN REDUNDANCY
- TOOL & FIXTURE DESIGN, DRAFTING, ANALYSIS	- INTERACTIVE COMPUTER GRAPHICS - COMPUTER AIDED ENGINEERING	- PRODUCTIVITY INCREASE - DESIGN STANDARDIZATION - MINIMIZE DESIGN ITERATIONS & IMPROVE DEVELOPMENT CYCLE TIME
- TIME STANDARDS	- GROUP TECHNOLOGY	- AUTOMATIC TIME STANDARDS GENERATION
- MATERIAL HANDLING & EQUIPMENT PLACEMENT	- INTERACTIVE COMPUTER GRAPHICS	- PRODUCTIVITY IMPROVEMENT - SIMULATION OF EQUIPMENT/MATERIAL LOCATION & FLOW
- N. C. PROGRAMMING	- INTERACTIVE COMPUTER GRAPHICS	- PRODUCTIVITY IMPROVEMENT - IMPROVED/CONSISTENT QUALITY - REDUCED SCRAP - UTILIZATION OF EXISTING ENGINEERING GEOMETRY

Table 6.4 Application of Technology to Production Engineering

SALES ENGINEERING APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- CUSTOMER PROPOSALS	- INTERACTIVE COMPUTER GRAPHICS	- PICTORIAL REPRESENTATIONS
- DETERMINE CUSTOMER VEHICLE PERFORMANCE CHARACTERISTICS	- CAE/CAD	- MASS PROPERTY INFORMATION - GRADABILITY - TURNING RADIUS - ETC.

PURCHASING APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- DRAWING ACCESS	- COMPUTER GRAPHICS (DISPLAY TERMINAL)	- IMMEDIATE ACCESS TO DRAWING INFO - ELIMINATION OF PAPER DRAWING FILES AND APERTURE CARDS
- VENDOR COMMUNICATIONS	- DIGITAL DRAWING FILES	- TRANSFER OF DRAWINGS TO AND FROM VENDORS

Table 6.5 Application of Technology to Sales Engineering

ASSEMBLY APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- DRAWING ACCESS	- COMPUTER GRAPHICS (DISPLAY TERMINAL)	- IMMEDIATE ACCESS TO DRAWING INFO - ELIMINATION OF PAPER PRINT FILES & APERTURE CARDS - THE RIGHT DRAWING AT THE RIGHT TIME

QUALITY CONTROL APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- DRAWING ACCESS	- COMPUTER GRAPHICS (DISPLAY TERMINAL)	- IMMEDIATE ACCESS TO DRAWING INFO - ELIMINATION OF PAPER PRINT FILES & APERTURE CARDS
- TOOL, GAUGE & FIXTURE RETRIEVAL	- GROUP TECHNOLOGY (CLASSIFICATION & CODING)	- AUTOMATED RETRIEVAL - LIMITS DESIGN REDUNDANCY (TOOLS ACTUALLY CODED IN M.E.)
- PRINTED CIRCUIT BOARD DESIGN (HAGERSTOWN)	- INTERACTIVE COMPUTER GRAPHICS	- PRODUCTIVITY IMPROVEMENT - DESIGN STANDARDIZATION - IMPROVED DESIGN QUALITY - PART LIST GENERATION

Table 6.6 Application of Technology to Assembly and Quality Control

PARTS OPERATION APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- TECHNICAL PUBLICATIONS (PARTS BOOKS)	- COMPUTER GRAPHICS	- EXPLODED ISOMETRIC ARRANGEMENT DRAWINGS & ASSOCIATED BILL OF MATERIAL INFORMATION
- DRAWING ACCESS	- COMPUTER GRAPHICS (DISPLAY TERMINAL)	- ELIMINATION OF PAPER PRINT FILES & APERTURE CARDS

GENERAL SERVICES APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- TECHNICAL PUBLICATIONS	- INTERACTIVE COMPUTER GRAPHICS	- VERY SIGNIFICANT PRODUCTIVITY INCREASE THROUGH USE OF GRAPHICS CREATED BY ENGINEERING

Table 6.7 Application of Technology to Parts Operation, General Services

INTERNATIONAL OPERATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- DETERMINE CUSTOMER VEHICLE PERFORMANCE CHARACTERISTICS	- CAE/CAD	- MASS PROPERTY INFORMATION - GRADABILITY - TURNING RADIUS
- DRAWING ACCESS	- COMPUTER GRAPHICS (DISPLAY TERMINAL)	- ELIMINATION OF PAPER PRINT FILES

FACILITIES APPLICATIONS

ACTIVITY	TECHNOLOGY	BENEFITS
- ARCHITECTURAL DESIGN & DRAFTING	- INTERACTIVE COMPUTER GRAPHICS	- PRODUCTIVITY IMPROVEMENT - IMPROVED SPACE UTILIZATION - DESIGN STANDARDIZATION - FACILITY DESIGN SIMULATION - ASSET MANAGEMENT

Table 6.8 Application of Technology to International Operations, Facilities

6.2 Criteria Weighting And Evaluation Methodology.

Having mapped the appropriate technologies to the various functions within the corporation, it became necessary to derive a methodology that would allow the department to evaluate the various turnkey CAD/CAM systems. Remembering that the major objective of the CAD/CAM project would be to establish a comprehensive product model database, the committee analyzed each major area to ascertain the impact of that area in achieving the project objective. A numeric value was assigned to each category:

5-6 - Most significant impact on objective

3-4 - Significant impact on objective

1-2 - Least impact

Category Weight	CAD/CAM Technology Area
6	Graphics
6	Database/Database Manager
5	Command Language
4	Service and Software Support
4	Communications and Networking
4	Hardware and Product Line
3	Bill of Material
3	Engineering Analysis and

6.2 Criteria Weighting And Evaluation Methodology.

Having mapped the appropriate technologies to the various functions within the corporation, it became necessary to derive a methodology that would allow the department to evaluate the various turnkey CAD/CAM systems. Remembering that the major objective of the CAD/CAM project would be to establish a comprehensive product model database, the committee analyzed each major area to ascertain the impact of that area in achieving the project objective. A numeric value was assigned to each category:

5-6 - Most significant impact on objective

3-4 - Significant impact on objective

1-2 - Least impact

Category Weight	CAD/CAM Technology Area
6	Graphics
6	Database/Database Manager
5	Command Language
4	Service and Software Support
4	Communications and Networking
4	Hardware and Product Line
3	Bill of Material
3	Engineering Analysis and

	Special Applications
3	Training and Documentation
3	Vendor Experience
2	Numerical Control
2	System Recovery Methods
1	Environment
1	Group Technology
1	Scanning Interface

Each category was then subdivided into specific items with each item being assigned a numeric value based on the following table:

3 = Critical to overall evaulation of the system

2 = Desired functionality

1 = Nice to have but not necessary

0 = Not significant

A compilation of the structured systems selection methodology (Chapter 5 of this thesis) along with the category and items weights is presented on pages 89 through 102.

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
	Graphics		
6	Solid Modeling	3	___
6	CSG (Constructive Solid Geometry)	1	___
6	Number of Primitives ___	2	___
6	B-Rep (Boundary Representation)	2	___
6	Ease of Creating/Editing Geometry	3	___
6	Mass Properties (mass; volume)	3	___
6	Automatic hidden line removal	2	___
6	Manual hidden line removal	3	___
6	Control (i.e. show hidden line as dotted)	3	___
6	Color shading (ease of developing/changing colors)	2	___
6	Ease/method of creating cross hatching	1	___
6	Users ability to specify size/density of crosshatching	2	___
6	Utilizing a plane to section	3	___
6	Utilizing multiple planes to section	3	___
6	Utilizing a contoured surface to section	1	___
6	Hardware (dynamic) pan and zoom,rotate	2	___
6	Software pan and zoom, rotate	3	___
6	Orthogonal view	3	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	Perspective view	1	___
6	Flying eye view	2	___
6	Number of simultaneously displayable views ___	2	___
6	3-D wire frame model	3	___
6	Point-to-point creating/editing geometry	3	___
6	Construction lines to create/edit geometry	3	___
6	Referencing existing geometry to create new geometry	3	___
6	Quality of visualization (true edge projection)	2	___
6	Ease of creating/editing geometry	3	___
6	Sectional properties (area; perimeter, etc.)	3	___
6	Automatic hidden line removal	2	___
6	Manual hidden line removal	3	___
6	Control (i.e. hidden line as dotted line)	3	___
6	Colored lines	2	___
6	Ease/method of creating cross-hatching	1	___
6	Ability to control size/density	2	___
6	Quality of sectioning representation (visualization)	2	___
6	Utilizing multiple planes to section	3	___
6	Hardware pan, zoom and rotate	2	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	Software pan, zoom and rotate	3	____
6	Orthogonal view	3	____
6	Isometric view	3	____
6	Perspective view	1	____
6	Flying eye view	2	____
6	Number of simultaneously displayable views ____	2	____
6	Surfaces	3	____
6	Creating/editing Bezier surfaces	1	____
6	C/E B-spline surfaces	2	____
6	C/E surface filleting	3	____
6	C/E surface offsetting	2	____
6	C/E surface intersections	3	____
6	Draft angle projections (castings-forgings)	2	____
6	Curve driven curves	2	____
6	Ease of creating/editing surfaces	3	____
6	Sectional properties (surface area)	3	____
6	User's ability to control "mesh" density	2	____
6	Color shading (ease of developing; changine hues)	2	____
6	Automatic hidden line removal	1	____

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	Manual hidden line removal	1	___
6	Control (i.e. show hidden lines as dotted)	1	___
6	Surface projections (i.e. surface pierce point)	2	___
6	Surface flatening/unwrapping	2	___
6	Conversions	2	___
6	3-D wire frame to solid	2	___
6	Solid to 3-D wire frame	2	___
6	Surface to solid	1	___
6	Drafting (ANSI Std. - Y14.5)	3	___
6	Manual dimensioning	3	___
6	Automatic dimensioning	1	___
6	Automatic text placement	1	___
6	User defined placement	3	___
6	Horizontal dimensioning	3	___
6	Vertical dimensioning	3	___
6	Angular dimensioning	3	___
6	Parallel dimensioning	3	___
6	Radial dimensioning	3	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	Diametral dimensioning	3	___
6	Complex surface (B-surf) dimensioning	2	___
6	English to metric conversion	2	___
6	Metric to English conversion	2	___
6	Dual dimensioning	2	___
6	Datum dimensioning	2	___
6	Chain dimensioning	2	___
6	Mini-max tolerancing	3	___
6	Plus-minus tolerancing	3	___
6	Linear, angular, circular tolerancing	3	___
6	Ability to selectively change	3	___
6	Geometric tolerancing symbols	2	___
6	Standard designs symbols library	2	___
6	User-generated symbols (creation of)	3	___
6	Text fonts (___)	2	___
6	Line types (___)	2	___
6	Standard line types	1	___
6	User defined line types	2	___
6	Arrowhead types (___)	2	___
6	Standard line weights	2	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	User defined line weights	2	___
6	Layering	3	___
6	Addition/editing of text on drawing	3	___
6	Associativity	3	___
6	Associate lines to dimension	3	___
6	Associate arcs to dimension	3	___
6	Automatic update of dimension	2	___
6	Geometry change in (1) view, automatically reflected in all views	3	___
6	Ability to construct geometry using multiple views (i.e. all views active)	2	___
6	Automatic update of model change to drawing	2	___
6	Controlled update of model change to drawing	0	___
6	Automatic update of model change to assembly	0	___
6	Controlled update of model change to assembly	2	___
6	Manual update of model change to assembly	1	___
6	Cross-hatching to model (i.e. cross-hatching automatically conforms to changes to model)	1	___
6	Dimensions to geometry (i.e. change text and geometry changes)	2	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	User defined line weights	2	___
6	Layering	3	___
6	Addition/editing of text on drawing	3	___
6	Associativity	3	___
6	Associate lines to dimension	3	___
6	Associate arcs to dimension	3	___
6	Automatic update of dimension	2	___
6	Geometry change in (1) view, automatically reflected in all views	3	___
6	Ability to construct geometry using multiple views (i.e. all views active)	2	___
6	Automatic update of model change to drawing	2	___
6	Controlled update of model change to drawing	0	___
6	Automatic update of model change to assembly	0	___
6	Controlled update of model change to assembly	2	___
6	Manual update of model change to assembly	1	___
6	Cross-hatching to model (i.e. cross-hatching automatically conforms to changes to model)	1	___
6	Dimensions to geometry (i.e. change text and geometry changes)	2	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	Window (magnified view of a small portion of the model) to model	1	___
6	Automatic update of NC related information	1	___
	Data Base/Data Base Manager		
6	Structure	3	___
6	Hierarchical data base	1	___
6	Network database	1	___
6	Relational database	2	___
6	Centrally stored - locally available	0	___
6	Locally distributed	0	___
6	Drawing management system (engineering administration)	3	___
6	Project control	2	___
6	Drawing location	3	___
6	Drawing status (i.e. terminated; production)	2	___
6	Revision history (accumulation of text)	2	___
6	Last access information	2	___
6	Drawing attributes (weight, cost, etc.)	3	___
6	Drawing protection (overall rating)	3	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
6	Drawing protection by user	3	___
6	Drawing protection by drawing status (i.e. Engineering, Production, Planning, Management)	2	___
6	Drawing protection by date	2	___
6	Revision control (multiple revisions active)	2	___
6	Charted drawings - dimensions	3	___
6	Charted drawings - drawing numbers	3	___
6	Archiving	3	___
6	Selectivity (i.e. by date, by user, other)	3	___
6	Method (i.e. ease of archiving)	3	___
6	Filing of arrangements/assemblies	2	___
6	Query capability and report writer	3	___
	Command Language		
5	System software language	0	___
5	Macro (parametric) language	2	___
5	System "user" FORTRAN interface	2	___
5	Journaling/keystroke log	2	___
5	Command driven user interface	3	___
5	Menu by-passability	3	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
5	Menu user definable options	3	___
5	Menu ease of use	3	___
5	Command input buffering by terminal	2	___
5	Calculator mode	2	___

Communications Networking

Category Weight	Item Description	Item Weight	Vendor Rating
4	Work station to host (56,000 baud)	3	___
4	LAN (Local Area Network)	2	___
4	IBM interface	3	___
4	HASP-RJE emulation	3	___
4	3270 emulation	2	___
4	SNA gateway	2	___
4	Network overhead (effect on system performance)	2	___
4	General networking acceptability	2	___

Hardware/Product Line

Category Weight	Item Description	Item Weight	Vendor Rating
4	Cursor control of design workstation	3	___
4	Command text location on screen	2	___
4	Display technology (raster, storage tube, vector refresh)	3	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
4	User-friendliness	3	___
4	Intelligent work station (local-terminal execution of graphic commands)	2	___
4	Stand-alone work station	2	___
4	Work station configuration (left hand adaptability)	2	___
4	Pen plotters	3	___
4	Electrostatic plotter	3	___
4	Monochrome hard copy unit	3	___
4	Color hard copy unit	3	___
4	COM (Computer Output Microfilm)	2	___
4	Photo composer	1	___
4	RGB interface (slides)	1	___
4	32 bit vs. 16 bit (graphics CPU)	3	___
4	Disc drive capacity	2	___
4	Tape drive recording speed	3	___
4	Tape drive recording density	2	___
4	Computer - vendor model	2	___
	Service and Software Support		
4	Response time	3	___

<u>VENDOR CONSIDERATIONS EVALUATION LISTING</u>

Category Weight	Item Description	Item Weight	Vendor Rating
4	Penalties	2	___
4	On-site support	3	___
4	User groups	2	___
	Bill of Material		
3	Ability to assign attributes to detailed parts	3	___
3	Ability to accumulate attributes at higher levels	3	___
3	Ability to extract attributes at assy/arrgt levels	3	___
3	Ability to format into user determined form	2	___
3	Automatic indentation/identification of sub-assy/details	2	___
3	Ability to network BOM into other non-graphic systems	2	___
3	Where used inquiry	2	___
3	Ability to compare and document the difference between existing and newly created sub-assys/arrgts	1	___
	Engineering Analysis/Special Applications		
3	Finite element modeling (FEM)	2	___
3	Pre and post processors	1	___
3	Automatic mesh generation	1	___
3	Ability to transfer part geometry directly to "ANYSYS"	2	___
3	Motion studies (DRAM & ADAMS)	2	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
3	Sheet metal flat pattern development	2	___
3	Interactive nesting of sheet metal parts	3	___
3	Automatic nesting of sheet metal parts	2	___
3	Piping/routing	2	___
3	Printed circuit board design	3	___
3	Facilities and space management	2	___
3	Technical publications	2	___
	Training and Documentation		
3	Proximity of training	1	___
3	Instruction manuals (concise and understandable)	1	___
3	Systems reference manuals	2	___
3	On-line documentation/"HELP" command	2	___
3	Types of training programs available	2	___
	Vendor Experience (CAD/CAM Related)		
3	Years experience	2	___
3	Financial strength	3	___
3	Number of customers and installation date	2	___
3	Number of employees in new development software	2	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
3	Credibility	3	___
	Numerical Control		
2	APT source capability	2	___
2	Machine code generation for punch press and machining and turning centers	2	___
	System Recovery Methods		
2	Recovery method/procedures acceptable	2	___
	Environment		
1	Special lighting requirements	1	___
1	Air conditioning requirements	0	___
1	Electrical requirements	0	___
1	Noise levels	0	___
	Group Technology		
1	Interface acceptability	2	___
1	Coding and classification (design and manufacturing)	0	___
1	Process planning	0	___

VENDOR CONSIDERATIONS EVALUATION LISTING

Category Weight	Item Description	Item Weight	Vendor Rating
1	Automatic time standards generation	0	___
	Miscellaneous		
1	IGES (Initial Graphics Exchange Specification)	3	___
1	SIF (Standard Interface Format)	0	___
1	Are capabilities interfaced or integrated?	2	___
1	Scanning/interface	1	___

6.3 Procedure of Evaluation.

The coding used to run this program is implemented on an IBM 3033 computer using the Statistical Analysis System from[26] the SAS Institute located in Gary, North Carolina. Acknowledgement must at this time be given to Titus Ruch who actually implemented the program and the required input formats. A closer analysis reveals that the methodology parameters weights, categories and formulas could with little difficulty be implemented on a personal computer using a commercially available electronic spreadsheet software package.

The universality of this method stems from the fact that the criteria classifies and quantizes items normally associated with the evolution of CAD/CAM systems as well as identifying those items that are not yet available but required to implement CIM. For example, the methodology evaluated the ability to dimension geometry - a feature surely any turnkey CAD/CAM system should have. On the other hand, however, the methodology accounts for integrated graphics relational database to control the interaction and associativity of geometry files within the CAD database. This product has not yet been demonstrated to the writer. This type of methodology also exhibits uniqueness in that the user can redefine the category weights and item weights based on the users specific application.

The next step in the process was to establish appropriate values to rate a specific vendor's product offering:

0 = Not available or "No"

1 = Poor implementation or "Yes"

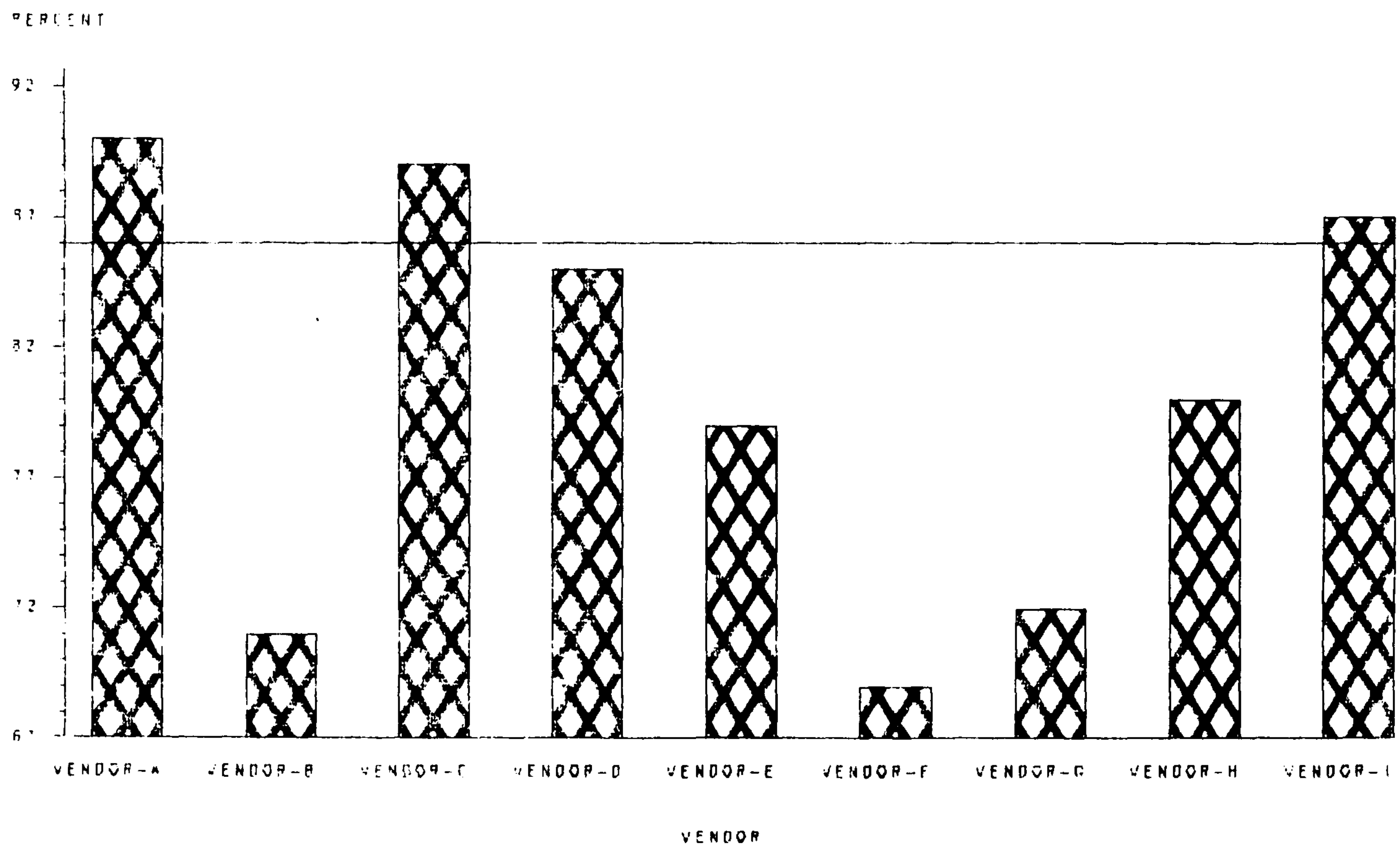
2 = Fair to Acceptable

3 = Good to Excellent

Having established the appropriate vendor rating system,the CAD/CAM department then evaluated a fictitious turnkey CAD/CAM vendor. Based on what was demonstrated and actually would be reasonable to expect in today's market, the rating for this practical CAD/CAM system turned out to be 86% of the total points available in the evaluation. Not realizing the weights applied to each item and category, each vendor was asked to respond to the consideration list. The responses, combined with information obtained in the course of the CAD/CAM department's investigations were analyzed and rated using the afore described rating sheets. The appropriate rates were input into the SAS program and results were analyzed against the 86% score for the fictitious CAD/CAM system. Note should be made that any vendor that failed to supply an item that was rated critical was immediately flagged for closer evaluation or was eliminated from the evaluation procedure.(Figure 6.1)

This first pass through the evaluation prodecure allowed the CAD/CAM department to reduce the number of possible suppliers from eight to three. Having consequently notified the five who were eliminated from the selection process, the CAD/CAM department focused their energies on the top three vendors, all of which had achieved scores greater than 86%. Each of the last vendors were probed in greater detail on the items that were reflected as being fair or poor from the initial evaluation. Benchmarks, as well as detailed specifications including a request for quotations, were submitted to each of the top three vendors. Responses were returned within a specific time frame. Again the responses combined with the results of the benchmarks were analyzed and rated using the described methodology. Results of this final evaluation yielded a turnkey CAD/CAM system that contained the system attributes needed for the implementation of an integrated CAD/CAM system.

CAD/CAM VENDOR EVALUATION SUMMARY



PERCENTAGE OF MAXIMUM SCORE ATTAINED

Figure 6.1 Vendor Evaluation Summary

Chapter 7 SUMMARY

The structured system selection methodology developed in this thesis provides an approach to evaluate and select a computer-aided design and computer-aided manufacturing (CAD/CAM) system that will ultimately become part of a computer integrated manufacturing system (CIMS). The literature search indicated that although methodologies to evaluate and select turnkey CAD/CAM systems exist, their scope is either based on specific application or financial justification. The structured system selection methodology is unique in that the user can prioritize specific needs through a flexible computerized criteria weighting system while at the same time it encourages the user to consider and pursue evaluation of areas that facilitate CIM. The ability to integrate CAD to CAM as well as to the various corporate business systems is of paramount importance.

Having concluded that a company's ability to remain competitive in the coming years depends on its capacity to apply computer technology to its operation, part two of this thesis developed the criteria needed to evaluate CAD/CAM systems. In order to establish the criteria, an analysis of the flow of engineering information throughout the corporation must first be completed. An analysis of this flow reveals that specific departmental functions can be enhanced through the application of particular computer based technologies. Having applied the technologies associated with CAD/CAM to the various functions within design and manufacturing, it then became necessary to categorize those areas to be evaluated during the selection of a CAD/CAM system. A listing of those categories along with a discussion of the items associated with each category was presented.

The final section examined a case study of how a corporation developed the project team to evaluate, select and implement an appropriate CAD/CAM system. This department's charter was to develop a technology strategy that would be product oriented and extend in scope from design concept through final assembly. After having mapped the appropriate technologies to the various functions within the corporation it was then decided to list each of the categories and items developed in section two to ascertain the impact of that area in achieving CIM. This listing was computerized and allowed the department to record vendor responses to a uniform rating system. The rating of each item was performed and results of the methodology were analyzed by the CAD/CAM department. The results of this analysis yielded a vendor that was consequently chosen to provide the corporation's CAD/CAM system. The system was subsequently installed and is functioning satisfactorily.

Chapter 8 CONCLUSION

It can be concluded that the structured system selection methodology presented in this thesis provides a means to uniformly evaluate various turn-key CAD/CAM systems. The feasibility of this methodology was demonstrated by a case study. The procedure developed allowed a corporate evaluation to narrow a field of eight possible CAD/CAM vendors to three. A benchmark then permitted the CAD/CAM department to further analyze the final three vendors, but the structured systems selection methodology was subsequently used to make the final vendor selection.

Through the experience gained in developing this structured system selection methodology, certain principles and strategies were developed that will aid in the evaluation of the spectrum of available technology.

First, integration is of paramount importance. This includes not only the relationship of CAD to CAM and computer aided engineering (CAE) but also embraces the appropriate connection with existing business systems. Having analyzed a company's requirement for CIM technology using the structured system selection methodology, it was learned that no single vendor could provide the total solution.

Second, during the evaluation process, top management support should be promoted and maintained. Conversations with experts in this field indicate the success of the system depends to a great degree on the amount of committment and support that comes from upper management. Implementation of this technology will require organizational changes that will remove the traditional walls between the manufacturing and engineering organizations. Therefore, it is imperative that management remain informed of the CAD/CAM project.

Finally, the described structured systems selection methodology provides an objective uniform procedure for evaluating turnkey CAD/CAM systems. CAD/CAM is the application of computers to the development and manufacture of projects where the user converses directly with the computer by using a graphic or non-graphic console in such a manner that his problem solving processes are highly responsive and essentially uninterrupted. Inherent in this definition are all the fundamentals that this thesis has used as the foundation for the development of a comprehensive computer integrated design and manufacturing system.

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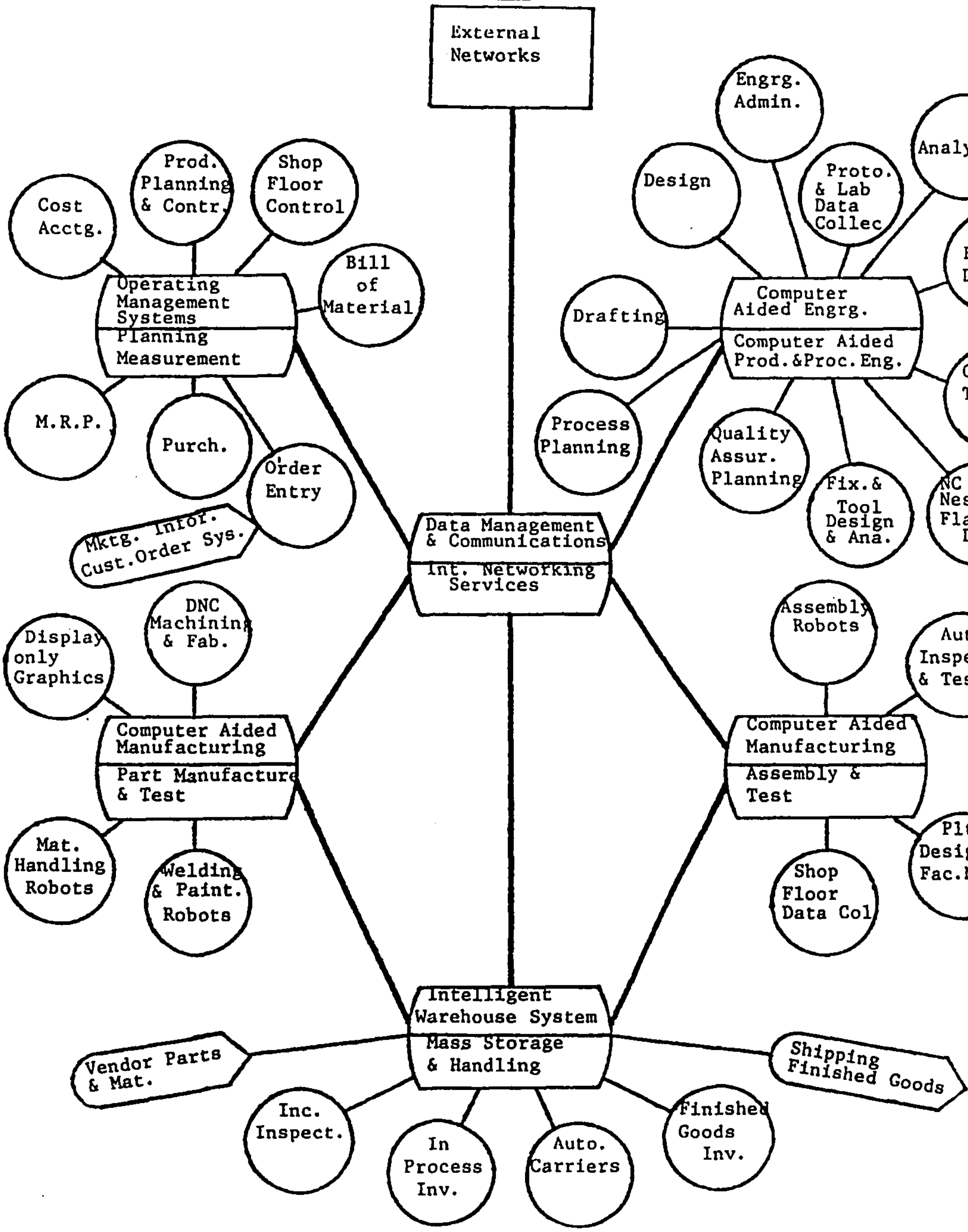
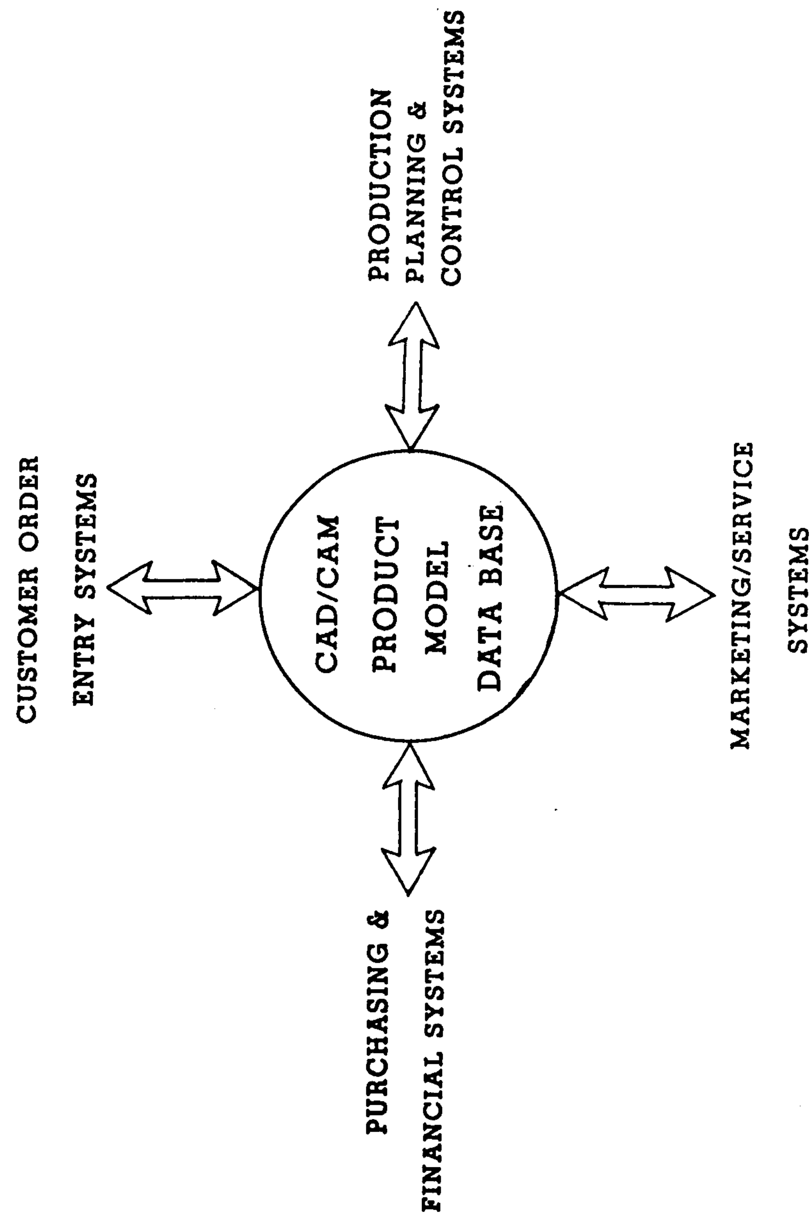
COMPUTER INTEGRATED ENGINEERING & MANUFACTURING

CIM



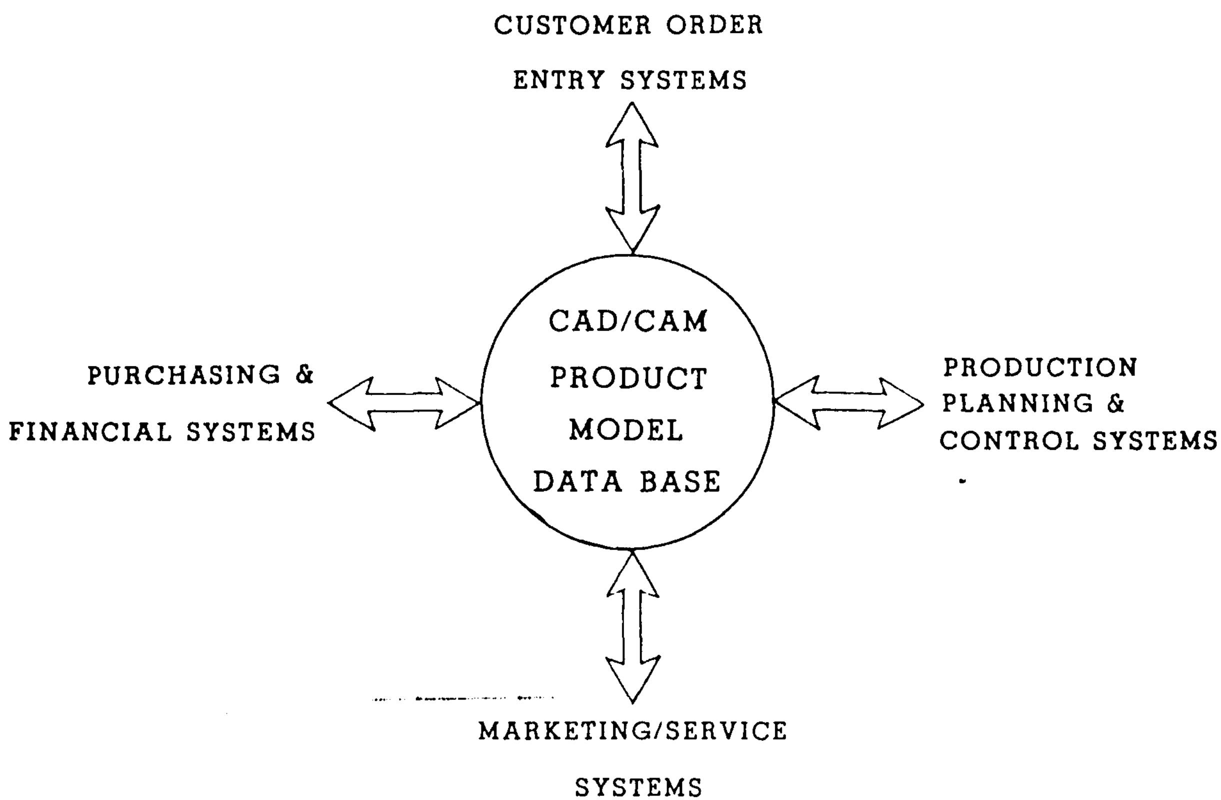
Appendix A - CIM Network

CAD/CAM PROJECT BOUNDARIES



Appendix B - Product Model Data Base

CAD/CAM PROJECT BOUNDARIES



VITA

The author was born in Allentown, Pa. on May 2, 1950. His parents are Edgar C. (deceased) and Irene M. Biery. He attended Northampton Area Senior High School where he was a member of the National Honor Society, the marching band and chorus.

He attended Kutztown State College, graduating in 1972 with a Bachelor of Science degree in mathematics. He was a member of Kappa Delta Pi and Kappa Mu Epsilon, honorary societies in the field of education and mathematics. Upon graduation, he received a teaching position in Parkland Senior High School, Orefield, Pa. where he taught mathematics for one year.

In 1973 he became employed at Mack Trucks, Inc., Allentown, Pa. as a process engineer. His most recent position at Mack Trucks, Inc. was as a project manager in the CAD/CAM department

He began graduate studies at Lehigh University in January 1984 in the Manufacturing Systems Engineering program. His goal is to receive a Master of Science degree in Industrial Engineering.

He is married to Sandra (Miller). They have two children and reside in Northampton, Pa.