A TECHNOLOGY MANAGEMENT METHODOLOGY IMPLEMENTED USING EXPERT SYSTEMS

A Thesis

Submitted to the Faculty of Graduate Studies and Research

In Partial Fulfillment of the Requirements

for the Degree of

Master of Applied Science

In Industrial Systems Engineering

University of Regina

by

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Regina, Saskatchewan

August, 1998

0-612-35837-2

ABSTRACT

Management of technology concerns the processes of managing technology development through research and development, and managing the introduction and use of technology. Expert systems are computer programs that encode knowledge about a problem into a knowledge base, and then use this knowledge to reason and draw conclusions about a particular problem or situation. Currently, expert systems are being used in many areas, but we have found no examples of expert systems being applied in the field of technology management. The objective of this research is to develop and test an expert system methodology for evaluating technologies for possible implementation in a small business.

The methodology compares customer objectives to the attributes of various technologies, and rates the technologies that should be considered for implementation. The matrix structure of the Quality Function Deployment ("House of Quality") approach to quality control is the basis for the expert system methodology introduced and described here.

A prototype expert system that evaluates and compares three technologies was developed and tested by conducting interviews with two small businesses. The results of this in-field evaluation are presented and discussed with respect to the expert system methodology and the system's recommendations. The expert system methodology developed and tested here has successfully streamlined the onerous task of selecting technologies in a small business.

ACKNOWLEDGMENTS

I would like to thank my thesis supervisors, Dr. D.G. (Doug) Vandenberghe, and Dr. J.D. (Jack) Katzberg, for their advice and guidance.

I would also like to thank Toby Hughes of USF Watergroup, and Merv Armstrong and Dwayne Chychrun of Ralph McKay Industries Inc., who agreed to help test the prototype computer program and provided valuable insight and feedback on the practicality of this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

1. INTRODUCTION

Because expert systems separate the control and logic functions from the actual information (knowledge), it is possible to take an expert system and enter into it information on any subject. The objective of this research was to develop a methodology for constructing an expert system tailored for use as an assistant to a technology management consultant. The methodology will provide a structured approach for evaluating technologies for possible implementation by the consultant's customer, and ensure consistent and repeatable results.

The expert system structure has a significant advantage over traditional computer programs, because once information pertaining to a technology is entered into the knowledge base, it can be easily modified, updated, and complimented. The addition of other technologies simply involves adding their characteristics and the results of the technology evaluation to the expert system. The expert system then functions with the enlarged knowledge base without requiring changes to the control or logic programming.

1.1. Technology Management

Management of technology "concerns the process of managing technology development, implementation, and diffusion in industrial or governmental organizations. In addition to managing the innovation process through [Research and Development], it includes managing the introduction and use of technology in products, in manufacturing processes, and in other corporate functions" [1].

Effective technology management in a manufacturing environment allows companies to compete more effectively against their competitors, by searching out and implementing the technologies that provide a competitive edge [2, 3].

Five key elements of technology management are: [1]

(1) Identification and evaluation of technological options.

(2) Management of Research and Development.

(3) Integration of technology into the company's operations.

(4) Implementing new technologies in a product/process.

(5) Management of obsolescence and replacement.

Because there is such a volume of material relating to many different technologies, and the technologies are changing continuously, it is very difficult for a single person, or even for several people within a company, to stay abreast of the changes, and be able to pick out beneficial technologies. For this reason, some type of automated system for providing information on technologies, with consideration being given to the specific application that is being considered, would be very beneficial.

1.2. Expert Systems

Expert systems are "computer programs designed to model the problem solving ability of a human expert" [4]. These systems encode knowledge about a problem into a knowledge base, and then use this knowledge to reason and draw conclusions about a particular problem or situation.

Expert systems can be beneficial when a procedure involving evaluation or heuristic reasoning must be performed repeatedly, or when the training and knowledge that a person possesses can not be easily replaced. Expert knowledge can be coded into the knowledge base of an expert system, preserving the knowledge and making it available to draw on in the future.

Expert systems are limited in the range of knowledge that they can accommodate, and function best if they are programmed with detailed knowledge about a very specific subject area [4]. They are not as effective when programmed with superficial knowledge of a broad subject area. In the case of this thesis, the expert system was coded with detailed knowledge about, and a procedure for, analyzing and recommending technologies for implementation in a small business.

1.3. Current Applications of Expert Systems

Currently, Expert systems are being used in many areas, such as Control Systems, Design, Diagnostics, Instruction (education), Interpretation, Monitoring, Planning, Prediction, Prescription, Selection, and Simulation [4, 5, 6].

Control expert systems govern the behavior of a given system. The control inputs are constantly adapted to changing conditions by monitoring the system, and interpreting the system's behavior (feedback) to determine if corrections must be made to the control inputs. An expert system called Ventilator Manager (VM) [7] was developed in 1978 to monitor and control the treatment of hospital patients in intensive care. By monitoring data such as the patient's heart rate, blood pressure, and other vital statistics, the expert system can control the mechanical ventilator (that assists the patient's breathing), and can also sound alarms and make other recommendations for therapies or treatments.

Design expert systems are used to configure objects under constraints. PEACE [8] was developed in 1980 to assist in designing electronic circuits. By merging aspects of Expert Systems with Computer Aided Design (CAD) programs, and working through a series of design steps, the system achieves the design specifications by synthesizing and analyzing the circuit based on known properties of electrical components.

Diagnostic expert systems infer problems from observable information. NEAT [9] troubleshoots data processing and telecommunications network equipment, allowing non-technical staff to perform the diagnosis. By considering the system specifications and configuration, and the symptoms of the problem, it can ask that simple diagnostic procedures be followed to gain more information, and can generate repair recommendations based on the given information. Model-Based reasoning approaches can also be used [10], and in these cases the system's normal behavior is modeled, and faults can be detected and diagnosed by comparing the model's behavior to the actual system's behavior.

Instructional expert systems guide the education of students in a given topic by comparing the student's test results against the subject matter to determine where the student's understanding is weak, or where there are gaps in the student's knowledge. GUIDON [11] was developed in 1979 to instruct medical students by having them perform a diagnosis of a known problem, and comparing the student's diagnosis and problem solving technique to the known solution to the problem.

Interpretation expert systems produce an understanding of a situation using available information. Foreign Exchange Auditing Assistant (FXAA) [12] was designed to find irregular transactions in foreign exchange trading at a major bank and bring them to the attention of the auditors.

Monitoring expert systems watch the behavior of a system, and sound a warning or initiate action when the watched parameters go outside the set boundaries. NAVEX [13] estimates position and velocity of the space shuttle. Using this information, it can detect errors, predict problems and recommend actions to be taken.

Planning expert systems formulate a series of steps required to meet a given goal. PLANPOWER [14] generates financial planning advice specifically tailored to a customer's needs based on knowledge of the investments (securities, real estate), insurance and the applicable tax structures.

Prediction expert systems use inference to predict the behavior of a system under given constraints or conditions. PLANT [15] predicts losses to crops from insect damage based on past experience and current environmental and weather conditions.

Prescription expert systems recommend solutions to a problem. BLUE BOX [16] uses information on the symptoms and medical history of patients suffering from depression and recommends the type of treatment or therapy to be used.

Selection expert systems identify the best choice from a set of options. IREX [17] selects industrial robots by first selecting the application area best suited for automation, then selecting the type and configuration of the robot, and finally by selecting a commercially available robot to be purchased.

Simulation expert systems model a system so tests of the system's operation can be conducted under various operating conditions. STEAMER [18] simulates the operation of the powerplant of a steam powered ship, allowing students to observe changes in the powerplant operation resulting from changes in operating parameters and control settings.

All of the expert systems in these diverse areas have performed well, have proven themselves, and have also proven that the concept of expert systems can be applied successfully to real world problems.

1.4. Application of Expert Systems to Technology Management

At the present time, no examples of expert systems being applied in the area of technology management have been found. Because of the complex relationships between technologies, and the rapid pace of technological advancement, a technology management expert system must contain elements of existing expert system applications such as diagnosis, instruction, and selection. The development of the expert systems methodology for technology management is daunting, but the potential benefits are significant.

Reduced repetition: Once the expert system is programmed, it can be run many times with very little additional effort. If the technology management analysis was performed manually, it would require considerable effort for each additional trial.

Consistent and repeatable results: Because the expert system follows a fixed set of logical rules and steps, the results will always be consistent from one trial to the next. Current methods are somewhat subjective in nature and can be influenced by human error (possibly caused by fatigue and stress) and human bias, conscious or unconscious.

Justifiable results: Because the logic can be traced throughout the expert system's analysis and recommendation process, the final results can be more easily justified or defended.

Ease of updating: Because the knowledge base is separate from the control and logic functions, it is relatively easy to update the knowledge base as the technologies change.

Expandability: Because the logic and control functions remain the same regardless of the size of the knowledge base, the complexity of the expert system is linearly related to the size of the knowledge base or the number of technologies being compared. When standard computer programs are used, the complexity may increase exponentially as the knowledge base is expanded.

Flexibility: Since the control and logic mechanisms of the expert system are separate from the actual information (knowledge) and each logical step is based on a relatively simple comparison strategy, the expert system can be used to compare all types of technologies.

1.5. Summary of Objectives

Because there are no known expert systems being used today for technology management, our objective is to develop an expert system methodology for technology management. During this process a prototype expert system that could be used for technology management as it relates to small business will be developed and evaluated.

The expert system methodology will perform technology management evaluations by assessing customer needs, and relating them to a broad spectrum of technologies. The knowledge base structure contains the information about the technologies and the requirements of the customer, in a format that facilitates the control and logic functions.

For the prototype expert system, the knowledge base will include information related to three technologies common to small manufacturing businesses. Interviewing two small manufacturing businesses that are knowledgeable in technology management practices will complete the verification of the methodology and the expert system.

It is intended that this thesis will provide a foundation for future work. The methodology and the prototype expert system developed here will guide the development of more advanced expert systems that will be able to function in more complex real world situations.

2. STRUCTURE AND METHODOLOGY OF THE EXPERT SYSTEM

This expert system methodology is to be applied to the evaluation of the technological options available to a small manufacturing business. The expert system is intended to assist and support technology management consultants whose customers are small manufacturing businesses. These businesses do not have the resources or the expert knowledge necessary to make informed decisions in the area of technology management, and are looking to choose one or more technologies for implementation that will provide the greatest overall benefits for the business. The structured methodology of this expert system makes it a valuable tool that allows the consultant to make accurate recommendations, in a consistent manner, with repeatable and traceable results.

2.1. House of Quality Matrix Structure

The matrix structure of the "House of Quality" [19] from the Quality Function Deployment approach to quality management and control was found to have many desirable attributes for storing and evaluating data about complex relationships that could be incorporated into a technology management expert system [20].

Quality Function Deployment (QFD) is a graphically oriented planning and communication tool that focuses on meeting the customer's requirements throughout the design, manufacturing, and marketing processes. QFD interrelates what the customer wants, with the technical features that the manufacturer can use to meet these requirements. QFD allows the manufacturer to use a graphical type of competitive benchmarking to compare their proposed product against existing products from other manufacturers, using the House of Quality shown in Figure 2.1.

The House of Quality compares a list of the attributes that the customer desires, Customer Attributes – the "Voice of the Customer", specified in terms that the customer is comfortable with, against a list of technical features, counterpart characteristics, that represent the customer attributes translated into technical language.

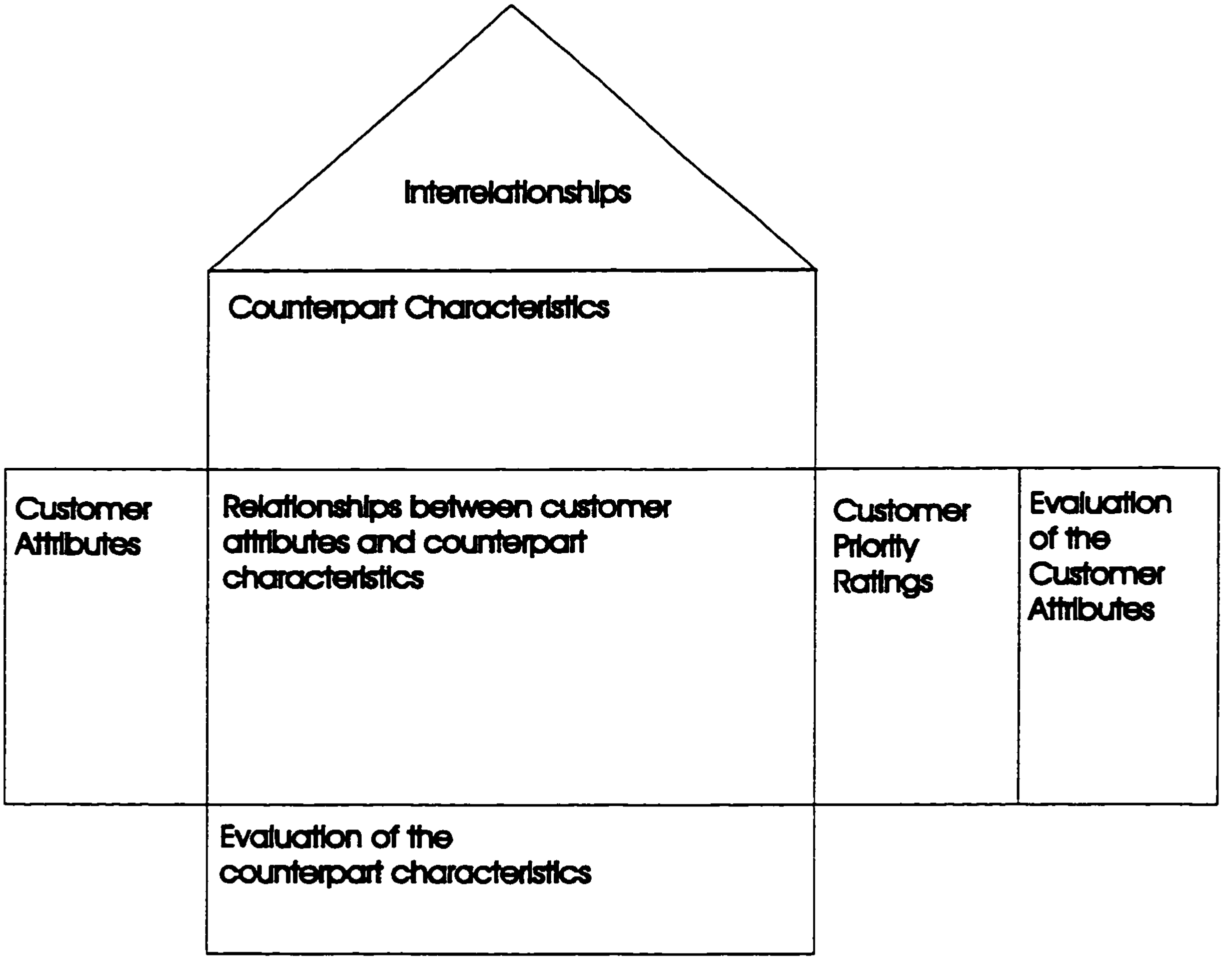

Figure 2.1. House of Quality Matrix Structure

Customer Priority Ratings are used to determine which of the customer attributes the customer considers more or less important. This is accomplished by assigning a numerical value to the relative importance of each customer attribute.

The Relationship Matrix contains a numeric representation of how well each counterpart characteristic meets the requirements of the customer attributes.

The evaluations of the customer attributes are calculated by multiplying the customer importance ratings by each element in the corresponding row of the relationship matrix, and calculating the sum of the multiplication for each row (customer attribute). The evaluations of the counterpart characteristics are similarly determined by performing the same multiplication and calculating the sum for each column.

The "Roof" of the House of Quality is a triangular matrix showing interrelationships between every possible combination of two different counterpart characteristics. This triangular matrix is used to quantify the effect of changes in one counterpart characteristic on others, and to assess trade-offs between design characteristics.

Adapting the House of Quality matrix structure to a computerized expert system methodology for technology management requires numerous changes to make the flow of information easier to follow, and easier to implement. In addition, some of the terminology used in the House of Quality was changed to make it easier to understand in the context of the technology management expert system. The result of these changes can be seen in Figure 2.2 in Section 2.2.

2.2. Modified House of Quality

Figure 2.2 shows the House of Quality matrix structure after it has been modified to better suit the technology management application. The variables used are described below. Sections A and B are descriptive row and column headings, sections C and D contain numeric data that is entered directly, and sections E, F, and G are calculated values:

A_x – Customer Objectives. A text description of the customer objectives (customer attributes) corresponding to each row of the technology comparison matrix. The subscript x indicates the row of the matrix, and ranges from 1 to the total number of rows.

B_y – Technology Implementation Areas. A text description of the technology implementation area corresponding to each column of the comparison matrix.

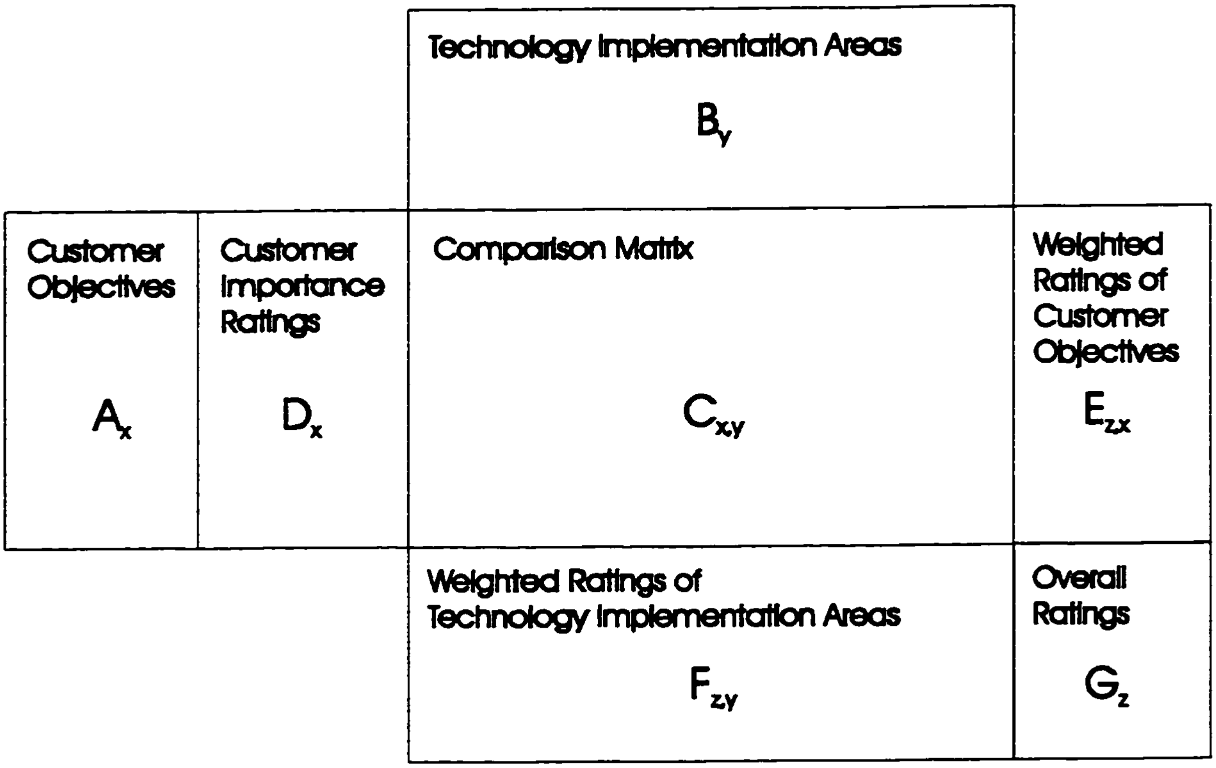

Figure 2.2. Expert System Matrix Structure

The subscript y indicates the column of the matrix, and ranges from 1 to the total number of columns. Technology implementation areas replace what is termed counterpart characteristics in the House of Quality matrix because they better relate to the customer's technology management objectives, making the evaluation process easier to complete and understand.

$C_{x,y}$ – Comparison Matrix. Numeric ratings in this area indicate how well each technology application area (B) meets the requirements of each customer objective (A). The subscripts x and y indicate the row and column of the matrix respectively. Values of the ratings range from 0 to 5, with the higher numbers indicating strong relationships and lower numbers indicating weaker relationships. Values for the matrix are generated by evaluating each implementation area for the technology against the list of customer objectives. This evaluation is performed when the technology is added to the knowledge base, and the values remain constant until technological change warrants a re-evaluation (see Appendix B).

D_x – Customer Importance ratings. Numeric ratings that indicate how important the customer considers each objective to be. The subscript x indicates the matrix row (customer objective) that the rating corresponds to. Values range from 0 (lowest importance) to 5 (highest importance). These numbers are based on the customer's priorities, and are determined during an interview process with the customer.

$E_{z,x}$ – Weighted ratings for each Customer Objective (A). The subscript z indicates the technology being considered, and the subscript x indicates the row or customer objective. Weighted ratings for each customer objective are calculated by multiplying the customer importance ratings (D) by the comparison matrix values for each of the implementation areas (C), and calculating the sum for all implementation areas of each technology.

$F_{z,y}$ – Weighted Ratings for each Technology Implementation Area (B). The subscript z indicates the technology, and the subscript y indicates the technology implementation area being considered. Weighted ratings for each technology implementation area are calculated by multiplying the customer importance ratings (D) by the comparison matrix values for the technology application area, summed over all customer objectives.

G_z – Overall Weighted Ratings. The subscript z indicates the technology. Overall weighted ratings are calculated from the sum of all weighted customer objective ratings (E) for each technology. Calculating the overall weighted ratings from the sum of all weighted technology implementation area ratings (F) also produces the same value.

The technology management expert system consists of four main sections: Data input, comparison matrix, calculations, and data output.

The data input and output sections will provide a method for entering the customer importance ratings, and will provide formatted output of the recommendations of the technology management expert system.

The comparison matrix serves as the knowledge base for the technology management expert system. It is where all the information on the technology evaluations is stored. The columns of the comparison matrix correspond to the technology characteristics being evaluated with respect to the rows of customer objectives. The central field of the matrix (C) contains numerical values that show how well the technology implementation areas fulfil the requirements of each of the customer objectives. Descriptions of the customer objectives (A) and technology implementation areas (B) serve as row and column headers. Both the customer objectives and technology implementation areas will be generally defined, so they do not have to be re-formulated each time the expert system is used. The customer importance ratings (D) derived from the interviews with the customers tailor the technology management requirements to the individual customer.

The weighted customer objective ratings (E), the weighted technology implementation area ratings (F), and the overall weighted ratings (G) are values calculated from the comparison matrix (C) and customer importance ratings (D). A recommendation on which technology would be the most beneficial is made on the basis of these calculated ratings.

Using an expert system structure for technology management has significant advantages over traditional computer programs.

Because the list of customer objectives (A) is general rather than specific, it can remain constant, and does not have to be changed for different customers, trials, or technologies. This means that the technologies only have to be evaluated once against the customer objectives, and the information within the core matrix can remain constant for multiple trials or for multiple customers, which maintains consistency. Once a technology is entered into the knowledge base, it can be added to easily when evaluating and adding new technologies, and can be modified or updated when evaluations change due to technological advances or fundamental changes in business practices. The expert system accepts the enlarged knowledge base without modifications to its structure or methodology.

2.3. Building the Knowledge Base

Before the expert system can be used, the knowledge base (comparison matrix) must be filled with information about the technologies being considered. This information is collected from a variety of sources, the relevant technology implementation areas determined, and numerical values attached to the ratings of the technology implementation areas against the customer objectives [21].

Because the purpose of the expert system is to provide advice and recommendations in a wide variety of situations, it is very important to have accurate and unbiased information in the knowledge base. Bad or biased information in the initial technology evaluations can result in poor performance of the expert system, and unreliable recommendations.

Because the data for each technology is kept in a single area of the matrix, adding additional technologies is simply a matter of increasing the size of the matrix, and adding the new technology characteristics and their ratings to the knowledge base, as shown in Figure 2.3.

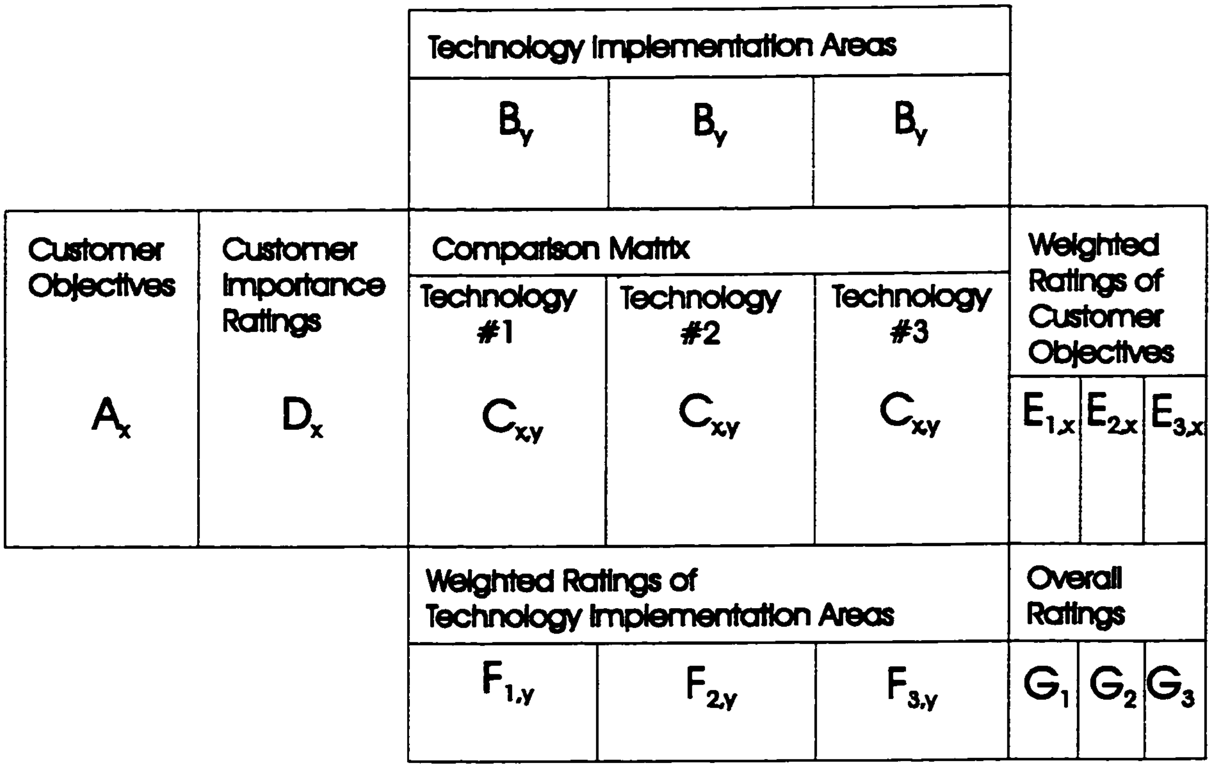

Figure 2.3. Expert System Matrix with Three Technologies

2.3.1. Defining Customer Objectives

The Customer objectives are a set of general business objectives that can fit a wide range of customers. A generalized set of customer objectives ensures that the objectives are relevant to the wide range of technologies that might be entered into the knowledge base. If the customer objectives are made too restrictive or too specific, only certain technologies would score points in specific categories, and the results would be skewed because of how the objectives were defined, rather than on the overall merits of the technologies. For example, if a customer objective was defined as "the replacement of an employee with specialized knowledge", the only technology that would score any points towards that objective would be expert systems. With general objectives such as "increased productivity", many technologies would meet this objective to varying degrees, which will result in a relative rating of the different technologies.

2.3.2. Choosing Important Technology Implementation Areas

The important implementation areas of each technology can be determined from a search of available literature, and also from the experience and knowledge of the consultant preparing the knowledge base. Only the most significant implementation areas should be chosen, and the total number of implementation areas for each technology should be limited, in order to keep the size of the knowledge base reasonable.

The number of application areas chosen for each technology should be approximately the same, in order to keep the comparison fair. Due to the way the overall ratings are calculated (detailed in Section 2.5), if one technology has many more application areas than another technology the results can become biased. The implementation areas should also be chosen so that they relate to the customer objectives.

2.3.3. Evaluating the Technologies

Before the expert system can be used to generate recommendations for a customer, the consultant must fill in the comparison matrix, which acts as the knowledge base. The technologies are evaluated with respect to the customer objectives to obtain the ratings for the comparison matrix, concentrating on the technology's suitability to fulfilling the various customer objectives. Details of technology implementation are only considered after a recommendation of which technologies are to be pursued has been made.

The rating system used in the comparison matrix is shown in Table 2.1.

Table 2.1. Rating system for technology evaluation

Ratings		Description
5	Excellent	Complete (80-100%) fulfillment of customer objectives
4	Good	60-80% fulfillment of customer objectives
3	Fair	40-60% fulfillment of customer objectives
2	Poor	20-40% fulfillment of customer objectives
1	Very Poor	0-20% fulfillment of customer objectives
0	No Relationship	Does not meet requirements at all

In cases where how much of the objective is met can be defined as a percent, the percentages above are used to determine the rating. It is expected that most of the ratings will be much less strictly defined, and will more often use the ratings ranging from "Excellent" to "Very Poor". To improve the clarity of the matrix, values of zero are left blank, which makes the non-zero values stand out more prominently.

In order to fill in the comparison matrix, each customer objective has to be compared against each technology implementation area and a numeric rating chosen for each relationship. This process was conducted for the prototype expert system, details of the evaluations are in Appendix B, and the results of the evaluations are shown in the comparison matrix in Figure B1. A 32 by 22 matrix as in the prototype expert system has the potential for over 700 comparisons, but eliminating the zero values reduces this to a more reasonable number, in this case 185.

2.4. Customer Importance Ratings

Fitting the customer objectives to actual customer's requirements is accomplished by a weighted rating of each objective. The customer is asked to input their priority for each of the customer objectives during an interview. The ratings that are entered are used along with the values in the comparison matrix to calculate the weighted ratings. The range of customer objectives is from zero to five, with zero indicating that the objective is completely unimportant, and five indicating the highest importance.

2.5. Calculations and Data Manipulation

Cumulative ratings are calculated for each customer objective (E), and for each technology implementation area (F). From these cumulative ratings, an overall rating (G) for each technology can be calculated.

The equations below use the same notation as in Figure 2.2. The subscripts x and y indicate the customer objective (row of the matrix), and the technology implementation area (column) respectively. The subscript z indicates the technology, with a value of 1 for expert systems, 2 for CAD/CAM and 3 for CIM.

The cumulative ratings for each customer objective (E) is calculated by multiplying the customer importance rating for that objective (D) by the values for each technology implementation area in the corresponding row of the comparison matrix (C), and summing over all the technology implementation areas for the technology. The only change in the equation for the different technologies (z) is the start point (M_z) and end point (N_z) of the summation, to match the columns in the matrix occupied by each technology's implementation areas.

$$E_{z,x} = \sum_{y=M_z}^{N_z} D_x \times C_{x,y} \qquad (2.1)$$

Repeating this calculation for each customer objective (x) and technology (z) provides a list of ratings of the customer objectives for each technology. Because we are multiplying the comparison matrix values by the customer importance ratings, the cumulative rating reflects how well each technology meets the requirements of the customer objectives that are important to the customer. The cumulative rating for the customer objectives (E) shows which customer objectives could benefit most from the implementation of the technologies.

The cumulative ratings for each technology implementation area (F) are calculated by multiplying each value in one column (y) of the comparison matrix (C) by the corresponding customer importance ratings (D), and summing them for all customer objectives (x). The variable L indicates the total number of customer objectives.

$$F_{z,y} = \sum_{x=1}^{L} D_x \times C_{x,y} \qquad (2.2)$$

This calculation is repeated for each technology implementation area of each technology. These ratings give an indication of how well each technology implementation area is suited to the customer objectives that are important to the customer. The cumulative rating for the technology implementation areas (F) shows which area the technology could be implemented in to achieve the maximum benefit for the customer.

The overall cumulative rating (G) of each technology is calculated from the sum of all the customer objective cumulative ratings (E) for the technology. Mathematically, this is the same as the sum of the technology implementation area cumulative ratings (F) for the same technology, which will result in the same value. As with Equation 2.1 above, the only change in the equation for the different technologies is a change of the summation limits (M_z and N_z) for the location of the technology within the matrix.

$$G_z = \sum_{x=1}^{L} E_{z,x} = \sum_{y=M_z}^{N_z} F_{z,y} \qquad (2.3)$$

Because the overall rating (G) is based on the technology's performance relative to the customer objectives (A) and weighted for the customer importance ratings (D), technologies with higher ratings for objectives that are considered more important will achieve higher overall ratings, indicating a better ability to meet the customer's requirements.

2.6. Interpretation of Results

From the overall ratings of each technology (G), a conclusion is drawn as to which technology should be considered for implementation by choosing the technology with the highest overall rating. The highest overall rating indicates that the technology rates higher against the customer objectives that are considered more important, and therefore has the highest potential for application in the areas that can be of greatest benefit to the customer.

Recommendations on which elements of each technology should be considered for implementation first can be developed from the cumulative ratings of the technology implementation areas (F). The higher cumulative ratings indicate that the customer could benefit the most from these implementation areas, so the highest rated areas should be considered for implementation first. Because the technology with the highest rating is considered to be the best choice, only the implementation areas for this technology will be considered when formulating the final recommendations. In future work, it may be possible to devise a system that will pick out high rated implementation areas from technologies that are not the highest rated overall, but for the prototype system the recommendations were kept as simple as possible.

Recommendations on what customer objectives the technology implementation should be directed towards can be developed from the cumulative ratings of the technology implementation areas (F) and customer objectives (E). The higher cumulative ratings indicate that applying the technology towards these objectives would provide the greatest benefit, so the technology should be applied against the highest rated objectives first.

The matrix display allows the user to see which technologies and what implementation areas were recommended for implementation, why they were chosen, and also which implementation areas were not chosen. The ratings for each technology implementation area are visible, so it is possible to see if certain areas missed being selected by one or two points, or if they were found to have very low priority. The matrix would also facilitate a form of sensitivity analysis through interactive adjustment of the customer importance ratings to see how the solution changes with different weighting values.

3. PROTOTYPE TECHNOLOGY MANAGEMENT EXPERT SYSTEM

The structure and methodology requirements for a technology management expert system have been outlined in Section 2 above. The goal of the prototype expert system is to provide a working model that we can use to prove the concepts under actual field conditions. The prototype system will allow us to evaluate the practicality of the expert system, to identify potential applications, and to identify and resolve problems.

3.1. Technologies to be Evaluated by the Prototype Knowledge Base

In order to evaluate the methodology, three technologies – Expert Systems, Computer Aided Design and Manufacturing (CAD/CAM), and Computer Integrated Manufacturing (CIM) - were chosen to be entered into the knowledge base of the prototype expert system.

Computer Aided Design and Manufacturing (CAD/CAM) was chosen because it is a widely used and generally accepted technology that many companies have implemented or have considered implementing. Therefore the companies that we contact to do the field trials will have some experience with CAD/CAM, and would be able to provide information on how accurately the expert system's recommendations follow the conclusions reached when they considered CAD/CAM for implementation.

Computer Integrated Manufacturing (CIM) was chosen because it is a widely accepted technology that is related to CAD/CAM. The intent here is to learn how the expert system differentiates between similar technologies.

Expert Systems was chosen because it is unrelated to the other two technologies, and as a consequence would provide an indication of the system's ability to choose between widely varying technologies.

3.1.1. Expert Systems

Expert systems are computer programs that encode knowledge about a problem into a knowledge base, and then use this knowledge to reason and draw conclusions about a particular problem or situation.

Expert systems are beneficial when a procedure (such as an evaluation or set of logical steps) must be performed repeatedly. Expert systems are also beneficial when an employee is leaving the company and the knowledge that he possesses cannot be easily replaced. The employee's knowledge can be coded into a knowledge base for an expert system, and most, if not all, of the knowledge can be saved, and made available to draw on for solving problems, or for training people to work in the same area.

The drawbacks to implementing expert systems include the public perception that computers and machinery are taking jobs away from humans. While this may be true in some cases, usually it creates new jobs, working with the computers and machinery. However, it is also true that many of the people who are displaced are not qualified for these new higher skilled jobs.

By their nature, expert systems are very limited in the range of knowledge that they can be programmed for. Expert systems function best if they are programmed with detailed knowledge about a specific subject area, and function poorly if they are programmed with superficial knowledge of a broad subject area. Because the decision making process sometimes relies on partial information or information that may be inaccurate, expert systems do make mistakes, but if constructed and programmed well, they should not make any more mistakes than a human expert would under the same conditions. The company should be well informed, in advance, of both the advantages and disadvantages of expert systems before it attempts implementation.

This technology requires little in the way of pre-requisites. A wide variety of software (expert system shells) is available, which can be run on a variety of hardware ranging from desktop PCs to mainframe computers is available for a variety of specific applications. The knowledge base already exists in the workers and management of the company, and a knowledge engineer can compile this knowledge into a useable form for an expert system.

The key technology implementation areas that will be used in the prototype expert system for Expert Systems are shown in Table 3.1 [4].

Table 3.1. Technology implementation areas for Expert Systems

	Implementation Areas
1	Continuous Monitoring
2	Continuous Control
3	Automate Repetitive Processes
4	Expert help available at all times
5	Instruct and educate employees
6	Planning and scheduling
7	Problem diagnosis
8	Design assistance
9	Prediction
10	Simulation

3.1.2. Computer Aided Design and Manufacturing

CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) are two separate but interrelated technologies that are well established in the manufacturing industry.

CAD uses computers with specialized software (such as AutoCAD) to generate drawings such as blueprints, architectural drawings, and assembly diagrams that may have previously been produced by manual drafting procedures.

CAM uses computers to control machinery, so that many of the restrictions associated with human operators are eliminated. CAM can be set up to read information directly from CAD drawings and determine what operations are required to produce a particular object.

CAD has many benefits over manual drafting [27].

1) Human errors are eliminated from the drafting process. Once all the information for the drawing is stored in the computer, and checked for accuracy, there is no possibility for any dimensions or details being changed by transcription errors.

2) The speed with which drawings can be produced is increased. Since manual drafting is a labor-intensive process, it takes a long time to complete properly. The speed advantages of CAD are even more apparent when a drawing has to be changed, which with manual drafting necessitates beginning over again, but with CAD the portions of the drawing that are not changed are not lost, and can be reused. From this feature, it is apparent that the more important the drawings are, and the greater number of changes that are made during development, the greater the benefit that can be derived from implementing CAD.

CAM also has many benefits.

1) Controlling machinery such as automatic milling machines, lathes, and welding robots with computers allows much better tolerances than human operators could achieve. Computer control usually allows work to proceed faster, as computers and computer controlled machinery do not suffer from fatigue, and do not need to stop for breaks. The advantages of CAM increase with the amount of precision and repeatability required. Repetitive tasks are perfectly suited for the application of CAM.

2) Being able to read dimensions directly from CAD decreases the chances of errors occurring when transferring measurements and dimensions from the drawings to the manufacturing process. This feature makes changes on the production side as easy as changes on the design side.

Some of the drawbacks to implementing CAD and CAM are:

Infrastructure Costs: CAD and CAM both require expensive computers and computer software. CAM also involves computerized control of production machinery. If the company does not already have some of this infrastructure in place, or if existing equipment (such as the production equipment) can not be upgraded to function with the computer control, it can be very expensive to implement CAD/CAM.

Support Services: CAD and CAM also require support services, such as computer maintenance, and installation and periodic upgrading of the software. If the company does not have personnel capable of providing these services, then more employees will have to be hired, existing employees will have to be trained, or an outside company will have to be hired to provide these services.

Employee Training: Both CAD and CAM require properly trained technicians to operate properly. These technicians cost more in wages than do the workers that they will replace, but in nearly all cases, the benefits of CAD and CAM more than make up for this small drawback. In some cases, the existing workers can be re-trained to work with the new system, but in many cases, workers have to be hired that already have experience with the new systems.

Document Control: With CAD, it is possible to generate a large number of revisions to drawings with a small amount of effort. This sometimes results in having too many different versions of drawings, and causes problems with being able to find the correct file. Because this may not have been a significant problem before, a new system of controlling document creation and distribution may have to be implemented.

CAD/CAM can be used as a foundation for implementing other related technologies, such as CIM (Computer Integrated Manufacturing).

The key technology implementation areas chosen for CAD/CAM are shown in Table 3.2 [27, 22].

Table 3.2. Technology implementation areas for CAD/CAM

	Implementation Areas
1	Design Creation
2	Design Analysis
3	Mathematical Modeling
4	Mechanical Modeling
5	Creation of Engineering Drawings
6	Drawing Cataloguing and Retrieval
7	Documentation
8	Production Planning
9	Machine Tooling/Robotics
10	Group Technology

3.1.3. Computer Integrated Manufacturing

Computer Integrated Manufacturing (CIM) "Refers to the integrated information processing requirements for the technical and operational tasks of an industrial enterprise" [23]. CIM is not one single technology, but rather a number of technologies that can be implemented together or separately depending on the requirements of each individual situation. The philosophy behind CIM is to "motivate, innovate, automate, then integrate" [25].

Among the benefits to implementing CIM are increased efficiency, better information flow, reduced manpower requirements, higher production rates, and increased quality.

The only drawbacks to implementing CIM are the requirements to radically redesign existing business and manufacturing processes, and the expense of implementing some of the technologies such as CAD/CAM, robotics, and integrated information systems.

There are no pre-requisites for implementing many of the elements of CIM, and because it is such a flexible system, future improvements can be built upon earlier work, or can be developed independently.

The key technology implementation areas chosen for CIM are shown in Table 3.3 [26, 23, 24, 25].

Table 3.3. Technology implementation areas for CIM

	Implementation Areas
1	Product Design
2	Analysis and Simulation
3	Documentation
4	Process Design
5	Quality Control
6	Facilities Planning
7	Scheduling
8	Materials Handling
9	Shop Floor Control
10	Robotics and Automation
11	Shared Data
12	Integrated Architecture

3.2. Customer Objectives for the Prototype Expert System

During the research for the development of the technology implementation areas described in Section 3.1, the list of customer objectives that the implementation areas will be compared against was also developed. These customer objectives were defined in a general way, so that they will apply to the broadest range of technologies possible. Most of the objectives are money driven (reduce costs, increase income), which reflects the current business environment. In the future, these objectives could change or be expanded to include other considerations (social, political, and environmental), but for the initial testing, the financial objectives are adequate.

The customer objectives that were developed for the prototype technology management expert system are shown in Table 3.4 [26, 27].

Table 3.4. Customer Objectives

Category	Objective
Minimize costs	Minimize inventory
	Minimize production costs
	Maximize productivity
	Standardize basic office tasks
	Reduce basic office tasks
	Increase production efficiency
	Maximize utilization of production equipment
	Increase efficiency of employees
	Reduce maintenance downtime
Increase revenue	Maximize production capacity
	Improve marketing and increase sales
Speed up processes	Minimize production time
	Reduce design cycle time
	Consistent on-time delivery
	Shortest possible delivery dates
	Increase production flexibility
	Improved scheduling
Customer Relations	Maximize reliability
	Maximize availability of resources to production
	Maximize availability of product to customers
	Maximize quality

3.3. Completing the Prototype Expert System Knowledge Base

Before the matrix method can be used for consulting and making recommendations, the knowledge base that it draws its information from must be completed. The main section of the knowledge base consists of a matrix of values generated by comparing the implementation areas of each technology developed in Section 3.1, against the customer objectives developed in Section 3.2.

By rating how well each implementation area of each technology fulfils each customer objective (on a scale of 0 to 5), we provide the base information on which all future calculations are based.

Comparing each technology implementation area against each customer objective to come up with numerical ratings is a long process. It involves first determining if the technology implementation area can have an effect on the customer's objective. Second this effect must be described, and the third step is putting a numeric value to the effect. This is an exhaustive process that takes many pages to fully document, so the details of the development of the ratings for the prototype expert system have been attached as Appendix B.

3.4. Expert System Shell Comparison

It was decided to build the technology management expert system based on an existing expert system shell. The shell provides the basics of the program such as data storage and retrieval, input and output, programming interface, and rule structure, allowing us to spend more time on the conceptual development of our expert system, and less on the small details of programming.

Features of the expert system shells were rated on a scale of zero to ten, with ten being the best rating, and a number of shells available at the University of Regina were compared based on these ratings, to determine the best available shell for this application.

3.4.1. Desirable Shell Features

Programming Interface: The programming interface is the screen displays that are used while programming the knowledge base into the shell. A good programming interface is necessary to make programming the system easier, and to make the programming proceed faster. Higher points were given to applications with graphic (windows type) interfaces (over text based interfaces), and interfaces that are intuitive and easy to learn and use (over those that were less user-friendly).

End User Interface: The End User Interface is the graphic screens that are used when the expert system generates and presents recommendations. The ability to customize the interface screens and incorporate graphics is a desirable feature.

Rule construction: Rule construction is the method by which the rules are entered into the knowledge base, stored, retrieved, and modified. Rule construction should be intuitive, fast, and robust (allow corrections or changes, and not require re-typing fields of data if a mistake is made).

Arrays and matrices: In order to store the data for the comparison matrix within the shell, it would be easiest if the shell could store arrays and matrices with two dimensions. Values could be referenced by the matrix or array name, and the location within the matrix, instead of having to have a separate variable name for each element of the comparison matrix.

Spreadsheets and Databases: Some expert system shells can read and write to spreadsheet and database files. The structure of a spreadsheet is a large two dimensional matrix that can easily be subdivided to contain many smaller matrices or arrays, and the spreadsheet commands can be used to manipulate the values within the matrix. Spreadsheet capabilities within the expert system shell (or the ability to remotely control an external spreadsheet) would provide all the matrix manipulation features we would need, without any extra programming.

External Programs: A shell that does not have the capability to manipulate matrices or spreadsheet files, could be made to work for this application by exporting the data to an external program that would then perform the calculations and return the results to the shell.

Data input/output: The ease with which data is saved to or retrieved from files, or transferred to external programs determines whether it is practical or even possible to use an external program.

Operating system: The operating system that the shell runs under is not a critical aspect of the shell, but does make some difference in the ease of use. Preference was given to shells that ran under DOS or Windows on IBM compatible PCs, because of ready access to this type of machine and operating system. Shells that run under UNIX and DEC VAX/VMS operating systems were also considered since both these operating systems are available at the University of Regina. Using either of these operating systems is not nearly as convenient since they are only on mainframes or workstations, and as such they must be accessed through terminals on campus or by modem.

Availability: Due to budget constraints, only those shells that were available through the University of Regina were considered. Higher ratings were given to programs where the software could be installed on a specific machine, or where access was available through terminals connected to the university's computer network.

3.4.2. EXSYS

The EXSYS [5, 28, 29] expert system shell provides a good user interface for developing the expert system, and for querying the system (rules would be used to implement the question and answer session), which include a good method of writing the rules to translate the answers into importance ratings. The three problems with EXSYS that would make implementing this particular expert system difficult are: (1) no capability to store or manipulate arrays or matrices. (2) limited input/output capabilities (cannot input or output large blocks of data easily). And (3) the version owned by the University of Regina runs only on the UNIX operating system. All of these problems could be overcome, but would require extensive work to create external programs to fill in the shortcomings. Advantages of EXSYS are that it can handle IF-Then-Else rules, frames, blackboarding, and other expert system methods.

EXSYS does not have any capacity to use arrays or matrices, to input or output large quantities of data, or to use "wild card" characters when specifying variables, so each variable would have to be individually defined and then passed to an external program. One possible solution would be to store the importance ratings in a frame (stored as an ASCII file), and update the ratings after each question, but this would require a large amount of disk access, which would slow the program down.

EXSYS does allow external programs to be called from within the current EXSYS session. We could pass the required data to a file, use an external program to perform the matrix manipulations and write the results to another file, from which EXSYS could then read the results of the calculations. This method would work, but would require writing a large amount of code to allow the matrix manipulations to be performed.

The third major problem with EXSYS is the operating system that it runs under. UNIX was developed in the 1960's, for use on the computers available at the time. For the time that it was developed, and the machines it was meant to run on, it was reasonable, but by current standards it is confusing and difficult to learn. [30, 31, 32]

3.4.3. GURU

The version of the expert system shell GURU [33, 34] owned by the University of Regina is a relatively old program (late 1980's), but it contains several elements that makes it a good choice for this application. Two of the elements that make GURU stand out above all the other software packages that have been evaluated are (1) the ability to store and manipulate information in Lotus-123 format spreadsheet files, and (2) the ability to write batch files to execute a sequence of commands within the shell.

The matrix structure of spreadsheets makes them a natural choice for storing the data for our expert system knowledge base matrix. While several of the other shells have the ability to read and write spreadsheet format files, they usually store the data in their own internal data structures, and in some cases all the interaction with the spreadsheet files is through reading from and writing to the file on disk. GURU allows the entire spreadsheet file to be read into memory without losing the spreadsheet format, allows rules to refer to spreadsheet cells and to place values in spreadsheet cells, as well as performing any other spreadsheet operation. Whenever a change is made to the value in any cell, the spreadsheet automatically recalculates any related values. In addition to allowing standard spreadsheet operations and cell definitions, GURU also allows spreadsheet cells to be defined in terms of a consultation with the expert system rules (allowing rules to be consulted whenever a cell is changed, or whenever a recalculation takes place).

The ability to process commands in a specific sequence allows the initial question and answer session to be programmed without much difficulty. While it is true that the sequence of questions could be generated using rules and forward chaining, the sequence of the questions may not be exactly what is desired, and adding additional questions (by adding additional rules) may change the sequence of questions in unexpected ways. Rules can still be used within the command sequence, but by placing the rules in small groups, we can more accurately control the sequence of the questions as well as being able to control whether certain questions have been made redundant by the answers to previous questions.

A feature of GURU that should be very useful during the question and answer session is the ability to display forms on the screen, which allow the user to read instructions, and then input the appropriate response on the screen. This makes the input and output easier to control, and allows the questions to be developed one screen at a time, with new screens being added when necessary.

3.4.4. G2

G2 [35] is a very powerful and flexible real time expert system shell. G2 uses a graphical interface and object oriented programming to allow application of expert system rules to real time problems such as monitoring, diagnosis, optimization, scheduling, and process control. G2 can connect to standard Programmable Linear Controllers (PLC), Distributed Control Systems (DCS), and Databases for data input, and can graphically display data using charts, graphs, tables, dial indicators and can also show animated displays such as wiring and piping diagrams, or data and logic flow.

For its intended purpose (real-time applications), G2 is an excellent expert system shell, with most of its power and flexibility centered around its ability to perform in real time, continuously monitoring data from outside sources. For technology management, the major features of G2's real time capabilities are not required, and it falls short in other areas such as the manipulation of large amounts of data in matrix form, and the limited ability to receive input from the operator. G2 can read from databases but its main strength is reading a large amount of data and then firing rules based on this data. G2's structure has attempted as much as possible to remove human intervention from the reasoning process by reading most of its information from automated data collection systems. The technology management expert system obtains input data from a human operator, and no information is read from PLC's or other real-time data collection devices.

Two other problems with G2 not related to its capabilities are that it is very expensive, and that the licensing agreement of the copy owned by the University of Regina Computer Science Department restricts the number of users, so it is difficult to arrange access, even on a temporary basis for evaluation purposes.

3.4.5. Comdale/X

Comdale/X [36] is an expert system shell that is used by the Computer Science Department at the University of Regina while teaching classes on expert systems. Comdale/X is a fairly basic expert system shell that offers many features based around the standard If-Then-Else rule structured database, and has other built-in programming functions that appear to be closely related to the logical structure of LISP (List Processing) type programs.

Comdale/X cannot store arrays. It can store object-attribute-value triplets that could be set up to approximate arrays, by the object denoting the array and the attributes denoting the individual array elements.

Based on an examination of the user manual for Comdale/X, I have found no evidence that it can call external programs. A source code developers library is available, so it is possible to write a C language program to add many of the required features to Comdale/X. This is a more difficult procedure than calling a program from the shell.

Comdale/X runs on IBM compatible computers using a Microsoft Windows based interface, which is much more user friendly than text based interfaces.

An educational/student version of Comdale/X is available for approximately $75 (Canadian funds), including a user manual, and a version is available on a computer at the university for evaluation purposes at no cost.

3.4.6. Level 5

Versions of Level 5 [37, 38] are available for IBM, Apple Macintosh, and VAX systems. The University of Regina owns the IBM version that runs on any IBM PC with 256k of RAM, using DOS 2.0 or higher. Later versions of Level 5 currently unavailable at the University of Regina use the windows interface and have the capability to access database files.

Level 5 supports both forward and backward chaining, but its forward chaining capabilities are limited. It supports confidence factors from 1 to 100%, and uses a text based programming interface with a customizable user interface.

No information was found on accessing external files (data or program), ability to store data in tables, or the base language of Level5.

3.4.7. Twaice

Twaice [39, 40] was written in Prolog, so can be expanded by adding functions and features also written in Prolog. It mostly uses if/then/else rules, and frames. Twaice uses a text based programming interface, and has a customizable user interface. It uses confidence factors ranging from 1 through 1000 to represent 0.1 through 100.0% confidence limits.

Twaice contains a built-in spell checker, so if data is entered incorrectly, it can check to see if it is close to a valid input and ask if that input is the desired one. Twaice allows the user to review and change answers to questions after they have been answered. It supports logic tracing, and can answer how a fact has been derived (from which rules or questions), and can answer why a question was asked (or the line of questioning the program is taking). Supports both forward and backward chaining. Twaice has on-line Help capabilities and can read from tables and external files. No information was available on its capabilities to write to tables or external files, or to perform calculations. Twaice runs on the VAX/VMS operating system, and can call external programs.

3.5. Shell Selection

The results of the shell comparisons are summarized in Table 3.5. Ratings range from zero to ten, with ten being the best. The features that most affected the shell selection were the ability to store and manipulate many variables, ease of data input and output, and budget constraints (the shell must be available for little or no cost).

Table 3.5. Expert System Shell Comparison

Shell Features	Expert System Shells					
	EXSYS	GURU	G2	Comdale/X	Level	Twaice
Programming Interface	7	7	10	8	7	7
End User Interface	7	8	10	8	7	7
Rule Construction	7	7	7	8	7	7
Arrays	0	0	0	0	0	2
Matrices/Tables	0	0	0	0	0	2
Spreadsheets	0	10	0	0	0	0
Databases	0	10	10	0	0	0
Data input/output	3	8	9	7	2	8
External Programs	8	8	9	0	0	8
Availability	9	10	0	6	8	6
Cumulative Rating	41	68	52	37	31	48

The GURU shell best satisfies the requirements for the technology management expert system. It has the ability to store information in a highly visible spreadsheet format, and has a relatively straightforward user interface and a well-developed set of expert system features to facilitate the development work. Another benefit is its ability to operate on a widely available platform (286 series and up PC's). For the initial development of the technology management expert system, GURU is the preferred choice of the expert system shells evaluated.

3.6. Coding of the Prototype Expert System

The layout of the matrix structure was done using GURU's spreadsheet. The row and column headings for the customer objectives and technology implementation areas developed in Sections 3.1 and 3.2 were placed to the left and above the comparison matrix. An empty column was left between the customer objective headings and the comparison matrix to receive the customer importance ratings, and the values from the technology evaluations (see Appendix B) were entered into the field of the comparison matrix.

The formulas for the cumulative and overall ratings (detailed in Section 2.5) were entered into the areas below and to the right of the comparison matrix. The resulting spreadsheet is shown in Figure 3.1.

In Figure 3.1, the ratings for the implementation areas, for the customer objectives, and for the overall ratings appear as zero, because the customer importance ratings have been left blank. The customer importance ratings will be determined during an interview process with the customers.

There are three basic methods of questioning that can be used to determine the customer's importance ratings: direct, indirect, and comparative [41]. With indirect questions the importance ratings are determined through inference from the customer's responses using a small rule base. Indirect questions are the most complicated and also the most likely to give accurate and balanced ratings of the three types.

Comparative questions ask the customer for numerical data that can then be compared against another value (such as industry standard information) in order to determine the importance rating. This requires collecting the data that the customer's information is to be compared against, and also requires the development of a rule set to convert the numeric differences into customer importance ratings.

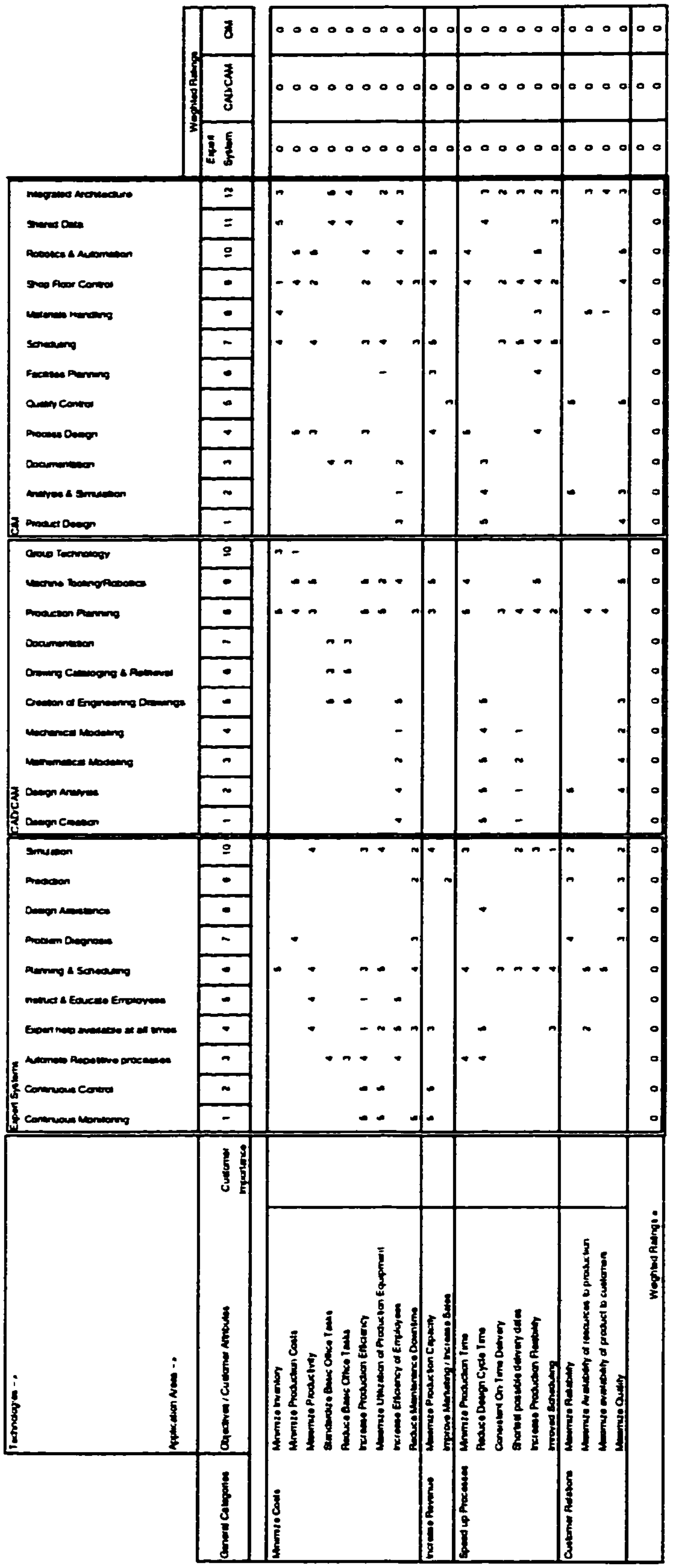

Figure 3.1. Expert System Matrix Structure Implemented in a Spreadsheet

The method of determining the customer importance ratings that was chosen for the prototype expert system was direct questioning, which asks the customer to input a numeric rating from zero to five for the customer objectives. This is the easiest method, because it does not involve any additional programming, and the customer importance values are collected directly with no additional steps. This method can cause problems because of inaccurate responses arising from factors such as political considerations (interdepartmental rivalry or personal bias), the customer not recognizing (or overstating) the importance of an objective, or not acknowledging that there is a problem.

Data entry screens were set up to ask the user to input their customer objective ratings, and to allow them to enter the ratings easily, and a data output screen was created to allow the program to display the results at the end of the analysis.

A sequential command file was developed to automate the analysis procedure. The command file opens the spreadsheet, displays the data entry screens in order, places the information collected from the data entry screens into the appropriate area of the spreadsheet, calculates the ratings, and displays the output screen. Details of the programming involved with implementing the technology management expert system using GURU are shown in Appendix A - Program Documentation.

4. TESTING AND VALIDATION

Evaluation of the system includes field testing the system with the cooperation of small local manufacturers. The system was evaluated by working through an analysis of the three test technologies, and comparing the results returned by the expert system to the expected results based on the customer's previous experience and expertise [42].

Trials of the expert system were conducted by interviewing two local businesses, Ralph McKay Industries Inc. and USF Watergroup, which are knowledgeable about the test technologies. The customer importance ratings as required by the expert system were determined through the interview process. In addition the companies were also asked questions about which of the technologies they would actually choose and the reasons for their choices, so that the expert system's recommendations could be evaluated against the recommendations of the company's representatives.

The company's priority ratings with respect to the customer objectives were entered in the expert system, and the expert system then evaluated the three technologies and provided a set of recommendations for implementation. These results were compared against the evaluation information obtained during the interview to validate the technology management expert system's results.

4.1. Test Case #1 – Ralph McKay Industries Inc.

Ralph McKay Industries Inc. is a manufacturer of pressed steel agricultural implement parts in Regina, Saskatchewan with 65 employees and annual sales in the range of $10 to $20 million. The production processes used include stamping, forming, and heat treating to produce products such as cultivator shovels and other tillage tools that are marketed mostly in Canada (70%) and the United states (25%), with approximately 5% of sales to other countries. The most recent major technological implementation at this company was the adoption of an ISO9002 quality control program three years ago.

The interview process [43] was conducted on June 1, 1998, with Merv Armstrong, Assistant Plant Engineer, and Dwayne Chychrun, Senior Design Technologist and Network Administrator. The customer importance ratings obtained from this interview are shown in Table 4.1.

Table 4.1. Customer Importance Ratings for Ralph McKay Industries Inc.

Category	Objective	Rating
Minimize costs	Minimize inventory	3
	Minimize production costs	5
	Maximize productivity	5
	Standardize basic office tasks	3
	Reduce basic office tasks	3
	Increase production efficiency	5
	Maximize utilization of production equipment	5
	Increase efficiency of employees	3
	Reduce maintenance downtime	5
Increase revenue	Maximize production capacity	5
	Improve marketing and increase sales	4
Speed up processes	Minimize production time	5
	Reduce design cycle time	3
	Consistent on-time delivery	3
	Shortest possible delivery dates	5
	Increase production flexibility	3
	Improved scheduling	3
Customer Relations	Maximize reliability	1
	Maximize availability of resources to production	5
	Maximize availability of product to customers	5
	Maximize quality	5

The results of combining the customer importance ratings from Table 4.1 with the prototype expert system matrix structure from Figure 3.1 can be seen in Figure 4.1.

Technologies --> / Application Areas -->

General Categories	Objectives / Customer Attributes	Customer Importance	Expert Systems: 1 Continuous Monitoring	2 Continuous Control	3 Automate Repetitive processes	4 Expert help available at all times	5 Instruct & Educate Employees	6 Planning & Scheduling	7 Problem Diagnosis	8 Design Assistance	9 Prediction	10 Simulation	Expert System Weighted Rating	CAD/CAM Weighted Rating	CIM Weighted Rating
Minimize Costs	Minimize Inventory	3						5					15	24	51
	Minimize Production Costs	5							4				20	60	70
	Maximize Productivity	5				4	4	4				4	80	40	70
	Standardize Basic Office Tasks	3			4								12	33	39
	Reduce Basic Office Tasks	3			3								9	39	33
	Increase Production Efficiency	5	5	5	4	1	1	3				3	110	50	60
	Maximize Utilization of Production Equipment	5	5	5		2		5				4	105	35	35
	Increase Efficiency of Employees	3			4	5	5						42	60	63
	Reduce Maintenance Downtime	5	5			3		4	3		2	2	95	15	30
Increase Revenue	Maximize Production Capacity	5	5	5		3						4	85	40	105
	Improve Marketing / Increase Sales	4									2		8	0	12
Speed up Processes	Minimize Production Time	5			4			4				3	55	45	65
	Reduce Design Cycle Time	3			4	5				4			39	72	57
	Consistent On Time Delivery	3						3					9	9	21
	Shortest possible delivery dates	5						3				2	25	45	60
	Increase Production Flexibility	3						4				3	21	27	78
	Improved Scheduling	3				3		4				1	24	6	39
Customer Relations	Maximize Reliability	1							4		3	2	9	5	10
	Maximize Availability of resources to production	5				2		5					36	20	40
	Maximize availability of product to customers	5						5					25	20	25
	Maximize Quality	5							3	4	3	2	60	80	120
													883	725	1083
	Weighted Ratings =		100	75	85	114	40	213	54	32	36	134	883	725	1083

Objectives / Customer Attributes	CAD/CAM: 1 Design Creation	2 Design Analysis	3 Mathematical Modeling	4 Mechanical Modeling	5 Creation of Engineering Drawings	6 Drawing Cataloging & Retrieval	7 Documentation	8 Production Planning	9 Machine Tooling/Robotics	10 Group Technology
Minimize Inventory								5		3
Minimize Production Costs								4	5	1
Maximize Productivity								3	5	
Standardize Basic Office Tasks					5	3	3			
Reduce Basic Office Tasks					5	5	3			
Increase Production Efficiency								5	5	
Maximize Utilization of Production Equipment								5	2	
Increase Efficiency of Employees	4	4	2	1	5				4	
Reduce Maintenance Downtime								3		
Maximize Production Capacity								3	5	
Improve Marketing / Increase Sales										
Minimize Production Time								5	4	
Reduce Design Cycle Time	5	5	5	4	5					
Consistent On Time Delivery								3		
Shortest possible delivery dates	1	1	2	1				4		
Increase Production Flexibility								4	5	
Improved Scheduling								2		
Maximize Reliability		5								
Maximize Availability of resources to production								4		
Maximize availability of product to customers								4		
Maximize Quality		4	4	2	3				5	
Weighted Ratings =	32	57	51	30	75	24	18	242	182	14

Objectives / Customer Attributes	CIM: 1 Product Design	2 Analysis & Simulation	3 Documentation	4 Process Design	5 Quality Control	6 Facilities Planning	7 Scheduling	8 Materials Handling	9 Shop Floor Control	10 Robotics & Automation	11 Shared Data	12 Integrated Architecture
Minimize Inventory							4	4	1		5	3
Minimize Production Costs				5					4	5		
Maximize Productivity				3			4		2	5		
Standardize Basic Office Tasks			4								4	5
Reduce Basic Office Tasks			3								4	4
Increase Production Efficiency				3			3		2	4		
Maximize Utilization of Production Equipment						1	4					2
Increase Efficiency of Employees	3	1	2						4	4	4	3
Reduce Maintenance Downtime							3		3			
Maximize Production Capacity				4		3	5		4	5		
Improve Marketing / Increase Sales					3							
Minimize Production Time				5					4	4		
Reduce Design Cycle Time	5	4	3								4	3
Consistent On Time Delivery							3		2			2
Shortest possible delivery dates							5		4			3
Increase Production Flexibility				4		4	4	3	4	5		2
Improved Scheduling							5		2		3	3
Maximize Reliability		5			5							
Maximize Availability of resources to production								5				3
Maximize availability of product to customers								1				4
Maximize Quality	4	3			5				4	5		3
Weighted Ratings =	44	35	36	112	42	32	168	61	174	167	72	150

Figure 4.1. Results of Trial for Ralph McKay Industries Inc.

4.1.1. Test Results

When the customer importance ratings for Ralph McKay Industries are entered into the spreadsheet, the calculations that have been programmed into the spreadsheet generate ratings for the technology implementation areas and customer objectives, as well as overall ratings. From the overall ratings shown in Figure 4.1, we can see that Computer Integrated Manufacturing (CIM) scored the highest overall rating, 1083. Expert Systems rated second with 883 and CAD/CAM third with 725.

The technology implementation areas of CIM were sorted in descending order by their cumulative ratings, as shown in Table 4.2. The areas that achieved the highest ratings, and should be considered for implementation were shop floor control, scheduling, robotics and automation, and integrated architecture. The remainder of the implementation areas have significantly lower ratings than the top five, and therefore would provide less benefit to the company, so could be considered for implementation at a later date.

Table 4.2. Final Ratings of CIM Technology Implementation Areas

Implementation Areas	Rating
09. Shop Floor Control	174
07. Scheduling	168
10. Robotics and Automation	167
12. Integrated Architecture	150
04. Process Design	112
11. Shared Data	72
08. Materials Handling	51
01. Product Design	44
05. Quality Control	42
03. Documentation	36
02. Analysis and Simulation	35
06. Facilities Planning	32

The Customer Objectives were sorted in descending order by their cumulative ratings as shown in Table 4.3. The areas that stand to benefit the most from the implementation of

CIM are maximizing quality, production capacity and flexibility.

In summary, this company should investigate implementing CIM in the areas of shop floor control, scheduling, robotics and automation, and integrated architecture, with the objectives of maximizing quality, production capacity and flexibility. This strategy uses the strengths of CIM to improve the areas that the company considers most important.

Table 4.3. Final Ratings of Customer Objectives

Category	**Objective**	**Rating**
Customer Relations	Maximize quality	120
Increase revenue	Maximize production capacity	105
Speed up processes	Increase production flexibility	78
Minimize costs	Minimize production costs	70
Minimize costs	Maximize productivity	70
Speed up processes	Minimize production time	65
Minimize costs	Increase efficiency of employees	63
Speed up processes	Shortest possible delivery dates	60
Minimize costs	Increase production efficiency	60
Speed up processes	Reduce design cycle time	57
Minimize costs	Minimize inventory	51
Customer Relations	Maximize availability of resources to production	40
Minimize costs	Standardize basic office tasks	39
Speed up processes	Improved scheduling	39
Minimize costs	Maximize utilization of production equipment	35
Minimize costs	Reduce basic office tasks	33
Minimize costs	Reduce maintenance downtime	30
Customer Relations	Maximize availability of product to customers	25
Speed up processes	Consistent on-time delivery	21
Increase revenue	Improve marketing and increase sales	12
Customer Relations	Maximize reliability	10

4.1.2. Customer Comments

The recommendation of the technology management expert system to investigate CIM for implementation was thought to be reasonable, because it agrees with the thoughts of the company representatives that were interviewed, and because they have already implemented some elements of CIM in their production facility.

The technology management expert system was thought to have good potential as a fact-finding tool, and would be useful to determine what areas should be looked at more closely. It was mentioned that the ability to achieve consensus on the customer importance ratings would be difficult in a large company, where different departments will have different priorities.

The data entry process for the customer importance ratings should be made more self-explanatory, with an explanation of the rating scheme displayed on the data entry screens, instead of relying on the data entry process and rating system being explained by the consultant.

The output from the prototype expert system was limited to being able to view the spreadsheet, and one output screen showing the overall ratings of the three technologies. The process of determining the customer objectives and technology implementation areas of highest concern should be automated and the top ten areas of highest concern should be displayed on an output screen. Converting the absolute ratings to a relative percentage would make it easier to see the relative importance of the customer objectives and technology implementation areas. Another desirable feature would be the ability to highlight how the recommendations would change based on changes in the customer importance ratings (sensitivity analysis).

The program would be easier to use if it were programmed to the standards of the Windows '95 operating system (the current standard in use), for look, feel, and operation. The idea of implementing the program as an add-in to an existing Windows based spreadsheet program was well received.

Targeting this program at consultants was thought to be a good idea. Consultants would use the program many times, while individual companies would likely only use it once or twice for general decision making and deciding on general policy. The ability of a consultant to demonstrate the program to the client, and explain along the way is important because some of the benefits of the program are not immediately obvious, or difficult to explain in printed documentation. It would advantageous if the consultant would set up the program, and leave it with the client, to evaluate the effect of different scenarios and ratings on the recommendations.

When asked if they thought the same system could be applied to areas other than technology management, they said they thought it would work for marketing, or for choosing general types of investments for financial planning, but would not work for more specific analysis (such as specific investments to make).

4.2. Test Case #2 – USF Watergroup

USF Watergroup is a manufacturer of water treatment and filtration equipment in Regina, Saskatchewan, employing 125 to 150 people, with annual sales of approximately $50 million, mostly within North America. The main product of USF Watergroup is water treatment equipment such as water filters and water softeners that are assembled from components. The entire assembly process is manual, with no automation or robotics, due to the wide variety of products that are assembled and the need for flexibility in the production process. USF Watergroup was recently purchased by US Filter [44], which operates over 2000 facilities in 94 countries, with annual sales in excess of $3.5 billion.

The interview process [45] was conducted on June 2 1998, with Toby Hughes, Manager – Process Improvement. The customer importance ratings obtained from this interview are shown in Table 4.4. The ratings indicate the priorities of the USF Watergroup Regina plant, and not the ratings of the larger parent company.

The results of combining the customer importance ratings from Table 4.4 with the prototype expert system matrix structure from Figure 3.1 can be seen in Figure 4.2.

Table 4.4. Customer importance Ratings for USF Watergroup

Category	Objective	Rating
Minimize costs	Minimize inventory	3
	Minimize production costs	5
	Maximize productivity	5
	Standardize basic office tasks	2
	Reduce basic office tasks	2
	Increase production efficiency	5
	Maximize utilization of production equipment	5
	Increase efficiency of employees	5
	Reduce maintenance downtime	4
Increase revenue	Maximize production capacity	4
	Improve marketing and increase sales	4
Speed up processes	Minimize production time	4
	Reduce design cycle time	3
	Consistent on-time delivery	3
	Shortest possible delivery dates	2
	Increase production flexibility	4
	Improved scheduling	4
Customer Relations	Maximize reliability	3
	Maximize availability of resources to production	3
	Maximize availability of product to customers	4
	Maximize quality	5

4.2.1. Test Results

When the customer importance Ratings for USF Watergroup are combined with the knowledge base of the prototype expert system, CIM is rated the highest with an overall rating of 1063, indicating that CIM has the most potential to meet the demands of the customer's objectives, and should be considered for implementation. Expert Systems placed second with a rating of 856 and CAD/CAM third with 703, as seen in Figure 4.2.

The implementation areas of CIM were sorted by their cumulative ratings as shown in table 4.5 and the top four areas of robotics and automation, shop floor control, scheduling, and integrated architecture were recommended for possible implementation.

Table 4.5. Final Ratings of CIM Technology Implementation Areas

Implementation Area	Rating
10. Robotics and Automation	171
09. Shop Floor Control	165
07. Scheduling	154
12. Integrated Architecture	133
04. Process Design	107
11. Shared Data	75
05. Quality Control	52
01. Product Design	50
02. Analysis and Simulation	47
08. Materials Handling	43
03. Documentation	33
06. Facilities Planning	33

The top three customer objectives (by cumulative rating) were recommended as being the most likely to benefit from the implementation of CIM. These objectives are to maximize quality, increase efficiency of employees, and increase production flexibility.

Table 4.6. Final Ratings of Customer Objectives

Category	Objective	Rating
Customer Relations	Maximize quality	120
Minimize costs	Increase efficiency of employees	105
Speed up processes	Increase production flexibility	104
Increase revenue	Maximize production capacity	84
Minimize costs	Minimize production costs	70
Minimize costs	Maximize productivity	70
Minimize costs	Increase production efficiency	60
Speed up processes	Reduce design cycle time	57
Speed up processes	Minimize production time	52
Speed up processes	Improved scheduling	52
Minimize costs	Minimize inventory	51
Minimize costs	Maximize utilization of production equipment	35
Customer Relations	Maximize reliability	30
Minimize costs	Standardize basic office tasks	26
Minimize costs	Reduce maintenance downtime	24
Speed up processes	Shortest possible delivery dates	24
Customer Relations	Maximize availability of resources to production	24
Minimize costs	Reduce basic office tasks	22
Speed up processes	Consistent on-time delivery	21
Customer Relations	Maximize availability of product to customers	20
Increase revenue	Improve marketing and increase sales	12

Technologies →

Application Areas →

Expert Systems

General Categories	Objectives / Customer Attributes	Customer Importance	1 Continuous Monitoring	2 Continuous Control	3 Automate Repetitive processes	4 Expert help available at all times	5 Instruct & Educate Employees	6 Planning & Scheduling	7 Problem Diagnosis	8 Design Assistance	9 Prediction	10 Simulation
Minimize Costs	Minimize Inventory	3						5				
	Minimize Production Costs	5							4			
	Maximize Productivity	5				4	4	4				4
	Standardize Basic Office Tasks	2			4							
	Reduce Basic Office Tasks	2			3							
	Increase Production Efficiency	5	5	5	4	1	1	3				3
	Maximize Utilization of Production Equipment	5	5	5		2		5				4
	Increase Efficiency of Employees	5			4	5	5					
	Reduce Maintenance Downtime	4	5			3		4	3		2	2
Increase Revenue	Maximize Production Capacity	4	5	5		3						4
	Improve Marketing / Increase Sales	4									2	
Speed up Processes	Minimize Production Time	4			4			4				3
	Reduce Design Cycle Time	3			4	5				4		
	Consistent On-Time Delivery	3						3				
	Shortest possible delivery dates	2						3				2
	Increase Production Flexibility	4						4				3
	Imroved Scheduling	4				3		4				1
Customer Relations	Maximize Reliability	3							4		3	2
	Maximize Availability of resources to production	3				2		5				
	Maximize availability of product to customers	4						5				
	Maximize Quality	5							3	4	3	2
	Weighted Ratings =		90	70	82	117	50	189	59	32	40	127

CAD/CAM

Objectives / Customer Attributes	1 Design Creation	2 Design Analysis	3 Mathematical Modeling	4 Mechanical Modeling	5 Creation of Engineering Drawings	6 Drawing Cataloging & Retrieval	7 Documentation	8 Production Planning	9 Machine Tooling/Robotics	10 Group Technology
Minimize Inventory								5		3
Minimize Production Costs								4	5	1
Maximize Productivity								3	5	
Standardize Basic Office Tasks					5	3	3			
Reduce Basic Office Tasks					5	5	3			
Increase Production Efficiency								5	5	
Maximize Utilization of Production Equipment								5	2	
Increase Efficiency of Employees	4	4	2	1	5				4	
Reduce Maintenance Downtime								3		
Maximize Production Capacity								3	5	
Improve Marketing / Increase Sales										
Minimize Production Time								5	4	
Reduce Design Cycle Time	5	5	5	4	5					
Consistent On-Time Delivery								3		
Shortest possible delivery dates	1	1	2	1				4		
Increase Production Flexibility								4	5	
Imroved Scheduling								2		
Maximize Reliability		5								
Maximize Availability of resources to production								4		
Maximize availability of product to customers								4		
Maximize Quality		4	4	2	3				5	
Weighted Ratings =	37	72	49	29	75	16	12	213	186	14

CIM

Objectives / Customer Attributes	1 Product Design	2 Analysis & Simulation	3 Documentation	4 Process Design	5 Quality Control	6 Facilities Planning	7 Scheduling	8 Materials Handling	9 Shop Floor Control	10 Robotics & Automation	11 Shared Data	12 Integrated Architecture	Expert System Weighted Rating	CAD/CAM Weighted Rating	CIM Weighted Rating
Minimize Inventory							4	4	1		5	3	15	24	51
Minimize Production Costs				5					4	5			20	50	70
Maximize Productivity				3			4		2	5			80	40	70
Standardize Basic Office Tasks			4								4	5	8	22	26
Reduce Basic Office Tasks			3								4	4	6	26	22
Increase Production Efficiency				3			3		2	4			110	50	60
Maximize Utilization of Production Equipment						1	4					2	105	35	35
Increase Efficiency of Employees	3	1	2						4	4	4	3	70	100	105
Reduce Maintenance Downtime							3		3				76	12	24
Maximize Production Capacity				4		3	5		4	5			68	32	84
Improve Marketing / Increase Sales					3								8	0	12
Minimize Production Time				5					4	4			44	36	52
Reduce Design Cycle Time	5	4	3								4	3	39	72	57
Consistent On-Time Delivery							3		2			2	9	9	21
Shortest possible delivery dates							5		4			3	10	18	24
Increase Production Flexibility				4		4	4	3	4	5		2	28	36	104
Imroved Scheduling							5		2		3	3	32	8	52
Maximize Reliability		5			5								27	15	30
Maximize Availability of resources to production								5				3	21	12	24
Maximize availability of product to customers								1				4	20	16	20
Maximize Quality	4	3			5				4	5		3	60	90	120
													856	703	1063
Weighted Ratings =	50	47	33	107	52	33	154	43	165	171	75	133	856	703	1063

Figure 4.2. Results of Trial for USF Watergroup.

Beyond the top four technology implementation areas and top three customer objectives, the ratings decline considerably. These lower rated implementation areas and customer objectives could be considered for implementation at a later date, but due to their low ratings they are not likely to provide a major benefit to the customer.

Summarizing the recommendations for USF Watergroup, the robotics and automation, shop floor control, scheduling, and integrated architecture areas of CIM should be considered for implementation, to address the objectives of maximizing quality, increasing efficiency of employees, and increasing production flexibility.

4.2.2. Customer Comments

The recommendation of CIM supports current thought at the company. A MRP (Manufacturing Resource Program) has been implemented at their facility with elements such as inventory control, materials handling, and purchasing information systems, basic elements of CIM, being supported.

USF Watergroup is not oriented towards custom engineering or quick product design changes, and design cycle time is not considered important, so CAD/CAM would not be considered a good recommendation for this situation. The company is more interested in improving production efficiency and customer service, reducing production costs, and quality control. The current production process relies on all employees acting as quality control personnel to catch problems during the production process rather than after.

The rating system of zero to five for the customer importance ratings should be clarified or explained in more detail before the customer begins rating the objectives.

It was suggested that some type of statistical analysis features should be added, such as how far apart the ratings of two technology implementation areas or customer objectives have to be before the difference becomes statistically significant [46]. Some type of sensitivity analysis was also suggested.

The program would not be used continuously if owned by this company. There have only been two major technological implementations in the 25 year history of the company, and the personnel at the company have enough experience and expertise that they know the technological options and need very little outside assistance, so there is little need for this type of software.

It would be a good program to use for a smaller company that was just starting out, and had a limited amount of capital to spend and wanted to get the most benefit out of their technology implementations.

There were no major surprises during the testing of the prototype expert system. The recommendations that were generated were found to be reasonable, and many of the potential problems or perceived shortcomings had been identified prior to the beginning of the testing phase. The results of the tests and the recommendations of the two test subject companies have been summarized in the Conclusions (Section 5) and Recommendations (Section 6).

5. CONCLUSIONS

The matrix methodology has very significant advantages for use in technology management. Once a technology is entered into the knowledge base, it can be modified and updated by simply adding the characteristics of the new technology to the knowledge base, and if necessary, expanding the list of potential customer objectives. This feature is particularly important when dealing with subjective decisions that can be expected to vary with different customers. The ability to demonstrate visually the basis of the system's recommendations is another feature of the expert system that serves to focus more in-depth discussions, leading to a better understanding of the problem. This highly interactive expert system methodology is an advanced and effective tool, for obtaining and understanding a solution in terms of business priorities.

The expert system shell GURU performed adequately for the development of the prototype expert system, but several disadvantages were found such that another program should be found to implement any further development of this methodology. GURU is an older program, and the user interface is based on old technology, with heavy use of menus and command lines. It does not live up to the standards of modern programs which use graphical user interfaces, and have had the benefit of an additional 10 to 15 years of development and advancements in program design.

This matrix methodology was only applied to technology management here, but it could be adapted to many other types of evaluation problems that may be difficult to solve using other expert system approaches. The type of problem best suited to the matrix methodology is one requiring a subjective evaluation of a large amount of data, to interactively support professional expertise when delivering a solution tailored to individual customer requirements. Some examples where the matrix methodology could be considered are Marketing, Financial, Environmental, Safety and Human Factors related issues, and Quality Control.

This methodology manages to operate on a broad knowledge base because it limits what it tries to do. By making recommendations on which technology to consider for implementation, we do not exceed the capabilities of the expert system. However, if we were to try to make recommendations on how the technologies were to be implemented, or to try to examine the technologies in too fine detail, we would quickly run into problems with maintaining a rapidly expanding database and managing more and more complex calculations. The methodology is ideal for applications that provide subjective support to an expert. The success of this methodology is naturally strongly dependent upon the knowledge and communication skills of the professional as well as the expert system tool.

6. RECOMMENDATIONS FOR FUTURE WORK

This thesis has provided the basis for future development of matrix methodology based expert systems. The following recommendations would make excellent additions to the work already done in this thesis, and should be considered by anyone wishing to proceed further with this work.

6.1. Interrelationships Pyramid

The Interrelationship pyramid that was part of the House of Quality matrix structure was omitted from the expert system methodology because of time constraints. In future work, it would be a worthwhile addition. The triangular matrix structure could be added to the top of the expert system matrix for cross-referencing technology implementation areas, with respect to the possibility of implementing two (or more) complementary technologies at the same time.

6.2. Logic Tracking

A logic tracking system added to the expert system would allow the user to see the process by which the expert system arrived at its recommendation. Because of the straightforward nature of the matrix structure, it would not be difficult to design the method for tracking the recommendations, and for displaying the relevant information to the user. The logic tracking was omitted from this work because of time constraints, and because of the difficulty of implementing it using the GURU expert system shell. Logic tracking may be easier to implement if a different program is chosen to implement future work, and would make a worthwhile addition to any future work.

6.3. Upgrade to modern software

The GURU expert system shell that we had access to functioned adequately for the initial development of this methodology, but it is old and outdated by the standards of the software being released in 1998 [47, 48]. Future development work should use newer software to take advantage of advances in computer programming, and to allow the system to be updated and expanded more easily.

6.4. Develop a Spreadsheet Add-In Program

Although the initial intent was to use a standard expert system shell as the core program, at the end the spreadsheet features of the shell were much more important and useful than the rule base and other expert system attributes. If the specialized features of an expert system shell are not required, a standard spreadsheet could be used as the base program, such as Microsoft Excel, Lotus 123, or Quattro Pro. A macro or add-in program could be created to perform the data input and output functions, to automatically set up the structure of the expert system matrix within the spreadsheet, and to provide any of the other additional features that may be desired.

The advantages of a modern spreadsheet include better user interfaces and a large number of statistical and data analysis tools that could be used to expand the capabilities of the expert system. Spreadsheets are widely accepted, and widely available as most people already have a spreadsheet program on their computers.

The disadvantages of spreadsheets are that it would require advanced computer programming skills to develop the add-in programs. Programming and debugging problems would be difficult.

Although we currently do not use expert system features such as if/then/else rules and frames, it may be useful to introduce them into a future version of this system.

Because spreadsheets do not contain these features, they would have to be coded into the add-in (increasing programming time and complexity), or an existing add-in would have to be found to provide these features.

6.5. Further Development of Questions for Determining Customer Objectives

The method used to determine customer objective ratings for this system could be improved with some additional work [41]. Indirect reasoning could be used to improve the accuracy of the ratings, without increasing the complexity of the end user interface. Using rules to control which questions are asked could reduce or eliminate the frustration associated with asking of unnecessary or redundant questions.

6.6. Sensitivity Analysis

Some type of sensitivity analysis to support the expert system recommendations would be beneficial. The sensitivity analysis could be used to assess the significance of variance in the customer importance ratings, as well as the expert's ratings of the technologies in the comparison matrix. This could be implemented by showing how many points each customer importance rating or comparison matrix rating would have to change before the technology implementation area ratings, customer objective ratings, or overall ratings change enough to alter the expert system's recommendation.

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APPENDIX A - PROGRAM DOCUMENTATION

The prototype expert system was developed using Version 2.01 of the expert system shell GURU. GURU is a DOS program, but will also run under Windows 3.1 or Windows '95 in a DOS window.

To implement the prototype expert system, nine files are required in addition to the shell files. There are five "form" files (.IFF) that define the data input and output screens shown in Figures A2 through A6, two "table" files (.ITB) defining the structure of the data tables that are used to store data within the shell, one spreadsheet file (.ICF) defining the spreadsheet structure, and one "perform" file (.IPF) containing the batch file that automates the program. The file names used are all referred to within the perform file.

The original GURU shell software was distributed on 5-1/4" floppy disks, and it is becoming more difficult to find computers equipped with 5-1/4" floppy disk drives. To make it easier to move the prototype expert system shell from one computer to another, the entire shell and all files required to implement the prototype expert system were placed in a compressed archive (.zip file) and stored on a 3-1/2" floppy disk. A copy of this disk will be left with the original GURU system disks at the Faculty of Engineering office at the University of Regina.

Instructions for installing GURU

To install the program on your computer, copy the two files on the floppy disk to an empty directory on your hard drive (I suggest C:\GURU). The file GURU.ZIP is a compressed archive of all the files required to run the program. The file PKUNZIP.EXE is the decompression utility required to extract these files. If you already have a copy of the utilities PKZip or WinZip, they can be used to extract the files.

In a DOS window or at the command prompt in the DOS shell, move to the directory where the files are stored and enter the command "PKUNZIP GURU", which will decompress the required files.

To start the program, type GURU at the DOS prompt (in the GURU directory), or specify the file GURU.EXE in the Windows "Run Programs" box. A shortcut can also be used under Windows '95, also specifying the GURU.EXE file.

Once GURU is running, follow the "instructions for running GURU" on the following page.

Running GURU under Windows '95 does introduce one slight bug. The first customer importance rating that you enter on each of the four data entry screens may retain the old value and append your new value to it (i.e. if the old value is 1 and you enter 3, the new value will become 31). If this happens, simply type the rating that you want three times to fill up the field (i.e. if you want to enter 4, type 444), then delete the last two numbers using the backspace or delete keys. This will allow the proper number to be entered when you press return. If you find that the value has been entered incorrectly, you can return to it using the up-arrow cursor key.

Under Windows '95, you cannot close the DOS window where GURU is running until you exit the program through the normal procedure (Windows cannot shut down the program automatically). If you are in GURU and want to quit quickly, you can issue the command "\BYE" to exit the spreadsheet mode, and "BYE" (without the backslash) at the GURU> prompt will return you from the command line to the menu system, from which you can chose to quit the program.

To remove GURU from your computer, simply delete all files in the GURU directory, and remove the directory. GURU does not store or use any files in any other directories, and will not leave any residual files behind. If your are using a Windows '95 shortcut to activate the program, also remember to delete the shortcut.

Instructions for running GURU.

1) At the DOS prompt type "GURU", or use a shortcut to start the file GURU.EXE.

2) Answer Y (for Yes) to the question 'Resume Previous Session?"

3) Choose the session named "Session" from the list.

4) On the menu list, choose "Change Environment", then "Command Mode"

5) At the GURU> prompt type "perform perform4.ipf"

6) Enter values from 0 to 5 for the priority ratings of each customer objective

- Pressing the Enter button after each value moves you to the next one.
- Values from the previous session are stored and can be re-used by pressing Enter without entering a new value.
- The cursor keys can be used to move up or down the list.
- There are four data entry screens. The cursor buttons can not be used to return to a previous screen.

7) At the blank spreadsheet screen type the following commands. Note that the COMMANDS MUST BE PRECEDED BY A BACKSLASH (\):

\one (reads in the starting spreadsheet).

\two (imports customer importance ratings that were entered previously).

\three (recalculates once).

\four (recalculates again – required to obtain accurate values).

- At this point, you can use the cursor keys to move around in the spreadsheet and examine the ratings of the various technologies.

\five (exports the results to output table).

\six (exits spreadsheet mode and displays results screen).

8) Press the Return button twice to return to the GURU menu system.

Listing of Guru Program / Batch File "Perform4.ipf"

```
/*============================================================*/
/*                                                            */
/*  Perform File for Matrix Structure Expert System           */
/*                                                            */
/*  File Name: PERFORM4.IPF                                   */
/*                                                            */
/*  By: Daniel Hemingway                                      */
/*      University of Regina                                  */
/*      Regina, Saskatchewan, Canada                          */
/*                                                            */
/*  Latest Revision: March 18, 1998                           */
/*                                                            */
/*============================================================*/

/*============================================================*/
/*                                                            */
/*  Set-up.  Opening files, doing maintenance, etc.           */
/*                                                            */
/*============================================================*/

/* Open table "PRIORITY.ITB" so it can be used                */
/*  - See pg. 2:23 & 2:119 of GURU manual 2                   */
/*  This table will contain the customer importance ratings.  */

USE PRIORITY.ITB


/* Open table "RESULT1.ITB" so it can be used                 */
/*  - See pg. 2:23 & 2:119 of GURU manual 2                   */
/*  This table will contain the results of the analysis.      */

USE RESULT1.ITB


/* Clear all records in RESULT1.ITB                           */

MARK RECORDS IN RESULT1 WITH TRUE ALL
COMPRESS RESULT1


/*============================================================*/
/*                                                            */
/*  The following commands will allow the user to enter the   */
/*    Customer Importance Ratings into data entry forms       */
/*                                                            */
/*============================================================*/

/* Clear Screen                                               */

CLEAR


/* Display input form and Literal Values                      */
/*  For first input screen "COSTFORM.IFF"                     */
/*  for customer objectives impacting costs                   */
/*  - see pg. 7:7 & 7:48 of GURU manual 2                     */
```

```
PUTFORM COSTFORM

/* Retrieve User Input From Form                                  */
/*  - see pg. 7:7 & 7:19 of GURU manual 2                         */

GETFORM COSTFORM


/* Clear Screen                                                   */

CLEAR


/* Display input form and Literal Values                          */
/*  For Second input screen "REVFORM.IFF"                         */
/*  for customer objectives impacting revenues                    */
/*  - see pg. 7:7 & 7:48 of GURU manual 2                         */

PUTFORM REVFORM


/* Retrieve User Input From Form                                  */
/*  - see pg. 7:7 & 7:19 of GURU manual 2                         */

GETFORM REVFORM


/* Clear Screen                                                   */

CLEAR


/* Display input form and Literal Values                          */
/*  For Third input screen "PROCFORM.IFF"                         */
/*  for customer objectives that speed up processes               */
/*  - see pg. 7:7 & 7:48 of GURU manual 2                         */

PUTFORM PROCFORM


/* Retrieve User Input From Form                                  */
/*  - see pg. 7:7 & 7:19 of GURU manual 2                         */

GETFORM PROCFORM


/* Clear Screen                                                   */

CLEAR


/* Display input form and Literal Values                          */
/*  For fourth input screen "CUSTFORM.IFF"                        */
/*  for customer objectives that improve customer relations       */
/*  - see pg. 7:7 & 7:48 of GURU manual 2                         */

PUTFORM CUSTFORM
```

```
/* Retrieve User Input From Form                                    */
/*  - see pg. 7:7 & 7:19 of GURU manual 2                           */

GETFORM CUSTFORM
/* Clear Screen                                                     */

CLEAR

/*================================================================*/
/*                                                                */
/* Setting up Macro Definitions to reduce typing in spreadsheet*/
/*                                                                */
/*================================================================*/

/*================================================================*/
/*                                                                */
/* Note: All commands in spreadsheet mode have a backslash in     */
/*       front of them.  So type the macro names with a           */
/*       backslash first!                                         */
/*                                                                */
/*================================================================*/


/* Load Spreadsheet from file                                       */
/*  - see pg. 3:39 of GURU manual 2                                 */

MACRO ONE LOAD FROM "MATRIX1.ICF"


/* Insert data from PRIORITY table into Spreadsheet                 */
/*  - see page 3:25 of GURU manual 2                                */

MACRO TWO CONVERT FROM PRIORITY TO CELL #C66 TO #W66


/* Re-Calculate all values in the spreadsheet                       */
/*  - see page 3:22 of GURU manual 2                                */

MACRO THREE COMPUTE

/* Re-Calculate again - for some reason the first recalc does      */
/*  not compute the values for some of the cells.                   */

MACRO FOUR COMPUTE


/* Attach cell values as new records in a table                     */
/*  - See page 3:14 of GURU manual 2                                */

MACRO FIVE ATTACH FROM CELL #B62 to #C64 TO RESULT1 WITH \
NAME,RATING


/* Close down Spreadsheet Mode                                      */

MACRO SIX STOP
```

```
/*================================================================*/
/*                                                                */
/* Entering interactive spreadsheet mode                          */
/*                                                                */
/*================================================================*/

/* Enter Spreadsheet Mode                                         */
CALC

/*================================================================*/
/*                                                                */
/* Steps to perform after exiting from spreadsheet mode           */
/*                                                                */
/*================================================================*/

/* Sort data in results table                                     */
/*  - see pg. 2:102 of GURU manual 2                              */

SORT RESULT1 BY DESCENDING RATING


/* Clear Screen                                                   */

CLEAR


/* Output Table of Results                                        */
/*  - see page 7:48 of GURU manual 2                              */

PUTFORM RESULTS1


/* Compute values of non-literal elements of screen form          */
/*  - See page 7:53 of GURU manual 2                              */

TALLY RESULTS1


/* "Wait" command pauses execution until user presses a key       */

WAIT


/* Close down "RESULT1.ITB" table                                 */
/*  - see page 2:22 & 2:68 of GURU manual 2                       */

FINISH RESULT1


/* Close down "PRIORITY.ITB" table                                */
/*  - see page 2:22 & 2:68 of GURU manual 2                       */

FINISH PRIORITY


/* End Command line session and return to menu system             */
```

```
/*  - See page 7:3 of GURU manual 1                                  */

BYE

/*================================================================*/
/*                                                                */
/*  End Of File                                                   */
/*                                                                */
/*================================================================*/
```

General Categories	Objectives / Customer Attributes	Customer Importance	1 Continuous Monitoring	2 Continuous Control	3 Automate Repetitive processes	4 Expert help available at all times	5 Instruct & Educate Employees	6 Planning & Scheduling	7 Problem Diagnosis	8 Design Assistance	9 Prediction	10 Simulation
Minimize Costs	Minimize Inventory	5						25				
	Minimize Production Costs	5							20			
	Maximize Productivity	5				20	20	20				20
	Standardize Basic Office Tasks	5			20							
	Reduce Basic Office Tasks	5			15							
	Increase Production Efficiency	5	25	25	20	5	5	15				15
	Maximize Utilization of Production Equipment	5	25	25		10		25				20
	Increase Efficiency of Employees	5			20	25	25					
	Reduce Maintenance Downtime	5	25			15		20	15		10	10
Increase Revenue	Maximize Production Capacity	5	25	25		15						20
	Improve Marketing / Increase Sales	5									10	
Speed up Processes	Minimize Production Time	5			20			20				15
	Reduce Design Cycle Time	5			20	25				20		
	Consistent On Time Delivery	5						15				
	Shortest possible delivery dates	5						15				10
	Increase Production Flexibility	5						20				15
	Improved Scheduling	5				15		20				5
Customer Relations	Maximize Reliability	5							20		15	10
	Maximize Availability of resources to production	5				10		25				
	Maximize availability of product to customers	5						25				
	Maximize Quality	5							15	20	15	10
	Weighted Ratings =		100	75	115	140	50	245	70	40	50	150

Objectives / Customer Attributes	1 Design Creation	2 Design Analysis	3 Mathematical Modeling	4 Mechanical Modeling	5 Creation of Engineering Drawings	6 Drawing Cataloging & Retrieval	7 Documentation	8 Production Planning	9 Machine Tooling/Robotics	10 Group Technology
Minimize Inventory								25		15
Minimize Production Costs								20	25	5
Maximize Productivity								15	25	
Standardize Basic Office Tasks					25	15	15			
Reduce Basic Office Tasks					25	25	15			
Increase Production Efficiency								25	25	
Maximize Utilization of Production Equipment								25	10	
Increase Efficiency of Employees	20	20	10	5	25				20	
Reduce Maintenance Downtime								15		
Maximize Production Capacity								15	25	
Improve Marketing / Increase Sales										
Minimize Production Time								25	20	
Reduce Design Cycle Time	25	25	25	20	25					
Consistent On Time Delivery								15		
Shortest possible delivery dates	5	5	10	5				20		
Increase Production Flexibility								20	25	
Improved Scheduling								10		
Maximize Reliability		25								
Maximize Availability of resources to production								20		
Maximize availability of product to customers								20		
Maximize Quality		20	20	10	15				25	
Weighted Ratings =	50	95	65	40	115	40	30	270	200	20

Objectives / Customer Attributes	1 Product Design	2 Analysis & Simulation	3 Documentation	4 Process Design	5 Quality Control	6 Facilities Planning	7 Scheduling	8 Materials Handling	9 Shop Floor Control	10 Robotics & Automation	11 Shared Data	12 Integrated Architecture
Minimize Inventory							20	20	5		25	15
Minimize Production Costs				25					20	25		
Maximize Productivity				15			20		10	25		
Standardize Basic Office Tasks			20								20	25
Reduce Basic Office Tasks			15								20	20
Increase Production Efficiency				15			15		10	20		
Maximize Utilization of Production Equipment						5	20					10
Increase Efficiency of Employees	15	5	10						20	20	20	15
Reduce Maintenance Downtime							15		15			
Maximize Production Capacity				20		15	25		20	25		
Improve Marketing / Increase Sales					15							
Minimize Production Time				25					20	20		
Reduce Design Cycle Time	25	20	15								20	15
Consistent On Time Delivery							15		10			10
Shortest possible delivery dates							25		20			15
Increase Production Flexibility				20		20	20	15	20	25		10
Improved Scheduling							25		10		15	15
Maximize Reliability		25			25							
Maximize Availability of resources to production								25				15
Maximize availability of product to customers								5				20
Maximize Quality	20	15			25				20	25		15
Weighted Ratings =	60	65	60	120	65	40	200	65	200	185	120	200

Objectives / Customer Attributes	Weighted Ratings: Expert System	Weighted Ratings: CAD/CAM	Weighted Ratings: CIM
Minimize Inventory	25	40	85
Minimize Production Costs	20	50	70
Maximize Productivity	80	40	70
Standardize Basic Office Tasks	20	65	65
Reduce Basic Office Tasks	15	65	55
Increase Production Efficiency	110	50	60
Maximize Utilization of Production Equipment	105	35	35
Increase Efficiency of Employees	70	100	105
Reduce Maintenance Downtime	95	15	30
Maximize Production Capacity	85	40	105
Improve Marketing / Increase Sales	10	0	15
Minimize Production Time	55	45	65
Reduce Design Cycle Time	65	120	95
Consistent On Time Delivery	15	15	35
Shortest possible delivery dates	25	45	60
Increase Production Flexibility	35	45	130
Improved Scheduling	40	10	65
Maximize Reliability	45	25	50
Maximize Availability of resources to production	35	20	40
Maximize availability of product to customers	25	20	25
Maximize Quality	60	90	120
	1035	925	1380
Weighted Ratings =	1035	925	1380

Figure A1. Printout of GURU Matrix

For Minimizing Costs, Enter the priority ratings for the following objectives

Minimize Inventory	3
Minimize Production Costs	5
Maximize Productivity	5
Standardize Basic Office Tasks	2
Reduce Basic Office Tasks	2
Increase Production Efficiency	5
Maximize Use of Production Equipment	5
Increase Efficiency of Employees	5
Reduce Maintenance Downtime	4

Priority ratings should be numbers between 0 (zero) and 5 (five).

Figure A2. GURU Data Input Screen #1

Enter the priority ratings for the following objectives
relating to Increasing Revenue:

Maximize Production Capacity	4
Improve Marketing & Increase Sales	4

Priority ratings should be numbers between 0 (zero) and 5 (five).

Figure A3. GURU Data Input Screen #2

Please enter the importance ratings for the following objectives
relating to speeding up processes:

Minimize Production Time	4
Reduce Design Cycle Time	3
Improve On-Time Delivery	3
Shortest Possible Delivery Dates	2
Increase Production Flexibility	4
Improve Scheduling	4

Importance ratings should be numbers from 0 (zero) to 5 (five).

Figure A4. GURU Data Input Screen #3

Please enter the importance ratings for the following objectives
relating to Customer Service and Customer Relations:

Maximize Reliability	3
Maximize Availability of Resources to Production	3
Maximize Availability of Product to Customers	4
Maximize Quality of Product	5

Priority ratings should be numbers between 0 (zero) and 5 (five).

Figure A5. GURU Data Input Screen #4

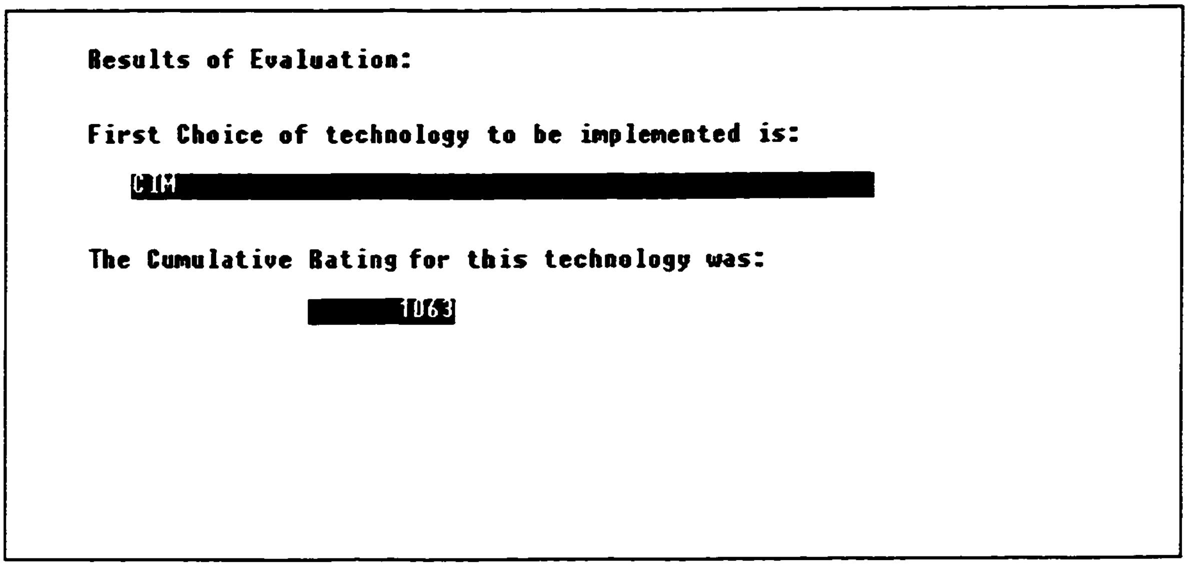


Figure A6. GURU Data Output Screen

APPENDIX B - TECHNOLOGY EVALUATIONS

In order to fill in the matrix, each customer objective has to be compared against each technology implementation area, and a numeric rating chosen for each relationship. This process was conducted for the prototype expert system, and the results are described below. Where no relationship exists between the customer objective and technology implementation area, or where the relationship was considered insignificant, the relationship was excluded from the comparisons below, and a rating of zero was assigned in the matrix. Ratings range from 0 through 5, and are shown in the comparison matrix, Figure B1. Out of 704 possible comparisons, 185 have ratings that are not zero.

Technologies -->

Application Areas -->

Expert Systems

General Categories	Objectives / Customer Attributes	1 Continuous Monitoring	2 Continuous Control	3 Automate Repetitive processes	4 Expert help available at all times	5 Instruct & Educate Employees	6 Planning & Scheduling	7 Problem Diagnosis	8 Design Assistance	9 Prediction	10 Simulation
Minimize Costs	Minimize Inventory						5				
	Minimize Production Costs							4			
	Maximize Productivity				4	4	4				4
	Standardize Basic Office Tasks			4							
	Reduce Basic Office Tasks			3							
	Increase Production Efficiency	5	5	4	1	1	3				3
	Maximize Utilization of Production Equipment	5	5		2		5				4
	Increase Efficiency of Employees			4	5	5					
	Reduce Maintenance Downtime	5			3		4	3		2	2
Increase Revenue	Maximize Production Capacity	5	5		3						4
	Improve Marketing / Increase Sales									2	
Speed up Processes	Minimize Production Time			4			4				3
	Reduce Design Cycle Time			4	5				4		
	Consistent On Time Delivery						3				
	Shortest possible delivery dates						3				2
	Increase Production Flexibility						4				3
	Imroved Scheduling				3		4				1
Customer Relations	Maximize Reliability							4		3	2
	Maximize Availability of resources to production				2		5				
	Maximize availability of product to customers						5				
	Maximize Quality							3	4	3	2

CAD/CAM

General Categories	Objectives / Customer Attributes	1 Design Creation	2 Design Analysis	3 Mathematical Modeling	4 Mechanical Modeling	5 Creation of Engineering Drawings	6 Drawing Cataloging & Retrieval	7 Documentation	8 Production Planning	9 Machine Tooling/Robotics	10 Group Technology
Minimize Costs	Minimize Inventory								5		3
	Minimize Production Costs								4	5	1
	Maximize Productivity								3	5	
	Standardize Basic Office Tasks					5	3	3			
	Reduce Basic Office Tasks					5	5	3			
	Increase Production Efficiency								5	5	
	Maximize Utilization of Production Equipment								5	2	
	Increase Efficiency of Employees	4	4	2	1	5				4	
	Reduce Maintenance Downtime								3		
Increase Revenue	Maximize Production Capacity								3	5	
	Improve Marketing / Increase Sales										
Speed up Processes	Minimize Production Time								5	4	
	Reduce Design Cycle Time	5	5	5	4	5					
	Consistent On Time Delivery								3		
	Shortest possible delivery dates	1	1	2	1				4		
	Increase Production Flexibility								4	5	
	Imroved Scheduling								2		
Customer Relations	Maximize Reliability		5								
	Maximize Availability of resources to production								4		
	Maximize availability of product to customers								4		
	Maximize Quality		4	4	2	3				5	

CIM

General Categories	Objectives / Customer Attributes	1 Product Design	2 Analysis & Simulation	3 Documentation	4 Process Design	5 Quality Control	6 Facilities Planning	7 Scheduling	8 Materials Handling	9 Shop Floor Control	10 Robotics & Automation	11 Shared Data	12 Integrated Architecture
Minimize Costs	Minimize Inventory							4	4	1		5	3
	Minimize Production Costs				5					4	5		
	Maximize Productivity				3			4		2	5		
	Standardize Basic Office Tasks			4								4	5
	Reduce Basic Office Tasks			3								4	4
	Increase Production Efficiency				3			3		2	4		
	Maximize Utilization of Production Equipment						1	4					2
	Increase Efficiency of Employees	3	1	2						4	4	4	3
	Reduce Maintenance Downtime							3		3			
Increase Revenue	Maximize Production Capacity				4		3	5		4	5		
	Improve Marketing / Increase Sales					3							
Speed up Processes	Minimize Production Time				5					4	4		
	Reduce Design Cycle Time	5	4	3								4	3
	Consistent On Time Delivery							3		2			2
	Shortest possible delivery dates							5		4			3
	Increase Production Flexibility				4		4	4	3	4	5		2
	Imroved Scheduling							5		2		3	3
Customer Relations	Maximize Reliability		5			5							
	Maximize Availability of resources to production								5				3
	Maximize availability of product to customers								1				4
	Maximize Quality	4	3			5				4	5		3

Figure B1. Comparison Matrix

1. Minimize costs - Minimize inventory - Expert Systems

Expert Systems 6. Planning and scheduling Rating: 5

By entering planning and scheduling information into the rule base of the Expert System, complex relationships can be considered, and inventories can be reduced by scheduling raw materials to arrive when needed, and finished product to be completed only when required (not before).

1. Minimize costs - Minimize inventory - CAD/CAM

CAD/CAM 8. Production Planning Rating: 5

Production planning rules can be easily entered into an expert system, and the expert system can consider highly complex relationships to schedule production so that products are produced as close as possible to their shipping date.

CAD/CAM 10. Group Technology Rating: 3

Group technology can allow the use of the same raw materials for several different products, which allows the number of parts in inventory to be reduced, as well as the reducing the amount of material that must be kept on hand.

1. Minimize costs - Minimize inventory - CIM

CIM 7. Scheduling Rating: 4

The ability of CIM to share information between different areas will allow the company to implement tighter scheduling with less lead time both in the delivery of raw materials, and in the production of finished product, resulting in lower inventory levels.

CIM 8. Materials Handling Rating: 4

Improved materials handling through CIM will allow reduction in inventory levels because materials will be able to arrive at each workstation when required, instead of having small stockpiles of materials at each workstation due to inefficient materials handling.

CIM 9. Shop Floor Control Rating: 1

Shop floor control can help to minimize inventory by implementing aspects of "Just-In-Time" manufacturing procedures, so that inventory is limited to parts that are required immediately for production, and all unnecessary stock is eliminated.

CIM 11. Shared Data Rating: 5

The ability of CIM to share information between departments will allow inventory levels to be set to provide for the required level of production. Because any changes in production requirements will automatically transfer the information to all other areas, the inventory levels can be set lower because there is less danger of unexpected production requiring more inventory than is on hand.

CIM 12. Integrated Architecture Rating: 3

Integrated architecture can tie the production information systems to the inventory and purchasing systems, which makes it possible to ensure that parts and materials are on hand when required, but that inventory is kept to a minimum.

2. Minimize costs - Minimize production costs - Expert Systems

Expert Systems 7. Problem diagnosis Rating: 4

If the expert system's reasoning capabilities can be used to diagnose problems by means of simple rules, then the problems can be spotted and corrected faster, resulting in less downtime and lost revenues due to the problems.

2. Minimize costs - Minimize production costs - CAD/CAM

CAD/CAM 8. Production Planning Rating: 4

Improved production planning through CAD/CAM can reduce the production costs by reducing bottlenecks, and ensuring that equipment is used to its fullest capabilities.

CAD/CAM 9. Machine Tooling/Robotics Rating: 5

Using robotics can reduce the production costs by reducing the number of human workers required to perform a process, and by improving the quality and consistency of the process.

CAD/CAM 10. Group Technology Rating: 1

Group technology can reduce production costs by combining products and parts into groups that have similar features, similar production steps, and similar components, so that the entire group can benefit from improvements made to any one product within the group.

2. Minimize costs - Minimize production costs - CIM

CIM 4. Process Design Rating: 5

Improved process design by using CIM can reduce the production costs by reducing the number of manufacturing steps required.

CIM 9. Shop Floor Control Rating: 4

Shop floor control through CIM can reduce production costs when there are problems, because it allows decisions to be made instantly, and without the assistance of a human operator, if problems such as machinery breakdown occur.

CIM 10. Robotics and Automation Rating: 5

Using robotics can reduce the production costs by reducing the number of human workers required to perform a process, and by improving the quality and consistency of the process.

3. Minimize costs - Maximize productivity - Expert Systems

Expert Systems 4. Expert help available at all times Rating: 4

An expert system can provide advice and guidance to production, so that problems can be solved quickly and productivity can be kept high.

Expert Systems 5. Instruct and educate employees Rating: 4

An educated workforce can be more productive. Having an expert system where the workers are allows training to take place on the job, by having the expert system provide answers to questions, without disrupting the production process.

Expert Systems 6. Planning and scheduling Rating: 4

Expert systems can be used to maximize productivity by ensuring that production machinery is not left idle while waiting for something to do.

Expert Systems 10. Simulation Rating: 4

Simulation of the production process allows problems (such as bottlenecks) to be spotted in advance, and allows options to be evaluated for solving the problems that may lead to reduced productivity.

3. Minimize costs - Maximize productivity - CAD/CAM

CAD/CAM 8. Production Planning Rating: 3

Production planning can be used to maximize productivity by ensuring that production machinery is not left idle while waiting for something to do.

CAD/CAM 9. Machine Tooling/Robotics Rating: 5

Robotics can maximize productivity by improving the quality and consistency of the work, and by allowing work to proceed around the clock.

3. Minimize costs - Maximize productivity - CIM

CIM 4. Process Design Rating: 3

Process design can improve productivity by allowing products to be made with fewer processes, and by optimizing the order in which processes occur.

CIM 7. Scheduling Rating: 4

Scheduling can improve productivity by reducing machine idle time, and reducing bottlenecks in the production process.

CIM 9. Shop Floor Control Rating: 2

Automated shop floor control can improve productivity by ensuring that instructions are quickly and efficiently relayed to the production work stations, so that all workers know what they should be doing and are not sitting idle waiting for instructions. Shop floor control also allows feedback to the planning and scheduling processes that can be used to make improvements.

CIM 10. Robotics and Automation Rating: 5

Robotics can maximize productivity by improving the quality and consistency of the work, and by allowing work to proceed around the clock.

4. Minimize costs - Standardize basic office tasks - Expert Systems

Expert Systems 3. Automate Repetitive Processes Rating: 4

By automating basic office tasks, we can control standardization of the tasks so that all necessary information is recorded, and also so that we do not waste time collecting unnecessary data. Standardized information formats will make it easier to share information between departments.

4. Minimize costs - Standardize basic office tasks - CAD/CAM

CAD/CAM 5. Creation of Engineering Drawings Rating: 5

CAD/CAM can minimize costs by standardizing the creation of engineering drawings, by allowing repetitive information to be entered once and repeated on all drawings (i.e. standard design title block).

CAD/CAM 6. Drawing Cataloguing and Retrieval Rating: 3

A computerized catalogue of drawings allows a lot of information to be stored about the drawings, such as their titles and what appears on them. A computer search can be done to find which drawing is required, and where that drawing is located physically as well as the CAD drawing file name.

CAD/CAM 7. Documentation Rating: 3

CAD drawings make it much easier to document the changes that have been made to the drawings (revision numbers, dates, and what was changed), as well as allowing a standardized method of documentation to be programmed into the software so the documentation is done automatically.

4. Minimize costs - Standardize basic office tasks - CIM

CIM 3. Documentation Rating: 4

CIM can implement a standard method of documentation that can be accessed from any computer terminal, so the documentation is always consistent and there is no need for different departments to develop their own documentation methods.

CIM 11. Shared Data Rating: 4

CIM can reduce costs through standardizing data that can then be shared between all departments within the company, so no time has to be spent repeating data entry, or converting data formats.

CIM 12. Integrated Architecture Rating: 5

Integrated architecture allows computer applications in all departments to have the same look and feel, as well as standard features, so that when people move between different departments, or when it becomes necessary for departments to communicate with each other or access other computer systems, the transition goes smoothly.

5. Minimize costs - Reduce basic office tasks - Expert Systems

Expert Systems 3. Automate Repetitive Processes Rating: 3

By automating basic office tasks, these tasks can be completed faster, and we can reduce the amount of data entry by making information available to all departments once the information has been entered once.

5. Minimize costs - Reduce basic office tasks - CAD/CAM

CAD/CAM 5. Creation of Engineering Drawings Rating: 5

CAD/CAM can reduce the time required to produce engineering drawings, because it allows repetitive actions to be repeated automatically, and it allows the draftsman to begin with an existing copy of the drawing (if one exists) and simply modify it.

CAD/CAM 6. Drawing Cataloguing and Retrieval Rating: 5

Having all production drawings rendered with CAD allows the drawings to be stored and retrieved electronically, so they can be retrieved from any computer within the company. This allows all departments to have access to the drawings (possibly over the company's computer network) without having to print and distribute multiple paper copies.

CAD/CAM 7. Documentation Rating: 3

Because electronic CAD files can be updated and distributed so easily, every person or department that requires drawings can be sent a new set of drawings whenever there are changes, so everyone will be working with the most recent drawings.

5. Minimize costs - Reduce basic office tasks - CIM

CIM 3. Documentation Rating: 3

CIM can allow the automation of the documentation process.

CIM 11. Shared Data Rating: 4

Shared data under CIM can reduce the repetition of data entry for different departments. When a new customer's name, address, and what they bought are entered by sales, the same information automatically goes to the accounting department for billing, and to the customer service department for possible future service calls.

CIM 12. Integrated Architecture Rating: 4

Integrated architecture is necessary if all departments are to share the same information, since it becomes difficult to share information between different data structures and file formats. Integrated architecture also allows the data entry screens to be the same or similar for all departments, so there is no repetition of programming time for data entry screens.

6. Minimize costs - Increase production efficiency - Expert Systems

Expert Systems 1. Continuous Monitoring Rating: 5

By continuously monitoring all aspects of production, when production efficiency drops for any reason, the information is immediately available, and steps can be taken to find the problem and correct it. This monitoring can be reactive (waiting until a problem develops before acting), or pro-active (attempting to identify and solve problems before they cause a reduction in efficiency). Expert systems are excellent for this application because they allow the monitoring system to provide a recommendation on action to be taken, rather than simply providing raw data and requiring the equipment operators to determine what action to take.

Expert Systems 2. Continuous Control Rating: 5

Allows the company to make continuous small adjustments as production is ongoing, in order to maintain a high level of efficiency, for each individual piece of equipment, as well as for the overall production process. The benefits of continuous control are highly dependent on the implementation of continuous monitoring, for the information required to make effective control decisions.

Expert Systems 3. Automate Repetitive Processes Rating: 4

By automating repetitive processes, we can eliminate (or at least reduce to a minimum) variability due to human error. We can also likely reduce the number of people required for a process by automating it.

Expert Systems 4. Expert help available at all times Rating: 1

Will allow less experienced employees to maintain the production efficiency at a high level by allowing them to benefit from expert knowledge when more experienced employees are not available.

Expert Systems 5. Instruct and educate employees Rating: 1

Employees that have been properly educated about the production process will be able to identify problems with production efficiency, and recommend solutions.

Expert Systems 6. Planning and scheduling Rating: 3

Improved planning and scheduling can result in increased production efficiency by improving processes. Improved planning and scheduling is the basis for Just-In-Time manufacturing systems. The expert system allows the planning and scheduling to be completed faster, and reduces the possibility of problems due to errors in the planning, or due to oversights on the part of the planners, and can point out potential problems with the scheduling.

Expert Systems 10. Simulation Rating: 3

Simulation of a production process allows the operators to be able to identify potential problems with the process. The expert system can take all available information and provide more accurate analysis of the simulation, and can also provide suggested solutions to the problems that occur in the simulation.

6. Minimize costs - Increase production efficiency - CAD/CAM

CAD/CAM 8. Production Planning Rating: 5

CAM can be used for analysis of the manufacturing process, so changes to the operations can be implemented and simulated before production begins. The goal is to make the process more efficient, reduce the number of manufacturing steps, or determine the best sequence of steps to prevent quality problems.

CAD/CAM 9. Machine Tooling/Robotics Rating: 5

Robotics and automated machinery can increase production efficiency by allowing a smaller number of workers to do the same amount of work, and by improving product quality by increasing the accuracy and consistency of the work.

6. Minimize costs - Increase production efficiency - CIM

CIM 4. Process Design Rating: 3

By improving the design of the production process, bottlenecks can be eliminated, and maximum use can be made of all production equipment.

CIM 7. Scheduling Rating: 3

Scheduling can increase production efficiency by allowing maximum utilization of all production processes and machinery. Time spent waiting for work due to bottlenecks elsewhere in the production process can be reduced or eliminated.

CIM 9. Shop Floor Control Rating: 2

Shop floor control can increase production efficiency by allowing changes and improvements to be made to the process in real time. The effects of machinery not working properly or breaking down can be minimized by diverting work to other stations, and making other changes to the scheduling in real time.

CIM 10. Robotics and Automation Rating: 4

Robotics and automation can increase production efficiency by increasing the accuracy with which tasks are performed. Increased accuracy in manufacturing results in fewer rejects due to defects, and less material wasted.

7. Minimize costs - Maximize utilization of production equipment - Expert Systems

Expert Systems 1. Continuous Monitoring Rating: 5

Constant monitoring will allow us to know when a piece of equipment is idle, or even project when a piece of equipment may become idle (based on the rate at which jobs are completed and the rate at which jobs are being added to the queue). Changes can be made on the fly to improve scheduling, locate and eliminate bottlenecks, or re-task equipment from one job to another to improve utilization. Expert systems can accomplish this easily by providing recommendations, or even by controlling scheduling tasks directly.

Expert Systems 2. Continuous Control Rating: 5

Combined with continuous monitoring, continuous control will allow us to change scheduling, or re-task equipment from one job to another to improve utilization

Expert Systems 4. Expert help available at all times Rating: 2

Expert systems can be used to advise on how to best employ the production equipment to get maximum use out of it.

Expert Systems 6. Planning and scheduling Rating: 5

Expert systems can be used to create work schedules that make maximum use of all available production equipment.

Expert Systems 10. Simulation Rating: 4

Expert system simulation can be used to determine where production equipment is not being used to its full potential, and can offer recommendations on how to improve the situation.

7. Minimize costs - Maximize utilization of production equipment - CAD/CAM

CAD/CAM 8. Production Planning Rating: 5

CAM's production planning capabilities can be used to find under used equipment, and re-work the production plan to take full advantage of all available resources.

CAD/CAM 9. Machine Tooling/Robotics Rating: 2

Robotics can increase the use of production equipment by allowing one multipurpose robot to function as several different machines as needed, thus allowing it to be fully used at all times, when a single purpose machine might not be used as efficiently.

7. Minimize costs - Maximize utilization of production equipment - CIM

CIM 6. Facilities Planning Rating: 1

Facilities planning can be used to maximize the utilization of production equipment by placing the equipment in the optimum location, so the flow of material to and from each work station does not cause bottlenecks anywhere in the production process.

CIM 7. Scheduling Rating: 4

Scheduling can increase the utilization of production equipment by ensuring that the products being produced make equal use of each work station, and that no work station is either over-used or sitting idle.

CIM 12. Integrated Architecture Rating: 2

Integrated architecture can improve the utilization of production equipment by allowing communication between departments when demanding products and usage of equipment.

8. Minimize costs - Increase efficiency of employees - Expert Systems

Expert Systems 3. Automate Repetitive Processes Rating: 4

Automating a repetitive process will allow employees to produce more in less time, and with more accuracy and quality. It is likely that this increase in efficiency will allow us to reduce the work load on the employees, which will reduce errors caused by fatigue and stress.

Expert Systems 4. Expert help available at all times Rating: 5

Will allow less experienced employees to maintain the production efficiency at a high level by allowing them to benefit from expert knowledge when more experienced employees are not available.

Expert Systems 5. Instruct and educate employees Rating: 5

Employees that have been properly educated will be able to work more efficiently and more effectively. By having an expert system available at all times, employees always have a source of information if they want to refresh their memory, or to find out something that they do not know.

8. Minimize costs - Increase efficiency of employees - CAD/CAM

CAD/CAM 1. Design Creation Rating: 4

Allows employees to perform more work with less effort. CAD allows employees to create complex designs and drawings in a short period of time, and reduces the time required to make changes and corrections. CAM allows a single employee to accurately control equipment that would otherwise require skilled operators. CAM also allows a procedure to be repeated many times with identical results, where a human operator may make small mistakes due to fatigue.

CAD/CAM 2. Design Analysis Rating: 4

Allows employees to perform more work with less effort. CAD allows the designers to see their design as a three dimensional model on the computer screen, from different perspectives, and will allow them to see potential problems such as interference between components before the design is finalized. Some CAD programs can even find interference problems automatically and bring them to the attention of the operator. CAD can also be linked directly to analysis software (i.e.

Finite Element Analysis programs), allowing the design to be analyzed without duplicating work when entering the design parameters into the analysis software.

CAD/CAM 3. Mathematical Modeling Rating: 2

Mathematical modeling can be used in two ways to increase the efficiency of employees. First it can automate the analysis of products and production processes, which can reduce the number of employees required, and second, it can perform analysis of the production process to redesign the production process to improve the efficiency of the workers on the shop floor.

CAD/CAM 4. Mechanical Modeling Rating: 1

Mechanical modeling can be used to improve the efficiency of the workers on the shop floor.

CAD/CAM 5. Creation of Engineering Drawings Rating: 5

Allows employees to perform more work with less effort. CAD allows employees to create complex designs and drawings in a short period of time, and reduces the time required to make changes and corrections.

CAD/CAM 9. Machine Tooling/Robotics Rating: 4

The efficiency of the employees can be increased through the use of robotics and CAM, by allowing one employee using advanced machinery to perform the work that was previously done by many people.

8. Minimize costs - Increase efficiency of employees - CIM

CIM 1. Product Design Rating: 3

Using CIM for product design allows the designers to rely on automation and computer power to perform the mundane and repetitive processes, and frees the designers to concentrate on the aspects of design that cannot be satisfactorily performed by computers.

CIM 2. Analysis and Simulation Rating: 1

Simulation and analysis of the production process can result in methods for reducing the effort required by the employees to perform the same amount of work.

CIM 3. Documentation Rating: 2

Employees should always have proper documentation on hand so they do not have to go searching for information.

CIM 9. Shop Floor Control Rating: 4

Using shop floor control can ensure that employees are being used as efficiently as possible to maximize production and minimize costs.

CIM 10. Robotics and Automation Rating: 4

Robotics and automation can allow employees to perform more work with the same effort.

CIM 11. Shared Data Rating: 4

Shared data allows employees to reduce repetitive work (entering the same data more than once) by sharing the same databases. When data is entered into the company database by one department, it is immediately available to all other departments.

CIM 12. Integrated Architecture Rating: 3

Allows employees to move from one part of the company's information system to another with the shortest possible learning time.

9. Minimize costs - Reduce maintenance downtime - Expert Systems

Expert Systems 1. Continuous Monitoring Rating: 5

Continuous monitoring of equipment can be used to determine when a machine will need service, and the time of the next service can be scheduled in advance based on statistics such as the rate of rejected parts produced by that machine and whether tolerances of parts are changing with wear on the machine. Giving advance notice of required service will allow the machine to be out of service for a minimum amount of time, rather than having the machine fail unexpectedly. Scheduling service based on actual performance is more efficient than scheduling service far in advance based on average maintenance data, because if a machine is performing poorly, the service can be moved up, or if the machine is performing better than expected and does not need service, then we may be able to move the service back and not service the machine unnecessarily.

Expert Systems 4. Expert help available at all times Rating: 3

Expert systems can reduce maintenance downtime by providing advice on what needs to be done and in what order so that the maintenance work can proceed as quickly and efficiently as possible.

Expert Systems 6. Planning and scheduling Rating: 4

Expert systems can reduce maintenance downtime by improving and automating the planning and scheduling of the maintenance work so as to minimize the disruption to the production process.

Expert Systems 7. Problem diagnosis Rating: 3

If the problems can be diagnosed more quickly, then the maintenance can begin sooner and be tailored to the problem.

Expert Systems 9. Prediction Rating: 2

Expert systems can reduce maintenance downtime by predicting when maintenance is needed so that preparations and scheduling to be made in advance.

Expert Systems 10. Simulation Rating: 2

Using expert systems to simulate the production process can provide insight into the maintenance patterns required for the production machinery.

9. Minimize costs - Reduce maintenance downtime - CAD/CAM

CAD/CAM 8. Production Planning Rating: 3

Planning of the production process can be used to provide alternate processes that will circumvent production machinery shut down for maintenance. This could involve re-routing production to alternate machines or using the functioning machines to produce products that do not require the machine that is out of service.

9. Minimize costs - Reduce maintenance downtime - CIM

CIM 7. Scheduling Rating: 3

CIM can reduce the effects of maintenance downtime by finding the most effective way to use the resources that are not down for maintenance.

CIM 9. Shop Floor Control Rating: 3

Shop floor control can be used to reduce maintenance downtime by continuously monitoring the performance of each machine and using this information to predict when maintenance is needed. Preparations can then be made in advance to have all the parts and materials available for the maintenance work, as well as scheduling the production around the machinery that is down for maintenance (either by shifting the production to other machines, or by changing the product being made so it makes less use of the machine being serviced).

10. Increase revenue - Maximize production capacity - Expert Systems

Expert Systems 1. Continuous Monitoring Rating: 5

Allows the company to continuously adjust their production schedules to fit changing conditions (i.e. machines out of service, unexpected line stoppages, other unanticipated problems).

Expert Systems 2. Continuous Control Rating: 5

Allows the company to continuously adjust their production schedules to fit changing conditions, based on information from the continuous monitoring.

Expert Systems 4. Expert help available at all times Rating: 3

An expert system can provide advice on how to employ production assets to maximize the output of production.

Expert Systems 10. Simulation Rating: 4

Simulation can be used to find ways of increasing production within the limits of existing equipment.

10. Increase revenue - Maximize production capacity - CAD/CAM

CAD/CAM 8. Production Planning Rating: 3

Allows the production process to be planned so that capacity is maximized.

CAD/CAM 9. Machine Tooling/Robotics Rating: 5

CAM can increase the production capacity of a plant by allowing the same number of people to accomplish more work through the use of automated machinery and robotics.

10. Increase revenue - Maximize production capacity - CIM

CIM 4. Process Design Rating: 4

Improving the production process will allow production to be increased by reducing the amount of work required (or the number of steps in the process) and by reducing repetitive or redundant work.

CIM 6. Facilities Planning Rating: 3

A properly designed facility promotes smooth production flow with less material handling, to allow more effort to be put into more productive activities.

CIM 7. Scheduling Rating: 5

Allows production flow to be scheduled so there are fewer bottlenecks, and no equipment is left sitting idle while waiting for work to do.

CIM 9. Shop Floor Control Rating: 4

Allows production flow to be monitored and optimized in real time to maximize the production output.

CIM 10. Robotics and Automation Rating: 5

Allows fewer workers to do more work. Also allows production to continue around the clock with less overtime to be paid because automated machinery does not need to rest.

11. Increase revenue - Improve marketing and increase sales - Expert Systems

Expert Systems 9. Prediction Rating: 2

Expert systems can be used to predict marketing trends, and allow the company to take advantage of these trends. Prediction can also be used to anticipate changing demand for a product and prepare in advance to take full advantage of these changes.

11. Increase revenue - Improve marketing and increase sales - CIM

CIM 5. Quality Control Rating: 3

Improved quality control will result in less consumer complaints and more customer satisfaction.

12. Speed up processes - Minimize production time - Expert Systems

Expert Systems 3. Automate Repetitive Processes Rating: 4

By automating repetitive processes on the shop floor, we can reduce the total production time (from raw materials to finished product).

Expert Systems 6. Planning and scheduling Rating: 4

Production time can be minimized through planning and scheduling by ensuring that machinery is not left idle waiting for work, that parts and raw materials are where they are needed when they are needed, and that work is synchronized to realize smooth production flows.

Expert Systems 10. Simulation Rating: 3

Production time can be minimized by simulating the production process to find anything that is slowing the production process and resolving those problems.

12. Speed up processes - Minimize production time - CAD/CAM

CAD/CAM 8. Production Planning Rating: 5

Production planning can be used to minimize the production time by mixing products being produced so that they minimize the usage on machines that are known to be bottlenecks, and increase the usage on machines that have high idle times.

CAD/CAM 9. Machine Tooling/Robotics Rating: 4

Robotics can be used to speed up the production process where there is a bottleneck by allowing faster processing of product in the critical area.

12. Speed up processes - Minimize production time - CIM

CIM 4. Process Design Rating: 5

Improving process design can help to locate areas where the production time can be shortened.

CIM 9. Shop Floor Control Rating: 4

Shop floor control can be used to reduce idle time on machinery, and to avoid or reduce the effect of bottlenecks in the production flow.

CIM 10. Robotics and Automation Rating: 4

Robotics and automation can be used to increase throughput at critical bottlenecks.

13. Speed up processes - Reduce design cycle time - Expert Systems

Expert Systems 3. Automate Repetitive Processes Rating: 4

Because the design process is by nature repetitive, with standardized procedures and calculations, we can reduce the amount of time required to produce a new design if we automate the processes and calculations that are most repetitive.

Expert Systems 4. Expert help available at all times Rating: 5

By having the knowledge gathered from previous product design work coded into a knowledge base, many of the small problems that occur in the design process can be eliminated or dealt with automatically by having the expert system review the design work being done, notifying the designers of potential problems, and suggesting possible solutions to the problems.

Expert Systems 8. Design assistance Rating: 4

Expert systems can assist designers by automatically doing the basic and repetitive work.

13. Speed up processes - Reduce design cycle time - CAD/CAM

CAD/CAM 1. Design Creation Rating: 5

CAD allows the designers to create products, that can the products to be seen, inspected, and manipulated inside the computer before they are produced. In this way the design can be improved and problems worked out before the first prototype is built.

CAD/CAM 2. Design Analysis Rating: 5

Automating the analysis of new designs can reduce the design cycle time by having computers do most of the basic set up work in advance.

CAD/CAM 3. Mathematical Modeling Rating: 5

Many CAD programs have built-in mathematical modeling capabilities, or can output the computer models of the product to computer analysis programs, that can mathematically model the product.

CAD/CAM 4. Mechanical Modeling Rating: 4

Mechanical modeling can reduce design cycle time by providing feedback on the design, isolate possible problems, and suggest possible product improvements.

CAD/CAM 5. Creation of Engineering Drawings Rating: 5

Creation of engineering drawings is what CAD does best. Once the design has been entered into the computer, CAD allows drawings to be made and updated in minutes instead of days.

13. Speed up processes - Reduce design cycle time - CIM

CIM 1. Product Design Rating: 5

CIM provides tools to perform many of the steps in the design process that are common to all designs, thus reducing the design time by performing the basic work automatically and allowing the designers to concentrate on more important issues.

CIM 2. Analysis and Simulation Rating: 4

Automating the simulation and analysis of a new product design can reduce the amount of time required to develop the design.

CIM 3. Documentation Rating: 3

Automating the process of documenting a new design can reduce the time required to produce the design by reducing the time spent on the documentation, and also by having the documentation available earlier in the design process for the designers for reference purposes.

CIM 11. Shared Data Rating: 4

Sharing data between departments allows for faster access to critical information, so that processes such as the design process can proceed more rapidly.

CIM 12. Integrated Architecture Rating: 3

Using integrated architecture can reduce the design cycle time by facilitating communication between departments to reduce development time requirements. As well, good communications can result in potential problems being identified and dealt with earlier in the process, reducing the need for redesigning later in the process.

14. Speed up processes - Consistent on-time delivery - Expert Systems

Expert Systems 6. Planning and scheduling Rating: 3

Using expert systems for planning and scheduling allows the company to achieve their production goals more easily, as well as on time shipping and delivery to customers.

14. Speed up processes - Consistent on-time delivery - CAD/CAM

CAD/CAM 8. Production Planning Rating: 3

Production planning with CAD/CAM can ensure that products are delivered on time by ensuring that the products that are needed are produced in the quantities required and at the times required.

14. Speed up processes - Consistent on-time delivery - CIM

CIM 7. Scheduling Rating: 3

Using the scheduling capabilities of CIM can ensure that products are produced and shipped on time.

CIM 9. Shop Floor Control Rating: 2

Having continuous monitoring of the shop floor allows problems to be identified and corrected before they cause delays in the production process. This allows the production to stay on schedule, which in turn will allow the product to be delivered to the customer on schedule.

CIM 12. Integrated Architecture Rating: 2

Having consistent information systems throughout the company allows information on delivery dates and critical dates in the manufacturing process to be distributed to all departments, so that every department knows what has to be done, and the completion date of the activity.

15. Speed up processes - Shortest possible delivery dates - Expert Systems

Expert Systems 6. Planning and scheduling Rating: 3

Using expert systems for planning and scheduling can identify ways of reducing the time between receiving and shipping the order.

Expert Systems 10. Simulation Rating: 2

Expert systems simulation capabilities can be used to determine what the critical path is for delivery of the product, and how the time line can be reduced.

15. Speed up processes - Shortest possible delivery dates - CAD/CAM

CAD/CAM 1. Design Creation Rating: 1

Being able to use CAD to rapidly change the design of products allows the manufacturer to take contracts for products with modified specifications, and deliver them in a time period not much longer than for standard products.

CAD/CAM 2. Design Analysis Rating: 1

Being able to use CAD to rapidly change the design of products allows the manufacturer to take contracts for products with modified specifications, and deliver them in a time period not much longer than for standard products.

CAD/CAM 3. Mathematical Modeling Rating: 2

Mathematical modeling of products and manufacturing processes can improve quality and reduce defective parts by improving the design to take into account the limitations of the manufacturing processes, and by ensuring that the product does not have any defects that would require parts to be recalled.

CAD/CAM 4. Mechanical Modeling Rating: 1

Mechanical modeling can be used to speed up processes by modeling the production process and looking for possible improvements.

CAD/CAM 8. Production Planning Rating: 4

Production planning can shorten the time period between order and delivery by reducing the time between production processes, and ensuring that there are no delays waiting for parts or components needed to continue with the next stage of production.

15. Speed up processes - Shortest possible delivery dates - CIM

CIM 7. Scheduling Rating: 5

Improved scheduling ensures that at every stage of the production process all required elements (raw materials and components, production facilities, and materials handling and storage capacity) are available. This ensures that the production process is never held up waiting for materials or machinery finishing another task.

CIM 9. Shop Floor Control Rating: 4

Continuous shop floor monitoring and control ensures that a problem can be dealt with quickly, and any unused production capability can be assigned a task to keep its utilization rate high.

CIM 12. Integrated Architecture Rating: 3

Integrated architecture allows all departments to know what is going on, so that they can prepare in advance for upcoming events such as the release of a new product, or the delivery date of a large order.

16. Speed up processes - Increase production flexibility - Expert Systems

Expert Systems 6. Planning and scheduling Rating: 4

Because expert systems can work with incomplete or inaccurate information, possible changes to the production process can be considered in advance so that the changes do not disrupt the production process, and changes can be made rapidly because the planning and scheduling process is automated and can be revised quickly.

Expert Systems 10. Simulation Rating: 3

Simulations can analyze the production process in advance, to accommodate changes in product demand while maintaining efficient production, by guiding the reorganization process.

16. Speed up processes - Increase production flexibility - CAD/CAM

CAD/CAM 8. Production Planning Rating: 4

Automated production planning can allow the entire production plan to be revised quickly if a change is required. Low priority production can be tasked to multipurpose machinery so that if a higher priority job comes along, the machinery will be available no matter what the job is. The high priority products that are unlikely to be canceled or rescheduled can use the machinery that is more difficult to reassign.

CAD/CAM 9. Machine Tooling/Robotics Rating: 5

Using multipurpose machinery and robotics allows this equipment be re-assigned to different tasks when changing demand for products alter equipment utilization factors.

16. Speed up processes - Increase production flexibility - CIM

CIM 4. Process Design Rating: 4

The design of the production process can accommodate flexibility in production.

CIM 6. Facilities Planning Rating: 4

Designing the production facility to accommodate a flexible production process.

CIM 7. Scheduling Rating: 4

Improved scheduling supports production flexibility because the demand for materials and the rescheduling of tasks can be transmitted quickly.

CIM 8. Materials Handling Rating: 3

Improved materials handling allows parts to be delivered to the workstation at the right time and on short notice.

CIM 9. Shop Floor Control Rating: 4

Improved shop floor control allows production to be re-routed around problem areas and production assets to be assigned or reassigned in the most efficient manner.

CIM 10. Robotics and Automation Rating: 5

Using robotics and automated machinery that can perform many tasks allows the equipment to be re-assigned to different tasks as a result of changing product demand.

CIM 12. Integrated Architecture Rating: 2

Production flexibility can be increased with integrated architecture because it allows easier and faster information flow between departments, reducing the amount of time spent waiting for data, information or decisions.

17. Speed up processes - Improved scheduling - Expert Systems

Expert Systems 4. Expert help available at all times Rating: 3

Having expert help available at all times means that the accumulated knowledge of many previous employees can be drawn upon to create scheduling that is much better than what can be accomplished by one person, or even a small group of people.

Expert Systems 6. Planning and scheduling Rating: 4

Expert systems can improve planning and scheduling by focusing the accumulated knowledge onto the planning and scheduling process and by being able to use heuristic reasoning to determine the best schedule.

Expert Systems 10. Simulation Rating: 1

Using the simulation capabilities of expert systems allows many different schedules to be simulated and analyzed before selecting the best one.

17. Speed up processes - Improved scheduling - CAD/CAM

CAD/CAM 8. Production Planning Rating: 2

Automating the scheduling process will allow it to be more consistent.

17. Speed up processes - Improved scheduling - CIM

CIM 7. Scheduling Rating: 5

CIM's scheduling capabilities can be used to ensure that all production processes are optimized by ensuring that machines are used to full capacity but not beyond, and ensuring that materials are delivered on time.

CIM 9. Shop Floor Control Rating: 2

Shop floor control can improve scheduling by providing real-time feedback to the scheduling process and allowing changes and improvements to be made in real time.

CIM 11. Shared Data Rating: 3

Sharing data between all departments provides the information needed for accurate scheduling in a timely fashion.

CIM 12. Integrated Architecture Rating: 3

Scheduling can be improved by improving the communication between departments.

18. Customer Relations - Maximize reliability - Expert Systems

Expert Systems 7. Problem diagnosis Rating: 4

Using an expert system's heuristic reasoning permits rapid and accurate analysis of a vast amount of accumulated knowledge to identify problems and suggest solutions.

Expert Systems 9. Prediction Rating: 3

Because expert systems can access large amounts of stored knowledge, they can be used to predict the reliability of a product and suggest how it can be improved.

Expert Systems 10. Simulation Rating: 2

Simulation can be used to improve reliability by finding and addressing product shortcomings.

18. Customer Relations - Maximize reliability - CAD/CAM

CAD/CAM 2. Design Analysis Rating: 5

CAD can be used to analyze designs and determine changes that can be made to improve the reliability of the finished product.

18. Customer Relations - Maximize reliability - CIM

CIM 2. Analysis and Simulation Rating: 5

Using CIM's analysis and simulation capabilities, products can be studied in detail, and any possible reliability problems can be addressed before production begins.

CIM 5. Quality Control Rating: 5

Improved quality control will improve reliability because fewer defects will ultimately be delivered to the customer.

19. Customer Relations - Maximize availability of resources to production - Expert Systems

Expert Systems 4. Expert help available at all times Rating: 2

Having an expert system program will help improve resource allocation by basing decisions on all previous experience.

Expert Systems 6. Planning and scheduling Rating: 5

Planning and scheduling will improve resource availability by reducing wasted resources (wasted time on production machinery).

19. Customer Relations - Maximize availability of resources to production - CAD/CAM

CAD/CAM 8. Production Planning Rating: 4

Proper planning of the production process will reduce wasted resources by ensuring that all production equipment is used to its full capacity.

19. Customer Relations - Maximize availability of resources to production - CIM

CIM 8. Materials Handling Rating: 5

Advanced materials handling systems can ensure that materials arrive where they are needed when they are needed and that finished products are taken away quickly as well.

CIM 12. Integrated Architecture Rating: 3

An integrated architecture facilitates rapid communication between departments. Potential delays because of parts or materials not arriving on time are reduced, allowing an order to be placed in a shorter period of time.

20. Customer Relations - Maximize availability of product to customers - Expert Systems

Expert Systems 6. Planning and scheduling Rating: 5

Expert systems can be used to schedule and plan production so that the maximum amount of product is delivered to the customers.

20. Customer Relations - Maximize availability of product to customers - CAD/CAM

CAD/CAM 8. Production Planning Rating: 4

CAD/CAM's production planning capabilities can be used to ensure production of the desired product mix.

20. Customer Relations - Maximize availability of product to customers - CIM

CIM 8. Materials Handling Rating: 1

Efficient material handling improves the efficiency of the production process, by reducing idle time and minimizing nonproductive material handling activities.

CIM 12. Integrated Architecture Rating: 4

An integrated architecture allows information to be distributed to all departments. The sales department will know exactly how many units are being produced, and if any orders are canceled so that the stock can be reallocated.

21. Customer Relations - Maximize quality - Expert Systems

Expert Systems 7. Problem diagnosis Rating: 3

Quality improvements can be realized when problems are accurately diagnosed and addressed. Because of their capability to deal with more variables and possible problems than a single human operator, expert systems can be used for this purpose and to diagnose problems that might otherwise go undetected.

Expert Systems 8. Design assistance Rating: 4

Having an expert system assist in the design process can improve product quality, by eliminating errors from the design process, and allowing more factors to be considered to identify and resolve potential problems.

Expert Systems 9. Prediction Rating: 3

Problem prediction allows solutions to be developed before product quality is affected.

Expert Systems 10. Simulation Rating: 2

Expert systems used for simulation will allow new designs to be checked and tested thoroughly before production begins. Potential problems can be corrected by design changes before the product reaches full production, resulting in fewer defects and problems after the customer receives the product.

21. Customer Relations - Maximize quality - CAD/CAM

CAD/CAM 2. Design Analysis Rating: 4

CAD programs can bring to the attention of the designer before production begins. CAM can be used to analyze the manufacturing process and changes to the operations can be tested in simulation before production. This capability can be used to reduce the number of production steps and to determine the best sequence of steps to minimize or prevent quality related problems.

CAD/CAM 3. Mathematical Modeling Rating: 4

Mathematical modeling can be used to improve quality by improving the design of the product before it reaches production.

CAD/CAM 4. Mechanical Modeling Rating: 2

Mechanical modeling can be used to find problems that may not be apparent in computer simulations.

CAD/CAM 5. Creation of Engineering Drawings Rating: 3

By improving the quality of engineering drawings, the product can be made better, because of fewer mistakes due to improper reading of the specifications.

CAD/CAM 9. Machine Tooling/Robotics Rating: 5

The use of robotics will improve quality by allowing parts to be produced with consistently narrow tolerances.

21. Customer Relations - Maximize quality - CIM

CIM 1. Product Design Rating: 4

Improvements in the product design processes will improve quality, because they will prevent problems from being built into the product in the first place.

CIM 2. Analysis and Simulation Rating: 3

Analysis and simulation can be used to improve quality by finding problems before the product reaches the production stage.

CIM 5. Quality Control Rating: 5

Improved quality control processes will improve quality by preventing defective parts from leaving the factory and by locating and correcting problems early.

CIM 9. Shop Floor Control Rating: 4

Shop floor monitoring and control can detect problems with the manufacturing process before tolerances on parts get outside the acceptable range, and steps can be taken to remedy the situation.

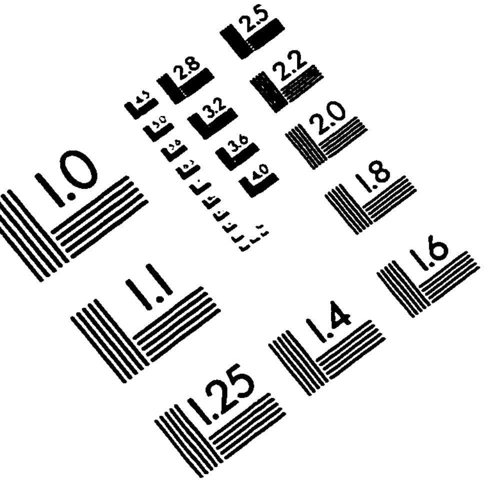
CIM 10. Robotics and Automation Rating: 5

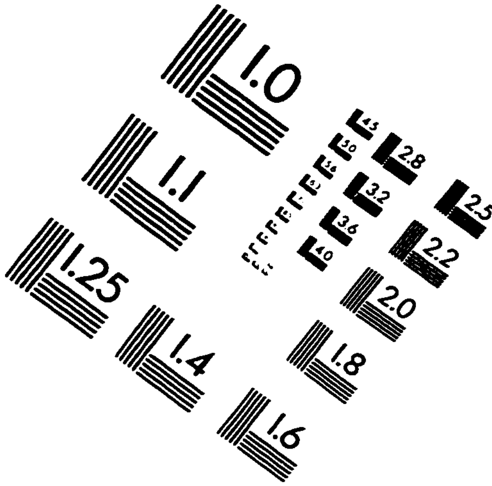
Robotics and automation allows products to be produced to consistently close tolerances.

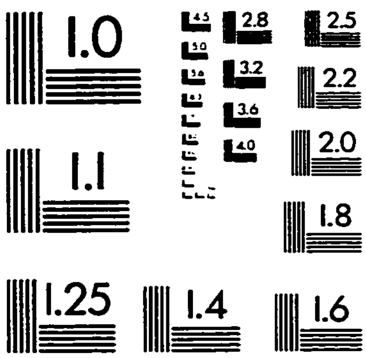
CIM 12. Integrated Architecture Rating: 3

Integrated architecture allows information from all departments to be quickly distributed, so if there are customer complaints about a product, the information can be transmitted to the production or engineering departments and the problem quickly resolved.

IMAGE EVALUATION TEST TARGET (QA-3)

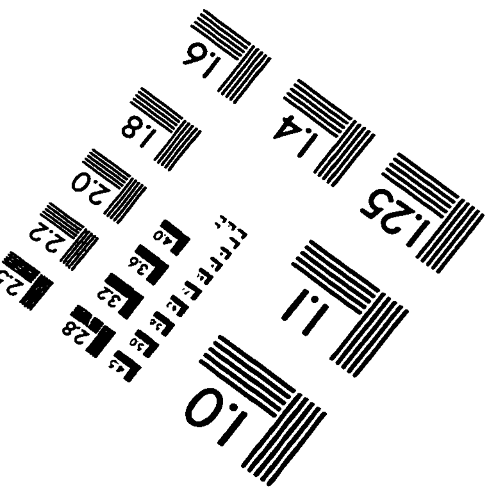


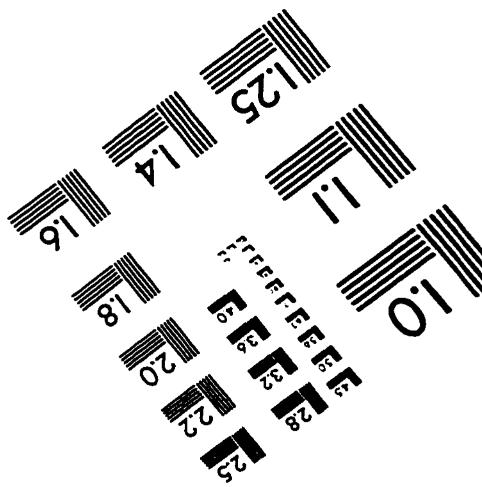




150mm

6"





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