8-2012

A Case Study for Financial Feasibility of Automated Costing Support in A Small Machine Shop

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A CASE STUDY FOR FINANCIAL FEASIBILITY

OF AUTOMATED COSTING SUPPORT IN

A SMALL MACHINE SHOP

A Thesis

by

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Submitted to the Graduate School of the
University of Texas-Pan American
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2012

Major Subject: Manufacturing Engineering

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August 2012

ABSTRACT

Gonzalez, Benito A., A Case Study for Financial Feasibility of Automated Costing Support in a Small Machine Shop. Master of Science (MS), August, 2012, pp. 78, 7 tables, 18 figures, references, 104 titles.

A knowledge-based cost estimating expert system is chosen by a Mexican machine shop. Differences between the traditional experience-based system employed and the automated system are studied. Data is gathered to analyze time effectiveness, accuracy and payback of the software. Data from seventy part models is recorded to study the time experiment, and data from fifty part models is used to study the accuracy and consistency. Data is analyzed by calculating mean, standard deviation, and test of hypothesis.

The results indicate that the software is faster than the traditional quoting system; however, the payback point is high. Also, results show the software has a smaller average time-to-manufacture percentage difference between the automated system and the actual time-to-manufacture (TTM) compared to the percentage difference between the traditional's TTM and actual TTMs, and this difference is statistically significant. The standard deviation for the automated system is also less implying better consistency.

DEDICATION

The completion of this master's thesis would not have been possible without the support of my friends and family. I want to show my appreciation to my father, Benito Gonzalez, my mother, Rosa Gonzalez and my sister, Anais Gonzalez. Also thank my girlfriend, Cynthia Garcia, and my friends from church for their continuing support and prayers.

ACKNOWLEDGMENTS

I would like to present my most sincere gratitude to Dr. Alley Butler, chair of my thesis committee and academic advisor, for his counsel, patience and advice. He helped me one step at time; he was present in all of the transactions involved in writing this thesis. From database searching and grammar editing to providing encouragement and showing patience.

My thanks go out also to Brian Glauser, VP Business Development in Galorath Incorporated for donating the software needed for the completion of this thesis. I also appreciate the work of Joe Falque who provided the training.

I want to mention that this thesis could have not been completed without the effort of the employees from MAQYPROYIND. I give my most sincere gratitude to Manuel Gamboa and Juan Antonio Sifuentes.

I would also like to the staff at the UTPA library that helped me locate supporting documents for my research.

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CHAPTER I

INTRODUCTION

1.1 The Tool of Cost Estimation

In today's competitive economy, manufacturing companies have to be careful not to put money and resources in an investment that cannot yield an appropriate return. And, one must realize that cost analysis is a tool to determine if an investment is a good or a bad business; therefore, most manufacturing companies are careful as they face a number of decisions that can directly or indirectly affect the cost of good sold (COGS). Whether the manufacturing company is a large company or a small company, cost analysis is important. Some of the direct decisions that managers make involve material selection, manufacturing process selection, man hours required, and machine hours required. Some of the indirect decisions involve maintenance, turn-over, quality, and administration. At the end, a bad business deal occurs when the costs to provide a given product or service are underestimated, and thus a loss of capital and investment is inflicted on the company. Alternately, when the costs are overestimated the company is not able to compete in the market. Good business occurs when the investment of resources to provide a service or goods (cost) produces a return with an increase, cost + profit = price, yet the price of the service or product is competitive in the market. Therefore, cost estimation is a crucial to the success of a company's financial well being.

1.2 The Tool of Make-or-buy Decision

Another tool, besides cost estimation, that influences cost analysis is the make-or-buy decision. The make-or-buy decision is an important technique that manufacturing companies use to regulate cost. They must decide whether to manufacture some of their models and sub-assemblies parts on site, or to outsource them to a specialized independent machine shop. Many times the best choice is to outsource the model parts. These parts are sent to manufacture at specialized machine shops. It is well known that Machine shops are small manufacturing companies that specialize in producing custom parts using machining technology. They are usually categorized as make-to-order companies because of their nature of operation. Machine shops usually manufacture parts that are new to them, and seldom do they manufacture parts that recur with any frequency. This leads to accounting and cost estimation difficulties.

1.3 Case Study Introduction

This case study deals with cost estimation in machine shops and small manufacturing companies. The place where experiment takes place and the data is collected is a machine shop located at Matamoros, Mexico named “Maquinados y Proyectos Industriales” (MAQYPROYIND) which in English stands for Machining and Industrial Projects. MAQYPROYIND is a machine shop that has been in the machining business since 1999, and ever since has been serving the manufacturing industry along the border of Mexico and the U.S..

1.3.1 Resources and Facility

Currently, the shop employs eight administrative and technical workers. The administrative personnel have an engineering degree and the technicians are all certified machinists in Mexico. The facility has a capacity of 5,143 square feet on the first floor and 1,500 square feet on the second floor. The shop specializes in traditional machining and automatic

(CNC) machining, and has the capacity for fabrication, repair and/or assembly of mold plates, fixtures, shafts, housings, gears, also has the capacity to design and manufacture special tooling if the job necessitates it. The shop has the following machine resources: four traditional lathes and one CNC lathe, four traditional turning machines and one CNC, two EDM wire machines, two traditional grinders and one semi-automatic grinder, one industrial oven, two band saws and other related machine shop equipment. Figure 1.1 and Figure 1.2 show some of these machines.

Figure 1.1: Traditional Mills (left) and CNC Mill (right).

Figure 1.2: Traditional Lathe.

1.3.2 Manufacturing Processes

MAQYPROYIND uses a variety of manufacturing processes. Some of the manufacturing process techniques that they utilize are: turning and milling machining, grinding, plastics thermoforming, Electric Discharge Machining (EDM), and die cutting. Also, there are some processes that are used regularly, while others are used only for special parts. Electric Discharge Machining is usually only used for projects with special features, such as the machining a 0.020” slot in some bar; and thermoforming is also used only based upon a special requirement.

Many times the shop deals with jobs that have no standardization of measurement or process, and thus special tools have to be manufactured to complete the job. Special tools are also manufactured and applied in the manufacturing processes utilized in the shop when the part to be manufacture has a high volume or is frequently ordered. These tools are manufacture to increase the efficiency of feature machining.

Figure 1.3 serves as an example of a special process where a tool is constructed for process optimization. It can be seen in the figure how a precisely-cut piece of aluminum is placed on a pre-drilled casing to facilitate drilling of holes on the piece. Prior to placing the raw stock on the casing, the aluminum part is previously machined to its surface dimensions, and then the part is placed on a pre-drilled casing. After this, the casing is turned around to the side that has pre-drilled holes and holes are drilled into the aluminum part.

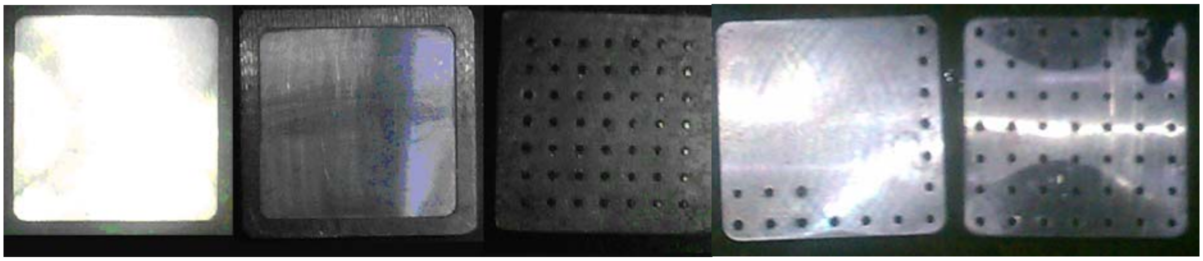


Figure 1.3: Example of Special Tool and Drilled Parts.

1.3.3 Industrial Projects

MAQYPROYIND has experience in industrial projects. These industrial projects involve assisting manufacturing companies towards better functioning. Some of the projects that the shop has participated in relate to the construction of semi-automatic machines. Examples of some of the semi-automatic machines that the shop has constructed are a conveyor belt that detects the flow of material, a pneumatic press with thermal resistances controlled with PLC's used to seal plastic tubes, and a thickness-measurement device used to inspect and measure the thickness across of a metal sheet and determine if the sheet is within the acceptable parameters of deformity. Most of the time, projects are manufactured on site; however, there are times when the client asks to send technicians to fix and/or modify parts for their machines at their location.

1.3.4 Cost Estimation

The cost estimation of the shop is determined by two administrative employees. The process that they undergo is: (1) the study of the part's drawing, which is usually provided by the client in a CAD model; (2) get quote of raw material price for part. This process is usually done by calling the material suppliers and getting the best deal; (3) determine the amount of hours for part to be manufactured, this data is based on machining experience; (4) calculate the parts overhead, which is obtained by multiplying the machining hours by a calculated factor; and finally (5) add all the calculated costs, determine a marketable price, and send the quotation to the client via e-mail.

One of the problems that small machine shops face is to provide a quick and accurate cost estimation of the jobs that they are in bidding. If the quotes under-estimate the bid and a company issues a purchase order to the quote, there can be financial loss, and not just for this quote but for future quotes that the company may do using the same price. On the other hand, if there is an over-estimate with the bid, there is no contract upon which revenue is based and a loss of other possible job offers is at risk. The determination of the indirect cost is also a key to cost estimation. Another problem of machine shops is that very often the projects that are being bid are new projects; therefore, there is no historical data on planning processes to facilitate the estimation process. The cost estimate totally depends on the experience of the estimators. Today with the accessibility of computer technology, manufacturing companies can be benefited in the area of cost estimation utilizing Computer Aided Process Planning (CAPP) systems, a system that uses methods such as the parametric modeling and can estimate the cost of a part model with or without prior knowledge of the model. The automated cost system used in this study is commercially available, and it is named SEER-MFG by Galorath Incorporated.

1.4 Focus of This Work

This study focuses on a financial feasibility for automated costing in a small machine shop. First, comparisons are made between automated costing and traditional costing. The goal is to determine a financial payback point. Secondly, the accuracy and consistency of the costing automated methods are compared with the traditional costing methods.

This thesis presents a case study of a machine shop's cost estimation process. The process consists of extracting data about the current method of cost estimation used in a machine shop and comparing it to the data of a developed cost estimation model. Essentially, an automated cost estimation system requires time and effort to gather the cost data, place the cost data into the automated system, and validate the results. While a system once completed may save time and effort, the question answered by this study is whether the effort to commission an automated system is worth the cost for a small business. Stated differently, what is the payback point for the use of an automated costing system in a small manufacturing business? On the other hand, it is considered that once an estimating system is constructed, the estimations determined by the system may be more accurate than the ones done by traditional estimation; therefore, what is the accuracy of the software compared to the actual manufacturing information and then what is the relationship between the software estimation and the shop's estimation?

1.5 Synopsis

This section presents a summary of the content provided in the next chapters as a guide and describes the way that this thesis is developed. First, a literature survey is presented in the next chapter as a foundation to the topic of computer systems, its programming approaches and its applications to manufacturing engineering. Then in the next chapter, the process of software training and a description of the software employed in this thesis are reported and explained. Then, the following chapter presents the technical aspect for gathering the data for the methods evaluated in this thesis. The next chapter reports the results from the data analysis. And finally, conclusions are drawn with recommendations for future work.

CHAPTER II

LITERATURE SURVEY

Computer Aided Systems have been increasingly capable of problem solving for many decades, and for this reason there is a wide variety of research available. This chapter provides a survey of computer expert systems research, and the survey covers benefits, programming approaches such as knowledge-based and object-oriented, and applications to engineering.

2.1 Cost Estimation Modeling Using Expert Systems

Automatic cost estimation modeling requires the implementation of a Computer Aided Process Planning (CAPP) system, and CAPP can be developed using expert systems technology. The following section covers an explanation of expert systems and a survey of different types of systems that affect cost estimation directly or indirectly, many through the automation of process planning.

Expert systems are very beneficial in problem-solution finding and standardization of a solution process. According to Cakir and Cavdar (2006), “A very strong benefit of expert systems is being able to distribute the knowledge of a single human expert or being able to accumulate the knowledge of several widely separate experts in one place.” In other words, the knowledge and experience of different experts on a given topic can be organized in a set of programming rules contained in one single computerized expert as shown in Figure 2.1. The combination of such knowledge also allows for the standardization of the problem’s solution which is another benefit of expert systems.

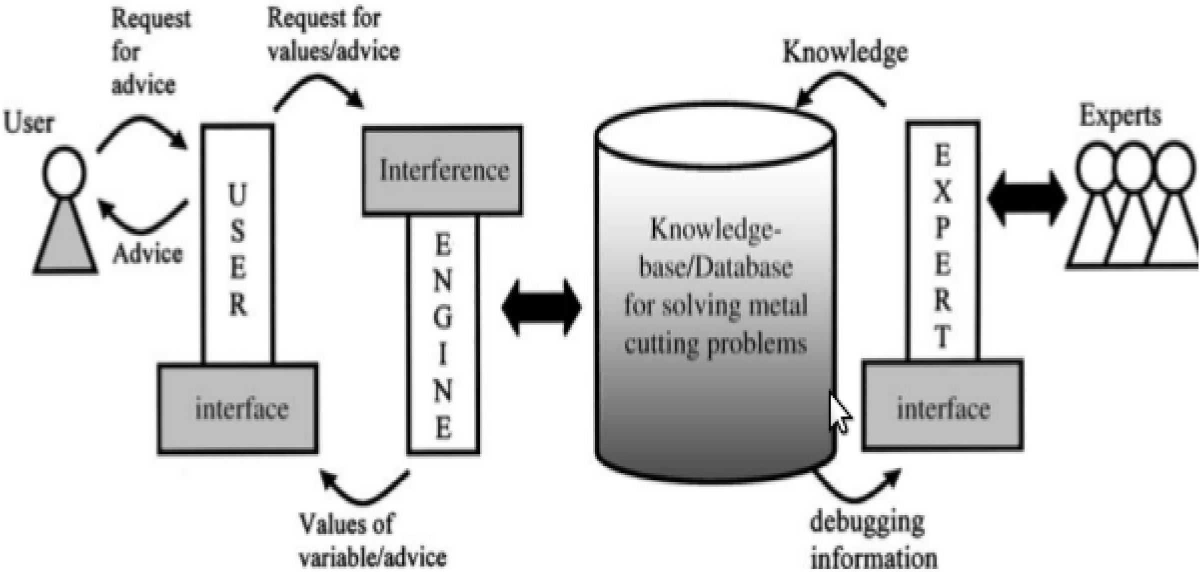


Figure 2.1: The Knowledge-based Expert System (Cakir and Cavdar 2006).

Currently, expert systems are used for a number of diverse topic areas; however, the principal methods of development and operation are the same regardless of the topic of information. Shukor and Axinte (2009) surveyed the basic methodology involved in expert systems in the area of product manufacturability. They explained the basic methodology to develop an expert system.

The first stage of an expert system is an input sub-system. For product manufacturability systems, a CAD modeler is generally used to extract data from the products CAD model. STEP, IGES and STL are common languages for data transferring. The input sub-system should also include user-system interaction as shown also in Figure 2.1.

The second stage is an analyzing data-acquisition sub-system. Artificial Intelligence techniques (AI) are used to develop this module. AI development tools include: an expert system shell, a tool-kit (ex: KEE, ART, Pro-Kappa), a programming language (ex: LISP), and a conventional programming language (ex: C, FORTRAN). The combination of these tools allows the development of a parametric knowledge-base that contains production rules that pertain to manufacturing process technology. This parametric method of data analysis has advantages and disadvantages. According to Duverlie and Castelain:

> The parametric method has the advantage of being made easily available within an enterprise. It brings out general tendencies that can be indicated to the designer. Its major disadvantage is its functioning as a "black box" that does not allow the users to verify or to ensure that they are not looking at a particular case" (Duverlie and Castelain 1999).

The last stage is the output sub-system. Re-design suggestions, process sequencing and selection of suitable manufacturing processes and materials are reported by this module (Shukor and Axinte 2009). It is important to mention that the intermediate between the user and the database is the expert system shell, which is the combination of the user interface module and the interference engine. The shell communicates back and forth inputting requests from the user to the interference engine to the knowledge base and outputting information from the knowledge base to the engine to the user. Figure 2.1 shows a schematic of an expert system process which was modeled to solve cutting metal problems.

2.2 Approaches in Expert Systems

Expert systems can be classified into different approaches: knowledge-based, which is composed on production rules, case-based, which is composed on similarity comparisons, multi-agent based, which is characterized for finding common ground using different agent systems at the same time, and object-oriented based, which is based on object data extraction. Usually expert systems approaches are combined to optimize the solution to the problem or to handle uncertainty.

2.2.1 The Knowledge-Based Approach

The knowledge-based approach is sometimes characterized by the rule-based method. The rule-based method involves the programming of rules into code that represent the knowledge of the experts. The rules are created using IF and THEN statements as well as AND/OR and other conditional language. The knowledge based method is used to develop the generative approach in CAPP system and other problem solving models.

The remainder of this section covers a survey of expert systems developed using knowledge based approaches. The systems covered were created for different purposes. For example, some were created for product development efficiency, others for cost estimation, and others for assembly and automation efficiency.

Gayretti and Abdalla (1999) developed a knowledge-based system with production rules written in LISP language to determine manufacturing requirements in the process of product development and of cost. The system architecture of the expert system included: a constraint-based system module, a consistency manager module, a design representation module, a process optimization and manufacturability module, and a user interface module. The cost determined by the system include: labor costs, tooling costs, machining cost, and overhead costs. Thurston (1996) developed two separate versions of Knowledge Based Systems (KBS) to perform the task of preliminary selection for the three elements of a car's bumper incorporating concurrent engineering into the system. The knowledge base was constructed with OPS5 as an expert shell running on a Texas Instruments micro Explorer Lisp computer that runs in a Macintosh II platform. In addition, Thurston worked with utility theory and multi Attribute Analysis combined with expert systems, and she determined that utility theory provided some advantages. In a different work, Kingsman and Souza (1997) developed a knowledge-based system for cost estimation and pricing decisions in make-to-order manufacturing. The system employed 200 production rules. They used Verbal Protocol to obtain these rules. The name of the system was CEPSS which stands for Cost Estimating and Pricing Support System. The cost estimation formulas are shown in equation, 2.1 and 2.2.

$$\textit{Price} = (\textit{Final estimated cost}) + (\textit{Risk with cost variances}) + \textit{Risk with estimators} + (\textit{Mark-up on materials}) + (\textit{Profit margin}) \tag{2.1}$$

$$\textit{Final estimated cost} = \sum (\textit{Estimated times} * \textit{Hour rates}) + \textit{Cost adjustments} + \textit{Cost of material} + \textit{Overhead} \tag{2.2}$$

Sharma and Gao (2007) developed a knowledge-base model to estimate the cost of a product design/redesign. The model used a Logic Designer, a CLIPS base, and FBCDS (Feature Based Conceptual Design System), and a Document Processor. A case study was provided of the re-evaluation of the cost of the manufacturing of a reducing flange.

Zha et al. (2001) developed a knowledge-based system for assembly-oriented design named AODES (Assembly-Oriented Design Expert System). It was developed using C and C++ and embedded in the CLIPS expert shell. The fuzzy extension, that handles the uncertainty of the KBS, and the object-oriented programming sections were written into the shell. In similar work, Zha and Lin (2000) developed a task planning and simulation system for assembly/disassembly using expert Petri nets. The system is constructed in such a way that it has similar results as production rules. An expert Petri net model is an abstract and formal information flow model that has the capacity to model and analyze serial and concurrent events and resource constraints. It assists the knowledge base in identifying existing and potential problems as the knowledge base is being developed.

In their research, Shehab and Abdalla (2006) developed a cost effective knowledge-base for design for automation, which involves: selection of the most economic assembly technique in early design, estimation of the assembly times and costs for manual, automatic and robotic methods, and analysis of the product design for automation with providing suggestions for design modifications without changing functionality. The system was built in Kappa-PC as an expert shell, Microsoft Excel as a database and AutoCAD as a CAD modeler. The knowledge-base contains more than 900 rules in IF-THEN format with forward and backward-chaining using frames.

In other work, Cakir and Cavdar (2006) developed a knowledge-base system to solve metal cutting related problems (Figure 2.1). They named the expert system COROSolve, and the system solved problems from milling, drilling and turning operations. DELPHI Visual programming language was used for the development.

2.2.2 The Case-Based Approach

The case based approach is characterized by a mathematical similarity comparison between a source case and a target case. The source cases are historical cases which are stored in a case database, and they contain information relating to problems solved in the past. The target case is a new problem that requests a solution. As mentioned before, the target case and the source case are tested for similarity, which can be done using different testing methods. The most common methods of similarity are the nearest-neighbor retrieval, shown in equation 2.3, and Euclidian distance.

$$NNR = \frac{\sum_{i=1}^{n} w_i \times Sim(f^I, f^R)}{\sum_{i=1}^{n} w_i} \tag{2.3}$$

where w_i = weight of feature *i,* and with *Sim* ( ) as a similarity function where

f^{I} and f^{R} = values of features of the input and retrieve cases.

Some argue that the case-based approach in expert systems provide a more precise result than knowledge-based experts systems because of the utilization of past solved cases. According to Duverlie and Castelain (1999):

> For the case-based reasoning method, its capacity to accept unknown information, to take into account the results as well as to process some particular cases (already processed) makes it very useful for the designer and allows, in a general manner, more precise results to be obtained than with the parametric method. However, its application in an enterprise is less easy because it requires a complete case-based reasoning system and a case base.

The remainder of this section covers a survey of expert systems developed using case-based approach. The systems covered are related to cost estimation problems and product design problems.

As one case-based study, Chang et al. (2010) used case-based reasoning to predict the manufacturing cost of a cellular phone. They used Artificial Neural Networks to manage the uncertainty of the cost estimation. Duverlie and Castelain (1999) used case-based reasoning to determine the best piston for a diesel engine. Similarity of indexation was done through nearest-neighbor retrieval. Ficko et al. (2005) used case-based reasoning to determine the optimal cost function for the manufacturing cost of a stamping tool. They used Euclidian distance for similarity evaluation and genetic programming. Humphreys et al. (2002) used a hybrid system, a knowledge-based in combination with a case-based system to assist corporation managers in the decision of making or buying a product. They looked at technical performance, analyzing vendors in the following areas: cost control, quality, customer service and delivery efficiency, and also considered suppliers organization skills, such as: culture, technology, achievement of sales objective, financial objectives. Due to its case-based approach, nearest-neighbor retrieval was used for similarity evaluation.

2.2.3 The Multi-Agent Based Approach

The characteristic of a multi-agent system is that it employs a number of agents that work toward solving a given problem at the same time. These agents are controlled by a manager that correlates a common ground from all the agent's outputs and thus finds a solution to the problem.

Ping (1995) developed a multi-agent system for cost estimation using an agent based approach. The agents that perform in Ping's system are: a knowledge-based system, a Fuzzy classification system and a Dynamic Optimization system. The Dynamic Optimization system functions in the following manner: the manager is the administrator of tasks, he chooses the cost estimator depending on the weight to him, and the Cost Estimator with the highest weight gets to complete the job. All cost estimators begin with a weight of 1 and are re-evaluated upon performance. Equation 2.4 serves as a representation of the Dynamic Optimization system:

$$\overset{Manager}{X} \underset{relationship}{\rightarrow} \overset{CostEstimator}{Y} \quad . \tag{2.4}$$

As other research in the area, Sanders et al. (2009) developed a multi-expert system for design-for-assembly composed of a CAD system, an Automated Assembly System, a Manual Assembly System and a Design Analysis Expert to manufacture a Signature capture device. The methods used for the system include: a ruled-base or knowledge-base database, intelligent agents and object-oriented methods.

2.2.4 The Object-Oriented Based Approach

Object-oriented approaches are characterized by the data extraction of a product's parameters and by the organization of such information into objects. The objects are classified in hierarchies and organized in sequential order. The remainder of this section surveys object-oriented based systems.

Gayretti and Abdalla (1999) used an object-oriented system to extract the frames and slots data from a 3D solid model in the process of a products development. In a similar manner, Fisher and Koch (1994) developed a CAD-system with an expert system shell that also uses an object-oriented approach for product development. A schematic for the object assignment of design and production parameters is shown in Figure 2.2. For their system, the cost estimation for the engineering process is done using activity based costing (ABC). They used STEP (Standard for The Exchange of Product) to share information. Also, Bramall et al. (2003) used an object-oriented process planner to investigate the manufacturability of a solid-state power amplifier chassis at its early design development state.

2.2.5 Other Approaches

There are many other approaches to develop an expert system. Some of these approaches are: Artificial Neural Networks (ANN), Bayesian Networks, Blackboard Model, Fuzzy Logic, Ant Colony Algorithm and Generic Algorithm among others.

Some people worked with ANN's. Chang et al. (2010) used back-propagation artificial neural networks (ANN) to predict the qualitative factors of the cost estimation of a cell phone, and Fazlollahtabar and Amiri (2007) used ANN with fuzzy rules back propagation for the cost estimation of a job shop under uncertainties.

In contrast, Fujikawa and Ishihara (1996) developed an expert system to detect forging process defects using Bayesian network probabilities and to determine its causes using a knowledge-based system rules. The rules were gathered by the empirical knowledge of experienced engineers and augmented by Finite Element Analysis.

As another approach, Huang and Miller (1995) used a Blackboard model approach. The model retrieves general information data from a CAD model, codifies and classifies planes and datums, and determines the machine availability for manufacturing and features representation. The system uses forward-chaining reasoning for feature sequencing and backward-chaining for the construction of the process plan. The system meets in the middle using the blackboard.

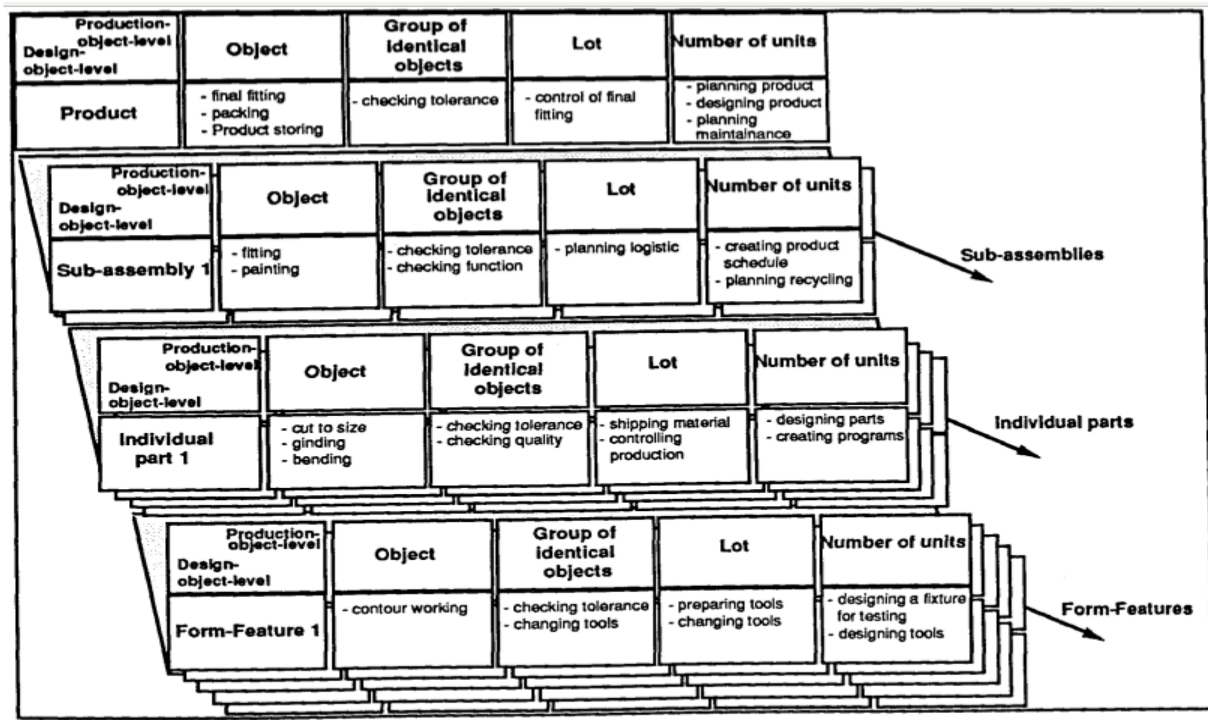


Figure 2.2: Design and Production Objects (Ficko and Koch 1994).

2.3 Expert Systems in Manufacturing

Expert systems are very beneficial for the automation of information processing and problem-solving, and expert systems in manufacturing engineering have been widely studied. This section discusses some models that have been developed to solve problems that occur in manufacturing engineering.

Concurrent engineering is an important tool for product development; therefore, expert systems have been explored in this area. Shehab and Abdalla (2001) developed a cost modeling system for product development using concurrent engineering. The system selects the product material using CMS (Cambridge Material Selection) software, then determines the process and machine selections by feature representation, frame-based knowledge representation, production rules in the form of IF/THEN conditions, and object-oriented knowledge representation. These selections are displayed and managed using the Kappa-PC shell. The costs involved are: machining cost, set-up costs and non-productive costs. The cost uncertainties are handled by a Fuzzy logic model.

Manufacturing optimization is another area that has been explored with expert systems. Bramall et al. (2003) determined the manufacturability of a Solid State Power Amplifier (SSPA) chassis and optimized cost at its early stage of development by getting the minima of equation 2.5 as an objective function.

$$E_s = W_q \sum_{j=1}^{J} q_j + \sum_{j=1}^{J} c_j + W_d \cdot L_d \left(T_d - \sum_{j=1}^{J} d_j \right) + W_k \sum_{j=1}^{J} c_j \cdot k_j \qquad (2.5)$$

where,

c_j, job cost,

q_j, financial cost of quality,

d_j, financial cost of delivery,

T_d, target delivery time for plan,

L_d, liquidated loss rate for plan,

k_j, financial cost of knowledge,

and it's respective weights as W_q, $W_{d`}$, and W_k. In a similar manner, Cus (2003) optimized cutting parameter conditions using Generic Algorithm technique for machining and metal cutting operations.

The objective functions are represented in equations 2.6 through 2.10.

$$\min T_p = 0.12 + \frac{231276\left(1+\frac{0.26}{T}\right)}{MRR}, \tag{2.6}$$

$$\min C_p = \left(\frac{13.55}{T} + 0.39\right) T_p, \tag{2.7}$$

$$\min R_a = 0.0088v + 0.3232f + 0.3144a, \tag{2.8}$$

$$T = 1575134.21v - 1.70f - 1.55a - 1.22, \tag{2.9}$$

$$MRR = 1000 \times 9.81vfa, \tag{2.10}$$

where,

T_p = Production rate,

C_p = Operation cost,

R_a = Cutting quality,

T = Tool life,

MRR = Material removal rate,

v = Cutting speed,

f = feeding, and

a = cutting depth.

Another area of manufacturing engineering that has been explored with expert systems is assembly optimization. Daabub and Abdalla (1999) used expert system to reduce total production cost focused on DFA (Design for Assembly), the Structure included: knowledge acquisition, knowledge representation, inference engine, DFA advising module and a user interface. Also, Zha et al. (2001) developed a knowledge-based system for assembly-oriented design named AODES (Assembly-oriented design expert system). Zha and Lin (2000) developed a task planning and simulation system for assembly/disassembly using expert Petri nets. In similar manner, Sanders et al. (2009) developed a multi-expert system for design-for-assembly composed of a CAD system, an Automated Assembly System, a Manual Assembly System and a Design Analysis Expert.

2.4 Computer Aided Process Planning Using Expert Systems

Computer Aided Process Planning (CAPP) is an automated technique for the planning of a product's manufacturing process that can be developed using expert system technology. The following section presents a survey of CAPP systems.

CAPP systems are employed to contribute to the improvement of the operation in a manufacturing company. According to Sood and Wright (1993) some of the benefits of an automated process plan are: (a) increasing the autonomy of flexible manufacturing systems, (b) improve turn-around-time and quality of rapid prototyping systems, (c) capturing the skills of retiring craftsman and machinist, and (d) providing information to upstream concurrent design engineering.

There are three different approaches in which a CAPP system may be constructed. The first is the variant approach, which is based in Group Technology (GT) coding systems that classifies parts into families. The second is semi-generative or constructive approach, which is based on GT classification but allows process modification, and the third, is generative approach, which is based in the creation of a new process plan using a logical manufacturing database (Sood and Wright, 1993 and Page, 1991).

Sood and Wright (1993) mentions the following list of published CAPP systems: APPAS, CADCAM, CAPP, CMMP, CAPPSY, AUTAP, COBAPP, AUTOPLAN, AACHEN, AUTOCAP, GENPLAN, GARI, TOM, ACAPS, MIPLAN, CMPP, PROPLAN, DCLASS, EXPSS-E, CUTTECH, HI-MAPP, AMRF, XCUT, SIPS, MACHINIST and NEXT-CUT.

The next section surveys CAPP system applications. Sood and Wright (1993) worked with an angle-part sketch drawn in Needles (a constructive solid geometry modeler) and determined its process plan using MACHINIST as a case-study. Page (2001) used a commercially available CAPP system named LOCAM to develop the process plan of a fan duct. He claims that in the experiment a duct was put into manufacturing in 20 minutes. Krishna and Rao (2006) developed a CAPP system for the optimization of the production of a cast shaft sleeve. They used ant colony algorithm (ACA) for error optimization. The population based ACA is shown in equation 2.11.

$$s = \begin{cases} \max_{u \in J_k(r)} \left\{ [\tau(r,s)][\eta(r,s)^{\beta}] \right\} & if \quad q \le q_0 \\ Otherwise, & S \end{cases} , \tag{2.11}$$

$\tau(\mathrm{r,s})$ = pheromone level (how useful to move s in r state),

$\eta(r,s)$ =heuristic function,

β = weight of heuristic function's importance,

$J_k(r)$ = number of operations to be visited,

q = random value with uniform probability ([0,1]),

q_0 = parameter between zero and one, and

S = random variable according to distribution chosen.

Bramall el al. (2003) implemented a commercially available process planner called CAPABLE to determine the manufacturability analysis of a product at early design stage. A SSPA (solid-state-power-amplifier) chassis was investigated.

2.5 Cost Estimation Systems

Given the importance of cost estimation in manufacturing job bidding, cost estimation is a field that has been well investigated. Garcia and Crespo (2009) surveyed machining price quotation methods that involve both traditional and automated methods: automated (expert systems) and non-automated (conventional costing methods). Table 2.1 contains references to cost estimation systems obtained from their paper.

Table 2.1: Knowledge-based Systems for Estimation (Garcia and Crespo 2009).

Reference	Description
Xie (2006)	Web-based decision support system that integrates tools and databases
Shehab and Abdalla (2006)	Expert system that decides the best assembly technique for the part and calculates the manufacturing costs
Hvam et al. (2006)	Knowledge-based system for estimating manufacturing price in the RFQ process. That knowledge-based system is based on a product configurator
Chougule and Ravi (2006)	System for determining the manufacturing process for a given part, based on case-based reasoning. The system estimates the cost of the part, using a parametric model
Bouaziz et al. (2006)	Cost estimation system based on the manufacturing process and the features of the part. The manufacturing process is determined by analogy with previous parts
Ko et al. (2007)	Knowledge-based system for evaluating the manufacturing costs of injection-moulded parts

Table 2.1(continued): Knowledge-based Systems for Estimation (Garcia and Crespo 2009).

Reference	Description
Doney (1971)	Application for the price estimation in the RFQ process. It is a modular application, programmed in C
Downs and Trappey (1992)	Methodology for the development of cost estimation software
Muntslag (1994)	Price estimation model based on benefit/risk analysis
Taiber (1996)	System for the automatic generation of manufacturing processes based on the features of the part. The system provides cost estimation for each process
Aderoba (1997)	Model for estimating production time and cost based on the ABC method. The model can be used for RFQ evaluation
Veeramani and Joshi (1997)	Veeramani and Joshy propose the architecture of an RFQ estimation system and two estimation methodologies based on similarity
Ou-Yang and Lin (1997)	Cost estimation system based on the design of the part. The design is stored in CAD files
Duverlie and Castelain (1999)	Comparison of a parametric model and case based reasoning
Ben-Arieh (2000)	System for cost estimation of machined parts. The system determines the manufacturing process required based on the features of the part
Maropoulos et al. (2000); Maropoulos and Baker (2000)	Cost estimation model based on the machines and operations required for the machining process. The machining process is determined based on the features of the part
Locascio (2000)	Cost model based on the production time and the assembly time for the part. The production time is based on the activities required for manufacturing the part
Layer et al. (2002)	A review of cost estimation research in Germany up to 2002
Lan (2002)	Numeric simulation model for minimizing machining costs and machining time
Jung (2002)	Cost estimation model based on four relevant features of a part
Koonce et al. (2003)	Cost estimation model based on the breakdown of the product into cost components
Chen et al. (2003)	Chen et al. identify requirements for a computer-aided cost estimation tool based on axiomatic design
Beil and Wein (2003)	Electronic bidding mechanism for the RFQ process. Based on the bidding information, the system estimates the cost of each supplier in order to select the best quotation
Ben-Arieh and Li (2003); Qian and Ben-Arieh (2008)	Agent-based architecture for the coordination of the RFQ process amongst several companies. The paper presents an estimation model based on ABC/Parametric method but the cost estimation module of the system is customizable. This model is extended in Qian and Ben-Arieh (2008)
Brinke et al. (2004)	Generic architecture for the estimation of manufacturing costs based on customizable modules
Venkatadri et al. (2006)	Model for the representation of the product's supply chain. Based on the supply chain features, the optimum price and the lead-time can be determined
Silva et al. (2006)	Web-based decision support system for production planning and control. The system supports the cost estimation based on data about past similar products.
Jiao and Helander (2006)	Web-based product configurator. It estimates the production cost based on the product features
Ruffo et al. (2006)	Experimental cost estimation model based on different types of cost related to the manufacturing process. Each type of cost has a set of related equations for calculating said cost
Masmoudi et al. (2007)	Decision support tool for estimating the cost of welding operations. The proposed cost estimation model links technical variables with economic variables
Tu et al. (2007)	Cost estimation model based on cost indexes for well-known products. The model is adaptable to new products.

Table 2.1(continued): Knowledge-based Systems for Estimation (Garcia and Crespo 2009).

Reference	Description
Lan and Ding (2007); Lan et al. (2008)	Web-based system based on two cost estimation models: a parametric model for early estimations and an analytical model for detailed estimations
Oduoza and Xiong (2008)	Decision support system for processing customer enquiries. Applies a multiple-objective, linear programming model for estimating the company's revenue
Kennedy and Shao (1989)	Expert system for advising on improvement of the RFQ process
Kadidal and Bidanda (1993)	Expert system for estimating the manufacturing cost of injection-mould parts
Cunningham and Smart (1993)	Expert system for generating manufacturing plans and estimating the corresponding manufacturing costs
Qiqin et al. (1996)	Expert system for production planning and cost estimation. The expert system is based on the features of the part, represented in a CAD file, and systems analysis techniques
Kingsman et al. (1996); Kingsman and de Souza (1997)	The authors identify the characteristics of versatile manufacturing companies and propose an expert system for price estimation based on heuristics
Mohamed and Celik (1998)	Expert system for estimating construction costs in the early design phase
Bidanda et al. (1998)	Rule-based expert system for analysing the casting process. The system estimates manufacturing costs based on a regression analysis
Wei and Egbelu (2000)	Expert system for defining manufacturing processes and estimating manufacturing costs of machined parts based on the AND/OR tree representation
Arezoo et al. (2000)	Expert system based on predicate logic for selecting cutting tools and parameters and determining optimal manufacturing costs and time
Er and Dias (2000)	Rule-based expert system for process selection of cast components based on cost comparatives
Jahna-Shahi et al. (2001)	Cost estimation model based on Fuzzy logic for the representation of non-process variables. These variables can affect manufacturing time and costs
Shehab and Abdalla (2002a); Shehab and Abdalla (2002b)	Knowledge-based system for generating manufacturing processes and estimating their costs
Sharma and Gao (2002)	Expert system for estimating manufacturing time and costs based on incomplete designs
Seo et al. (2002)	The authors present a comparison between a regression model and an artificial neural network-based model for cost estimations
Wang et al. (2003)	Cost estimation system based on case-based reasoning
Vidal et al. (2003)	Workflow management system for furniture budgeting
Tang et al. (2003)	Knowledge-based system for cost estimation in the part design phase. The system incorporates production rules for linking the features of the product with their cost
Maropoulos et al. (2003)	Design support system for the optimization of manufacturing costs and time, based on a low number of features
Chan (2003); Chan and Lewis (2000)	Expert system for determining machining costs and operation parameters of the machining process, based on the features of the part
Park and Seo (2004)	Cost estimation system for product maintenance based on artificial neural networks
Hvam et al. (2004)	Analysis of the impact of knowledge-based systems on the re-engineering of the RFQ process
Chan (2005)	Hybrid cost estimation system for the electroplating industry. The system is based on case-based reasoning, rules and fuzzy logic

More models are surveyed in Shehab and Abdalla (2001) involving cost estimation. Table 2.2 contains the references.

Table 2.2: Expert Systems on Cost Estimation (Shehab and Abdalla 2001).

Reference	Description
Abdalla and Knight (1994)	Developed expert system for concurrent engineering
Wei and Egbelu (2000)	Developed system to estimate the lowest product manufacturing cost
Venkatachlam et al. (1993)	Developed an object and rule-based expert system for process selection and cost estimation for cast and forged products
Luong and Spedding (1995)	Developed a generic knowledge-based system for process planning and cost estimation in hole making process.
Allen and Swift (1990)	Developed a technique to be implemented in the early stages of the design process, for the selection of manufacturing processes and costing.
French (1990)	Addressed the problems of modeling cost.
Bruckner and Ehrlenspiel (1993)	Developed a model to estimate the cost of gear drives.
Sheldon et al. (1993)	Proposed a framework for developing an intermediate cost database established between cost accounting system and the design for cost (DFC) system.
Feng et al. (1996)	Presented a mathematical model to determine the minimum cost design.
El-Baradie (1997)	Developed a fuzzy logic model for machining data selection.
Mason and Kahn (1997)	Developed a fuzzy logic expert system for estimating excavation cost.

Case-based systems are commonly used for cost estimation, since they work with real data. Chang et al. (2010) used case-based reasoning and ANN to predict the product unit cost of a cellular phone. Equation 2.12 applies.

$$PUC = \left(TC \times \frac{\sum \frac{TPQ \times (CT \times SQ)/60}{TOH}}{TPQ} \right) \tag{2.12}$$

where,

PUC = Product Unit Cost,

TC = Total Cost (Labor and Manufacturing),

TPQ = Total Production Quantity,

CT = Tact time,

SQ = Production Station Quantity, and

TOH = Total Output Hours.

In a cost estimation system, Duverlie and Castelain (1999) used case-based reasoning methods to determine the best estimation of cost of a piston. In similar manner, Needy et al. (1998) developed a cost model for cellular manufacturing which basically decides the number of cells and items inside to be produced. They used error optimization with a GA (Genetic Algorithm). The costs determined in the model are: set-up cost, material handling cost and investment cost.

In other work, Koltai et al. (2000) developed a system that allocated costs in flexible manufacturing systems (FMS). The Activity Based Costing (ABC) method was used in batching mode, together with mixed integer linear programming with binary variables and integer variables. They divide overhead into 5 activity centers: tooling, load/unload, material handling, inventory, and other. In similar manner, Culler and Burd (2007) integrate manufacturing processes with business features (ABC) for cost estimation. They used Autodesk Inventor as a CAD modeler, EdgeCAM as CAM planner, Visual Basic 6 to develop the graphical-user interface (GUI), MS Access and MS Excel to build the database and MS Word for report processing.

In a different works, Ping (1995) developed a multi-agent system for cost estimation, Sharma and Gao (2007) developed a knowledge-base model to estimate the cost of a product design/redesign, and Kingsman and Souza (1997) developed a knowledge-based system for cost-estimation and pricing decisions in make-to-order manufacturing. Clearly, cost estimation with intelligent systems has been well investigated.

There is plenty of information about the incorporation of computer technology into manufacturing processes and administration that manufacturing companies can utilize to improve performance. Information on how expert systems can improve autonomy of flexible manufacturing systems, turn-around-time, quality, and design process; also on how they can allocate experience of skilled workers into one computerized expert and thus the best combination of manufacturing practices are standardized into one procedure; The literature also focused on how they can also analyze and estimate cost with the help of accounting techniques such as Activity Based Costing (ABC). There is also a wide venue that a manufacturing company can take in respect to the available approaches of expert systems, the knowledge-based approach, and the case-based approach, the multi-agent based approach, among others mentioned before; however, there is no information of the cost absorbed by a company to employ a cost estimation expert system and how it may be of assistance. The following chapter covers the selection of a cost estimation system and the training using projects from MAQYPROYIND. In further chapters, a payback, time effectiveness and accuracy analysis is discussed.

CHAPTER III

SOFTWARE TRAINING AND DESCRIPTION

3.1 SEER for Manufacturing Software

In order to compare MAQYPROYIND's traditional estimation system with a computer based estimation system, SEER for Manufacturing version 6.1 is employed by the University of Texas-Pan American. The software license is provided as a full year donation by Galorath Incorporated. In addition to the software, Galorath Inc. provided training and counsel to start to use the software. Figure 3.1 shows a snapshot of the main window of the software at opening that contains the information of the license given by the software company.

3.1.1 Review of SEER for Manufacturing

SEER for Manufacturing is project estimation and engineering management software built with a user-friendly interface similar to Microsoft based products. The difference between SEER for Manufacturing (SEER-MFG) and other engineering software, such as a CAD software that uses computer technology to focus on design and functionality, is that SEER-MFG focuses on simulating, estimating, and optimizing process options (cost, schedule, labor, material and tooling), and it can be used to model virtually any manufacturing operation, including customer-defined processes. According to Galorath Inc, "more than 75 manufacturing processes are pre-configured in the core SEER-MFG solution (SEER for Manufacturing Product Brief 2011)."

SEER for Manufacturing uses a parametric approach to simulate manufacturing process. Its parametric modeling approach "enable organizations to model and test manufacturing processes and trade-offs when the design is very preliminary and little detail is known, and to refine process plans as information becomes available." This software is a fine tool to be used by engineers in process of design for manufacturing (DFM) and also for manufacturing engineers to assess the most cost effective way to make a product.

Not only does SEER for Manufacturing have a wide range of manufacturing processes, but it also contains a large database of materials. Aluminum alloys, composites, glass polyester, plastics, rubber, stainless steel, tool steel are just some of the materials available in the database. Cost of material, machinability, density are factors considered in the cost estimation model. Galorath Incorporated provides the currency, material, composites and manufacturing data files to add change or delete any item from the software database. This option is great for manufacturing companies that use their own patented materials, machinery, special tooling and currency in their manufacturing project estimation. SEER-MFG is operational under metric or imperial units.

3.1.2 SEER-MFG Cost Estimation Approach

To create an estimate in SEER-MFG, a new project file is started. See Figure 3.1 Start-Up Options Sub-window. Then, work elements are defined into parts, assemblies or process steps; finally, parameters are entered in the Parameters Window. See Figure 3.2. Once the parameters are considered in the estimation, SEER-MFG reports labor cost, additional costs and additional data. Labor cost includes: set-up, direct, inspection and rework costs; additional costs includes: material, vendor, tooling and other costs; and additional data includes: manufacturing index, raw weight, finished weight, mean-time between failures (MTBF) and mean-time to repair (MTTR).

Figure 3.1: Snapshot of Opening Window of SEER-MFG 6.1 Software.

3.1.2.1 Work Elements. The cost estimation software works in parent-to-child hierarchies called Work Elements as it is shown in top-left sub window of Figure 3.2; therefore, the overall project to be estimated can include a different number of part models that form one assembly, or just one part model. The Work Elements can be parent elements for the part models or child elements for the manufacturing processes such as molding/casting/forging, PC board fabrication, machining, fabrication, electrical assembly, assembly, finish and heat treat, tubing/welding and others. A combination of child manufacturing process elements can be amalgamated with a parent Work Element called a Roll-up. The Work Element sub window is shown at the top-left of Figure 3.2. Top-left part of Figure 3.3 shows Roll-up 1.1 JG10A109, which is a part model number, with child 1.1.1 machining operations, which is a machining work element, and 1.1.2 clear anodize, which is a finish & heat treat work element. Each Work Element type has a set of parameters that can be manually inserted from known process information to integrated mathematical equations or automatically inserted by using a template from the knowledge database formed by Galorath Inc. The bottom-part of Figure 3.3 shows the Create/Modify Work Element window where the manufacturing process type and the knowledge base template are chosen if applicable.

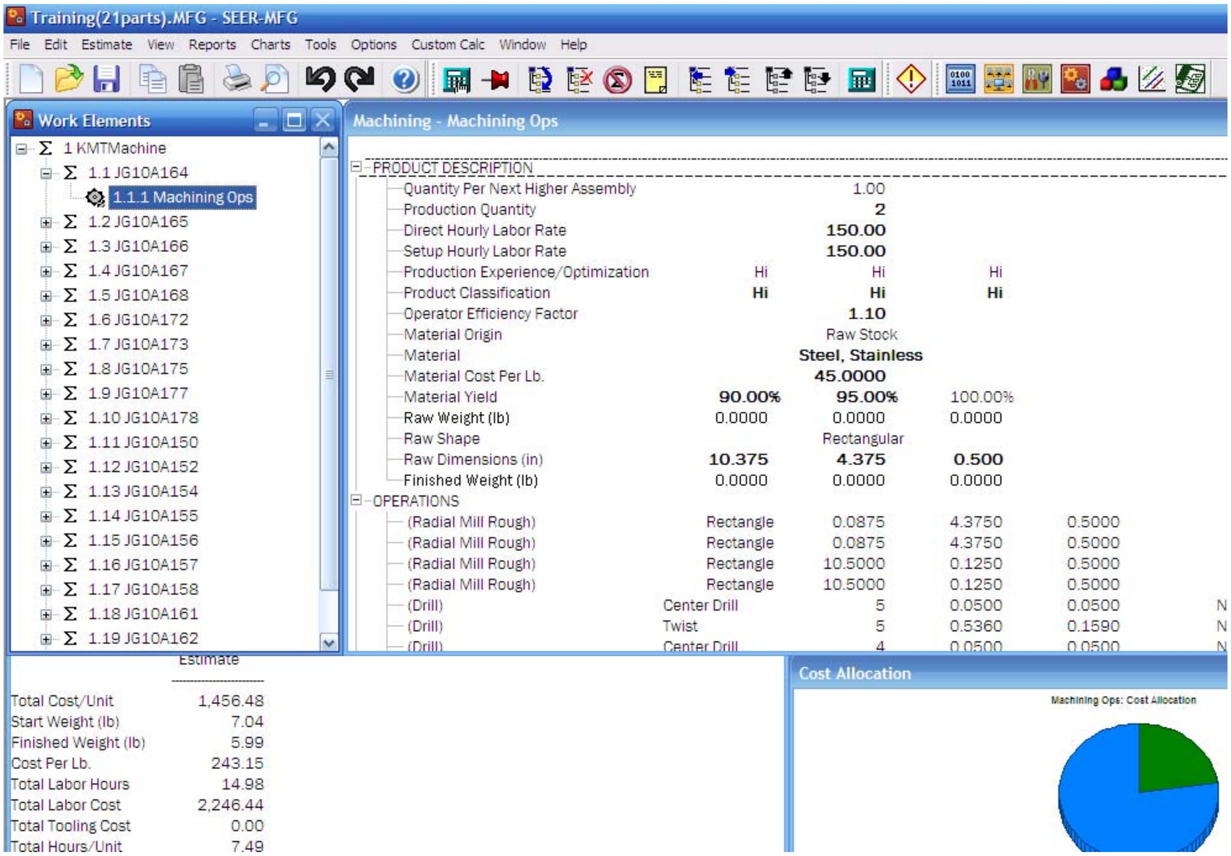


Figure 3.2: Schematic of the Work Elements (sub-window on top-left).

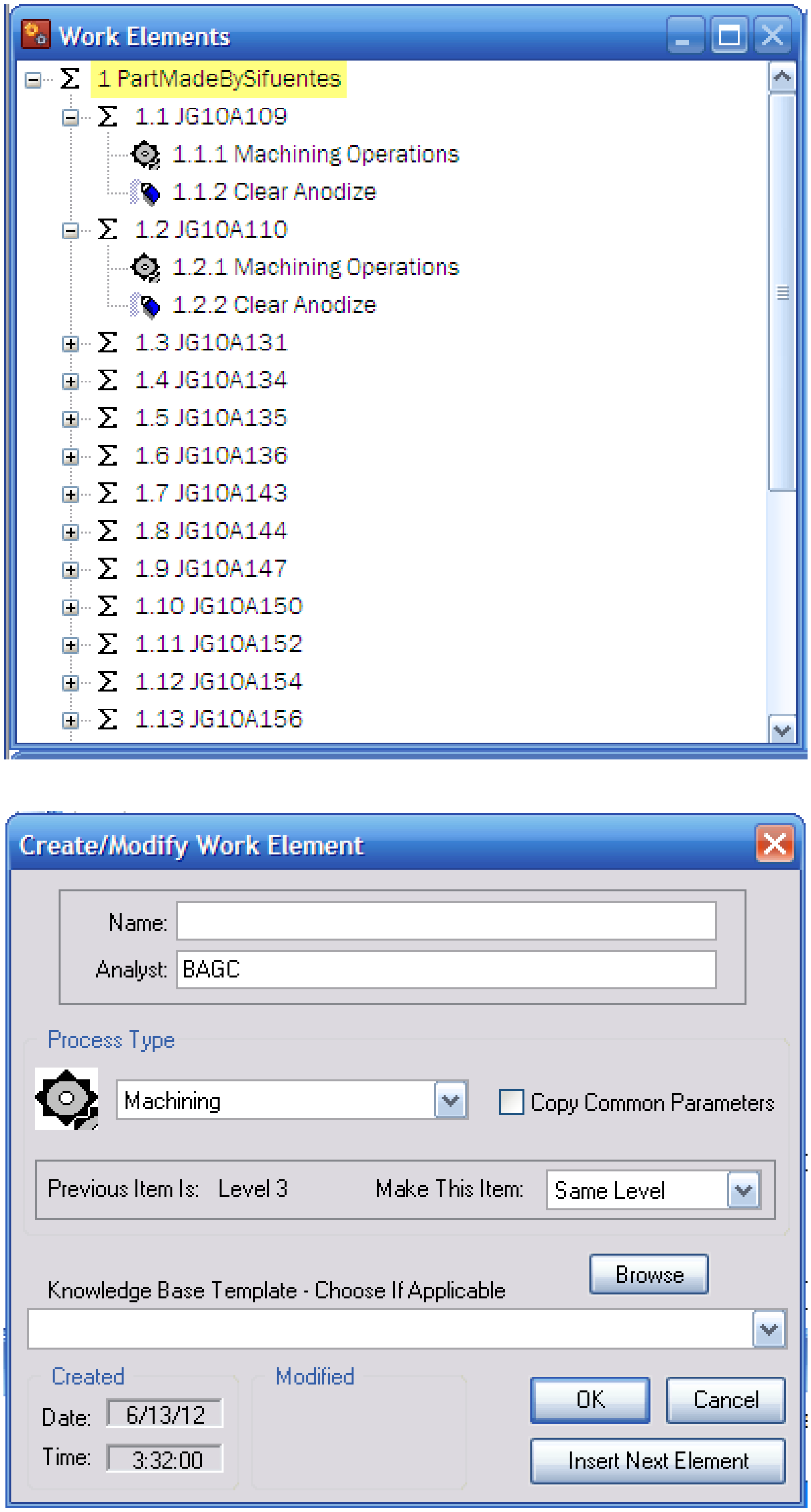


Figure 3.3: Schematic of Roll-up Work Element.

3.1.2.2 SEER-MFG 6.1 Modeling Parameters. As before mentioned, SEER for Manufacturing uses a parametric approach in order to mathematically simulate the manufacturing process of a product by built-in equation models. Also, the software is capable of adding unique processes to the model. SEER-MFG is very sophisticated with the data analysis; the simulation model is based on the Monte Carlo method.

Figure 3.4 shows the Machining Work Element parameters. The category labels of parameters for the Machining element are: Product Description, Operations, Manufacturing Description, Optional Cost Description, Tool Description, Inspection, Rework, Marking, Packaging, Labor Calibration, Probability (Risk), Part Assembly Contribution and Financial Factors, as shown in Figure 3.3.

The modeling of a part begins by specifying the parameters of the product description which includes: production quantity, direct hourly labor rate, set-up hourly rate, material, raw material dimensions, and others; then, the part is virtually shaped in the Operations module by removing material from the raw shape using operation types such as: radial mill, end mill, drill, turn, thread milling and others. Manufacturing parameters such as set-up complexity, tooling complexity, machine/tooling process capability and machine condition are entered in the Manufacturing Description module. The Tool Description module contains parameters such as size factor, tool prep, cleaning, packaging and storage, as well as an option for tool design and fabrication if appropriate. The Inspection/Rework module has parameters in-process inspection and in-process rework with a value assigned to represent the percentage of the process time dedicated to inspection or rework. The Manufacturing, Tool Description, and Inspection module values are specified in a range of probabilities: the least, the likely and the most possible outcome. For a probability and risk of 50%, the system gets the least times four times the likely plus the most with this quantity divided by six. Another important module is the Labor Calibration module. In this module the amount of prior production units is entered as well as the stepped learning curve percentage. In the Probability Risk module a risk percentage of the cost estimation is determined; the default value is 50%. The model assesses whether the part model is a part of an assembly contribution in the next module. Finally, the goal profit is entered into the model in the Financial Factors module.

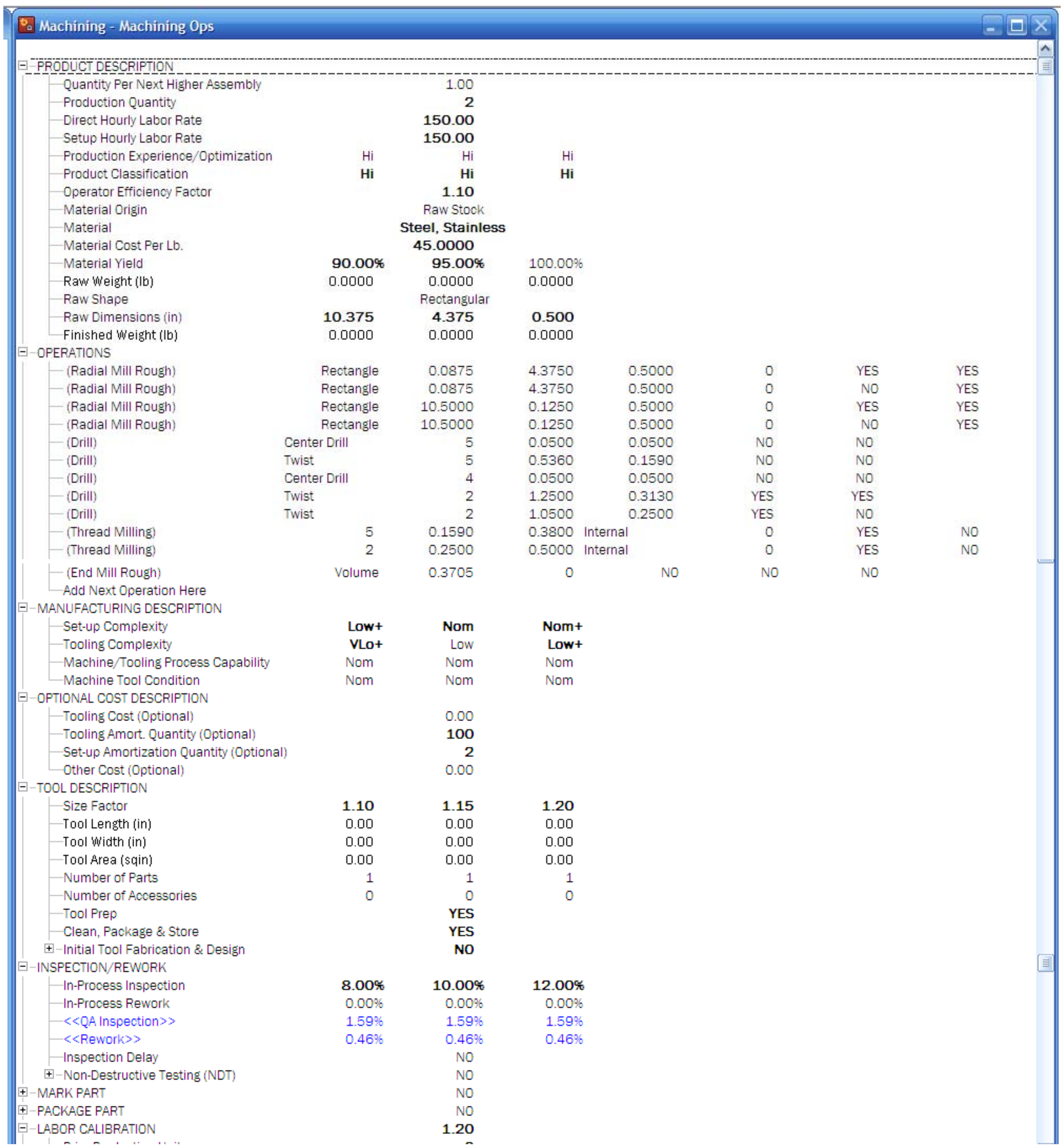


Figure 3.4: Machining Work Element Parameters Window.

3.2 Training with SEER-MFG 6.1

The training given by Galorath Inc. consisted of 5 hours of one-on-one training through web conferencing. The training sessions covered an overall review of the software, its capabilities and how to model a machine shop using it. Also, the training included the analysis of real part model quotes. Besides the training given by them, cost estimation practices were made of part models that MAQYPROYIND completed in the past and their manufacturing information was known. The purpose of having practice sessions was not only to become more familiar with the software, but also to calibrate the software to the machine shop capabilities and experience, to make sure that the model provided the known data and to become more time efficient with its utilization.

Twenty three part models were quoted and times to quote documented as shown in Table 3.1. The first two parts were done to be presented to the Galorath Inc. trainer so that they could be evaluated and corrected by him; the remaining 21 were done utilizing recommendations given. Figure 3.5 shows a part number vs. time-to-quote relation that was obtained in the training. The plot shows the learning regarding the quotation practices done in SEER-MFG 6.1. The first quotes took hours to quote. As more quotes were completed the learning approaches 12.3 minutes for the last fourteen part models. The total number of training hours was 27.08 of which it includes web conference training, practice models, and time for software manual reading.

Table 3.1: Part Number vs. Time Training Log.

#	PART	TIME (min)	#	PART	TIME (min)
1	JQ00A191	68	13	JQ00A191	11
2	JQ00A192	123	14	JG10A150	20
3	NH04A555	60	15	JG10A152	11
4	JG10A164	40	16	JG10A154	14
5	JG10A165	15	17	JG10A155	9
6	JG10A166	30	18	JG10A156	25
7	JG10A167	30	19	JG10A157	10
8	JG10A168	30	20	JG10A158	8
9	JG10A172	10	21	JG10A161	9
10	JG10A173	14	22	JG10A162	10
11	JG10A175	11	23	JG10A163	8
12	JG10A177	13			

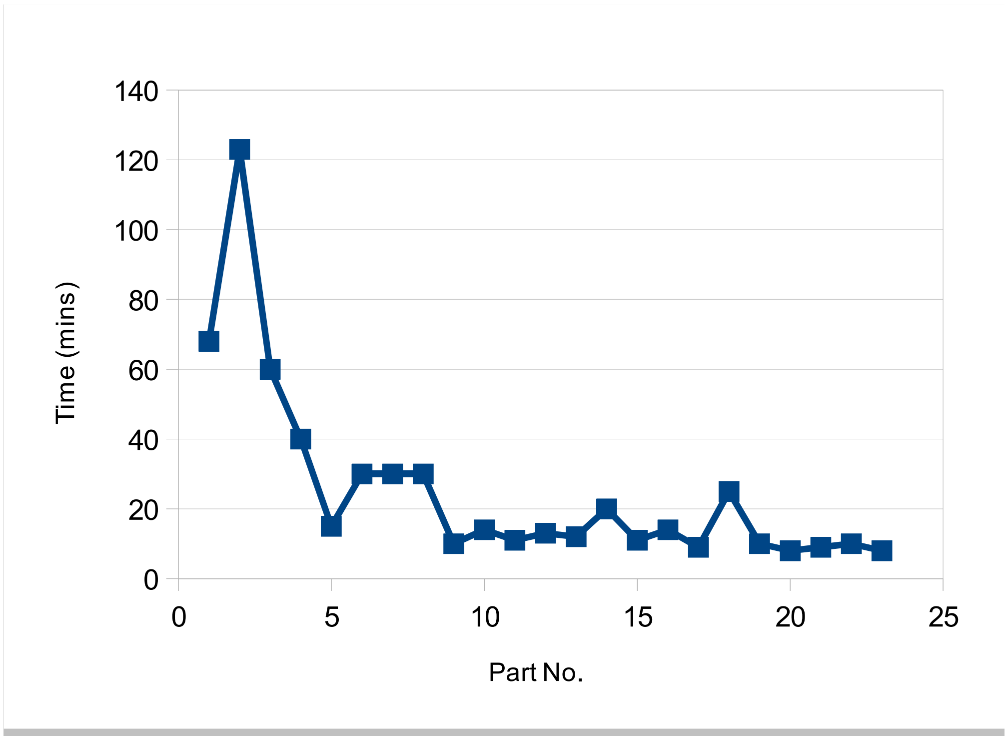


Figure 3.5: Plot of Part Number vs. Time-To-Quote.

3.3 Calibration of Model Machine Shop

In order for the software to provide more accurate data, SEER-MFG can be calibrated to represent the MAQYPROYIND work shop. Some of the parameters that can be adjusted to model the machine shop are: Production Experience/Optimization, Operator Efficiency Factor, Set-up Complexity, Tooling Complexity, Machine/Tooling Process Capability, Labor Calibration, Production Prior Units and Step Learning. The parameters modeled into SEER-MFG are found by MAQYPROYIND's recurring part models. Figure 3.6 shows some of the parameters.

PRODUCT DESCRIPTION			
Quantity Per Next Higher Assembly		1.00	
Production Quantity		2	
Direct Hourly Labor Rate		150.00	
Setup Hourly Labor Rate		150.00	
Production Experience/Optimization	Hi-	Hi	VHi-
Product Classification	Hi	Hi	Hi
Operator Efficiency Factor		1.10	
Material Origin		Raw Stock	
Material		Steel, Stainless	
Material Cost Per Lb.		45.0000	
Material Yield	90.00%	95.00%	100.00%
Set-up Complexity	Low	Low+	Nom-
Tooling Complexity	VLo-	VLo	VLo+
Machine/Tooling Process Capability	Nom	Nom	Nom
Machine Tool Condition	Nom	Nom	Nom
LABOR CALIBRATION		1.20	
Prior Production Units		0	
Stepped Learning			
Quantity	Curve %		
2	95.00%		
Add Next Step Here			

Figure 3.6: MAQYPROYIND Calibration in SEER-MFG.

Once the training is completed, the calibration is finished and the model is outputting satisfactory numbers, the data gathering process is started. The data collection is explained in the following chapter.

CHAPTER IV

DATA COLLECTION

4.1 The Acquisition of Data

This chapter covers the procedures to obtain the information that is necessary to for the determination of the payback point in the SEER-MFG investment, the time efficiency of using a computer system to quote instead of traditional quotation, and the accuracy of estimations with respect to the traditional system's estimation. See Figure 4.1 as an illustration of the experiments that are conducted.

The data was gathered by four different individuals: the traditional system's estimations and the actual time-to-manufacture (TTM) were provided by two of MAQYPROYIND's technicians and one administrator, and the SEER-MFG estimates were modeled and collected by the author.

4.2 Traditional Quoting System vs. SEER-MFG – Time Efficiency

The traditional quoting system vs. SEER-MFG analysis is an analysis between the time that it takes a MAQYPROYIND employee to quote a part model and the time it takes for SEER-MFG to quote the same part. This relationship is important because it determines the time effectiveness of the computer system compared to the traditional system. If the cost estimation process becomes faster, then the cost involved in estimation is reduced. This analysis is also used to determine the payback point of the investment. In order to determine the time efficiency, both quoting methods use the same part models.

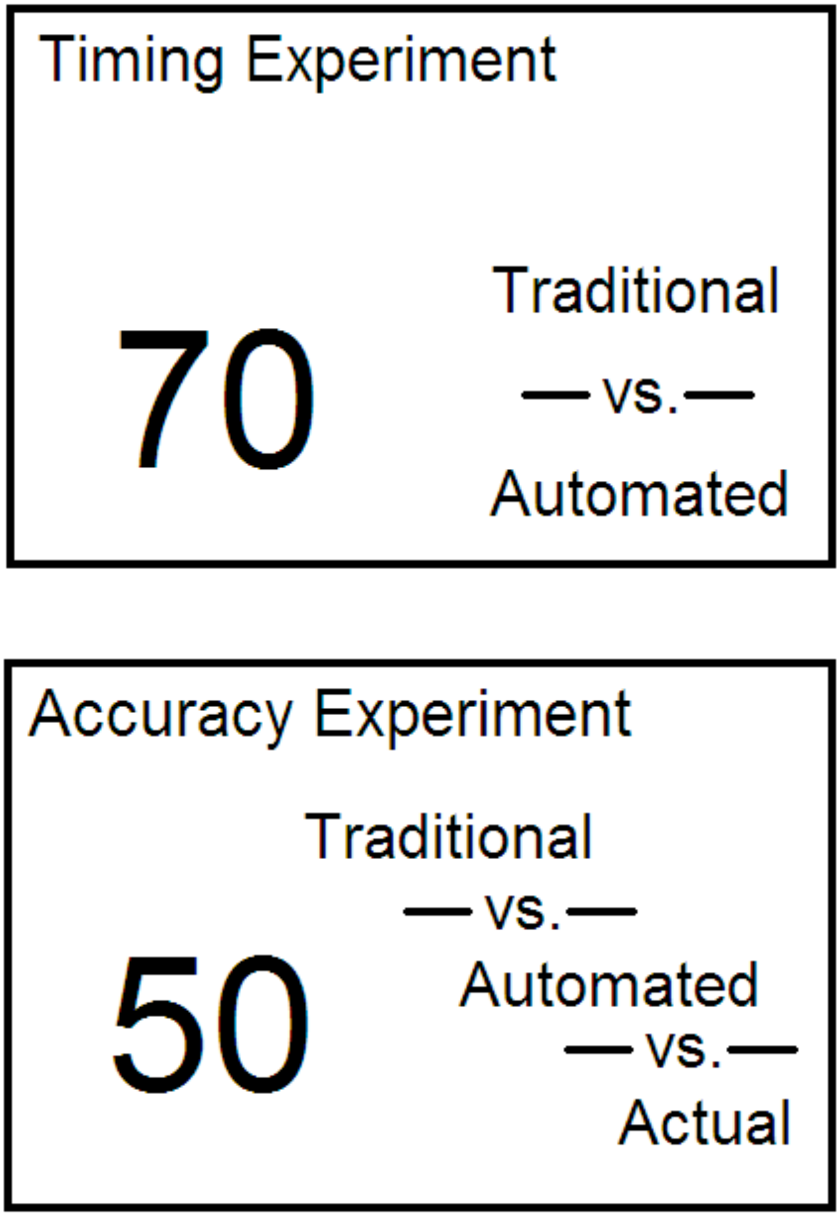


Figure 4.1: Data Collection Case Studies.

4.2.1 Part Models

Seventy part models provided by a customer of MAQYPROYIND for bidding were used in this part of the experiment. All of the parts are made of steel and require electroless nickel plating for surface finishing. Together they assemble a semi-automatic industrial machine; however, the assembly is to be done by the customer and assembly labor is not considered in the quotation. The cost of surface finishing treatment is almost constant per part since the parts are millimetric and treated in batches; therefore, its cost is easy to be estimated and not included in the experiment. These parts models are only used for evaluating the time effectiveness because the bidding was postponed by the clients, and there is no data available for manufacturing times and actual costs.

4.2.2 Traditional Quoting System Procedures

Seventy part models were given to a technician with special instructions. They are asked to quote all the parts and to provide an estimation that includes the following information: material cost estimation in Mexican pesos, time-to-manufacture (TTM) in hours, cost per part in pesos and the time-to-quote in minutes per part.

To determine the cost of raw material it is necessary to do an estimate using purchasing experience and to have knowledge of the material to be purchased. One of the reasons for this requirement is that most material suppliers do not like to be called often just to provide a quote, especially when many parts are involved. They prefer to give a price when the purchase is assured; otherwise, the relationship with the supplier is put at risk. Phone calling is minimized, and material cost is estimated based solely on experience.

The Time-To-Manufacture (TTM) of a part model is estimated in hours, and it is for the quantity of one part. In order to estimate the TTM, the technicians must use prior experience in part machining. Number of set-ups, material machinability, part features difficulty and size are considered in this stage.

The cost per part is determined by the following parameters: TTM, direct labor rate (DL), overhead rate (OH) and cost of the material (CM). The direct labor rate is the hourly wage paid to the machinist; and the overhead rate is a rate calculated every year that covers indirect fixed and variable cost. Both of these rates were provided by the machine shop's administration. Equation 4.1 describes these relationships.

$$C = MC + TTM \times (DL + OH) \quad , \tag{4.1}$$

where, MC = material cost,

TTM = time-to-manufacture,

DL = direct labor,

OH = overhead, and

C = cost per part.

If the part model requires a finishing treatment then Equation 4.1 is modified as shown in Equation 4.2.

$$C = MC + TTM \times (DL + OH) + FT \, , \tag{4.2}$$

where FT = finishing treatment.

The time-to-quote is the time in minutes that it takes the technician to estimate the cost per part. This is the data that is used for the time efficiency analysis.

4.2.3 SEER-MFG Quoting System Procedures

The semi-automatic industrial machine part models were quoted by me using SEER-MFG. As a demonstration, the procedures of estimating cost using SEER-MFG are explained in this section using part model 0001 as an example. Figure 4.2 is a drawing of part model 0001.

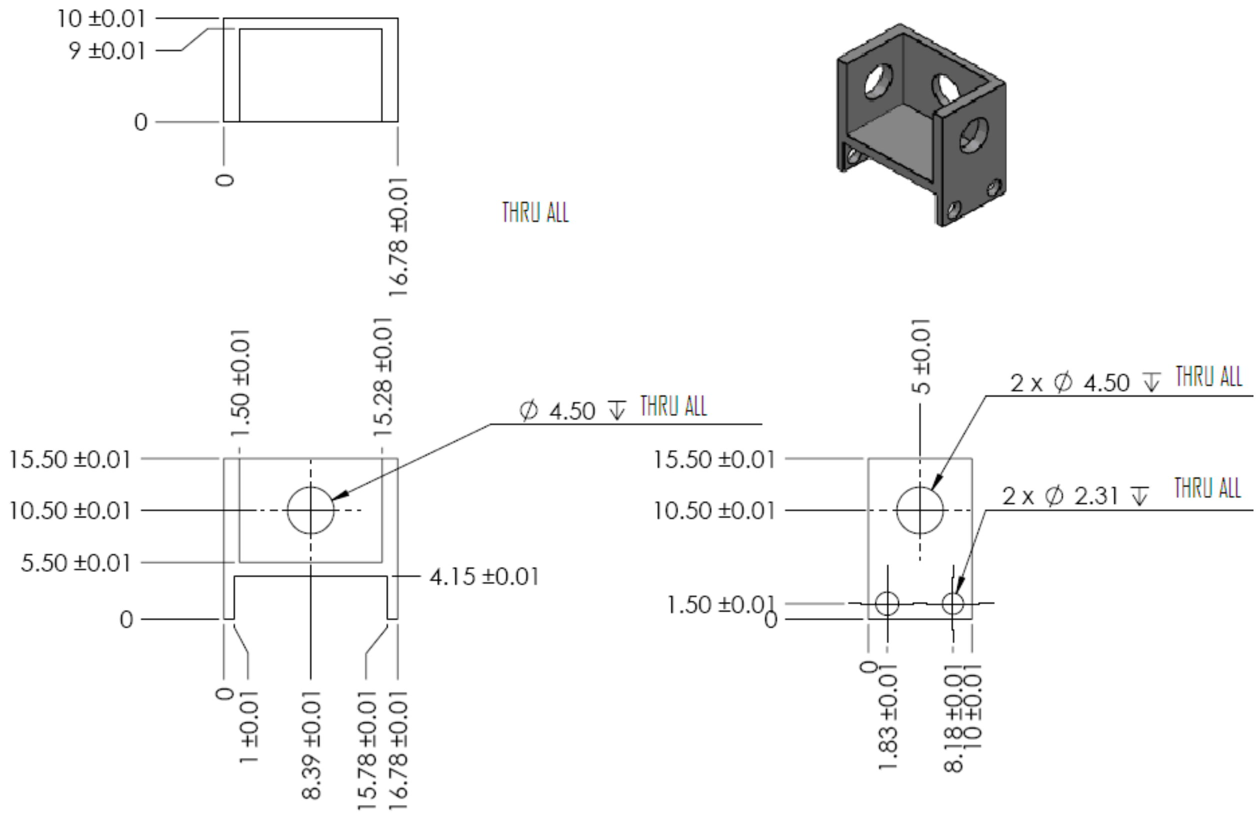


Figure 4.2: Part Model 0001.

The Work Element Parameters are considered next. In order to accomplish this estimate, a new project is opened and named "Milli0125" in SEER-MFG and is placed in level 1 of the hierarchy. Then, the project parameters are specified accordingly to the project. The currency is Mexican pesos, and the units are SI units as shown in Figure 4.3. The next step is to add a Roll-up work element under the part model's element in level 2 and name it to "0001." Then, two more process work elements are added under the part model's element in level 3, and they are named: "Machining Operations" and "Nickel Electroplating." The "Machining Operations" work element uses a Machining Knowledge Base, provided by SEER-MFG, and the "Nickel Electroplating" work element uses a Finish & Heat Treat Knowledge Base. Figure 4.4.1 and Figure 4.4.2 show a schematic of the process work elements and the work element window.

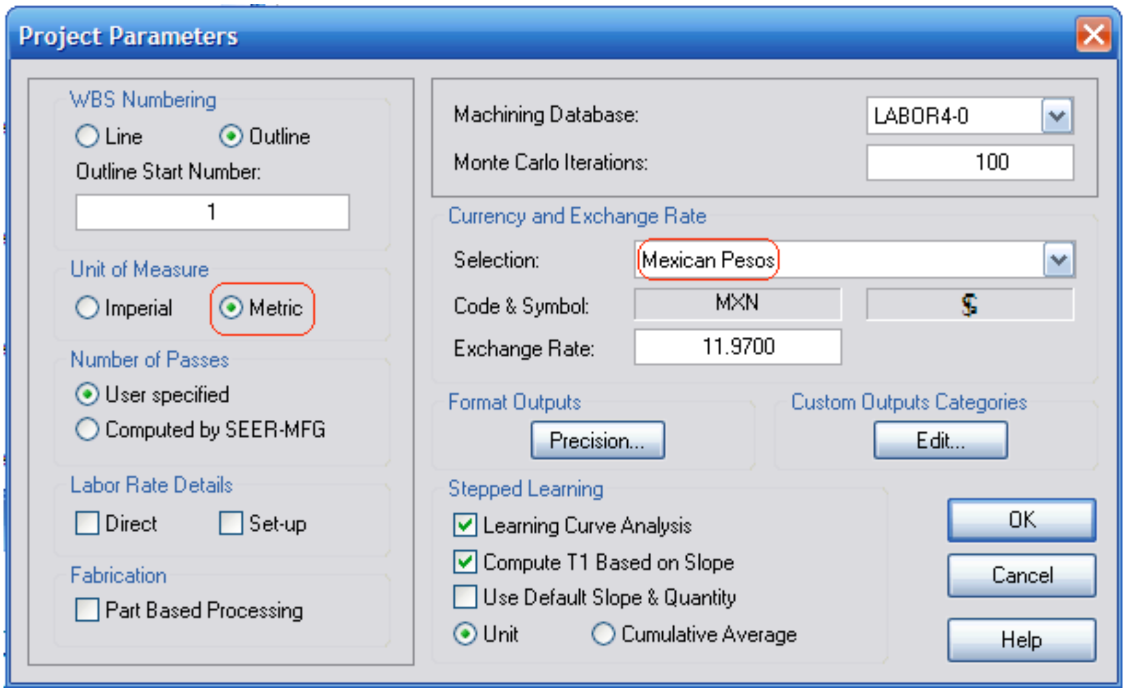


Figure 4.3: Project Parameters Window.

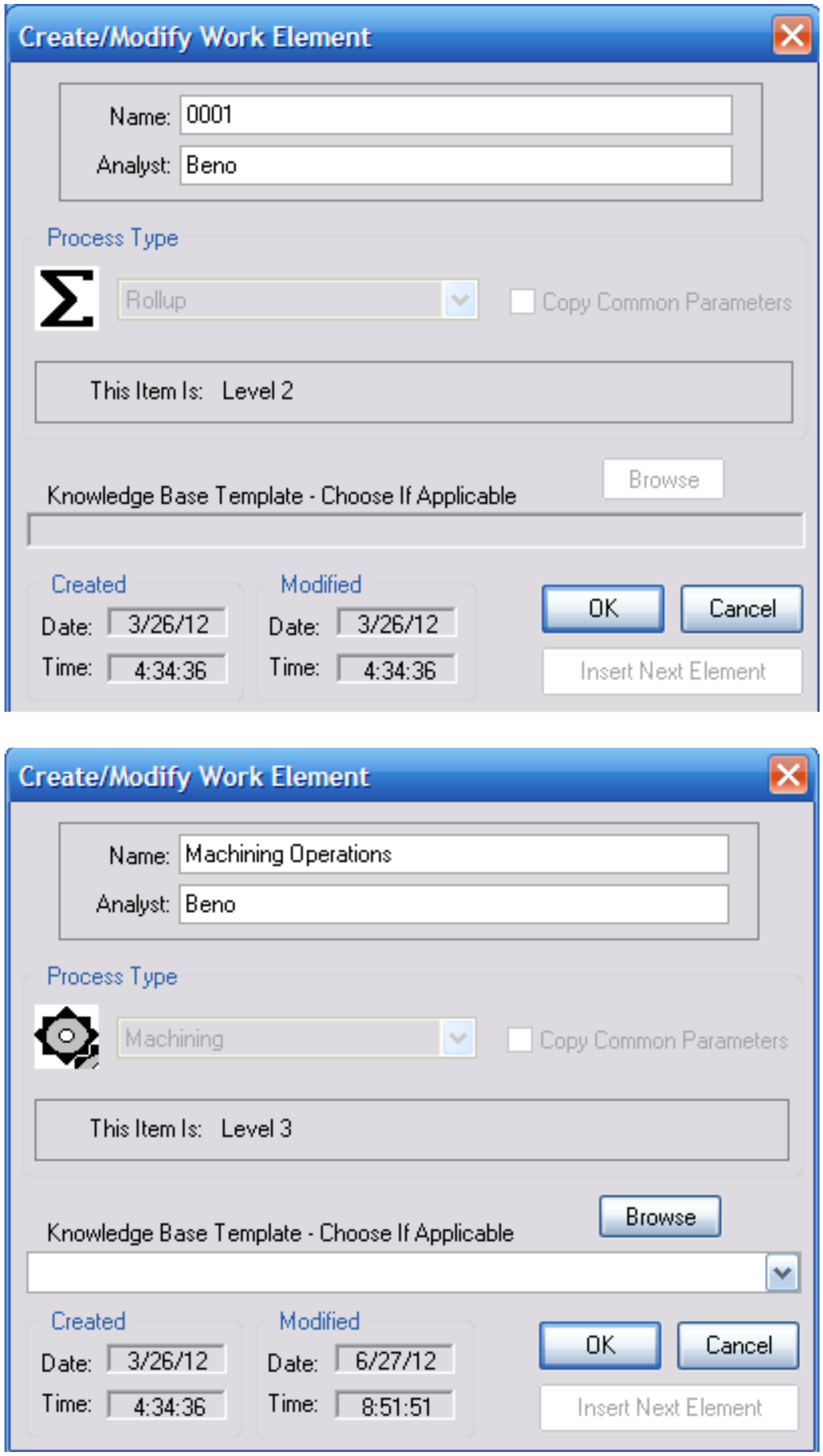
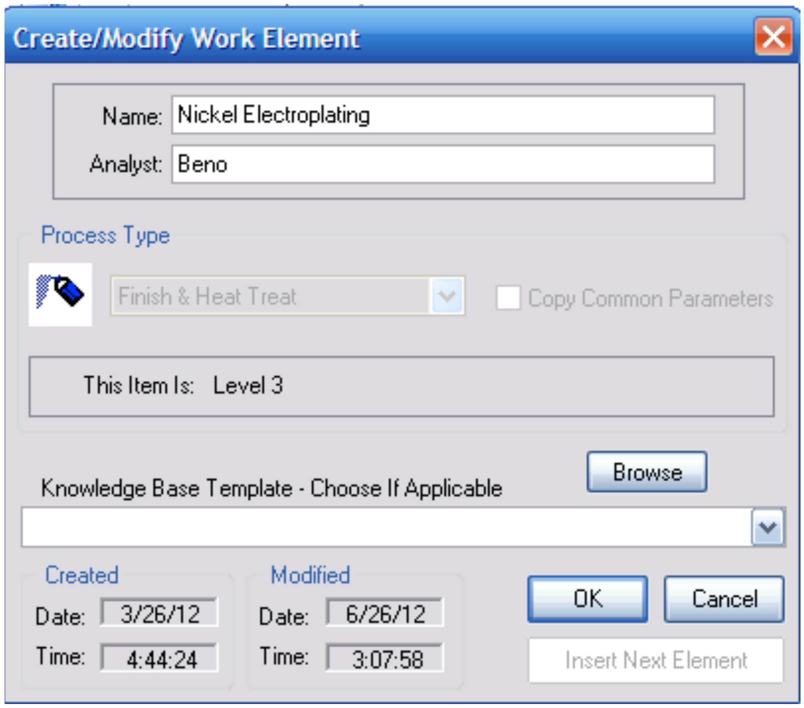


Figure 4.4.1: Create/Modify Work Elements and Work Elements Windows.



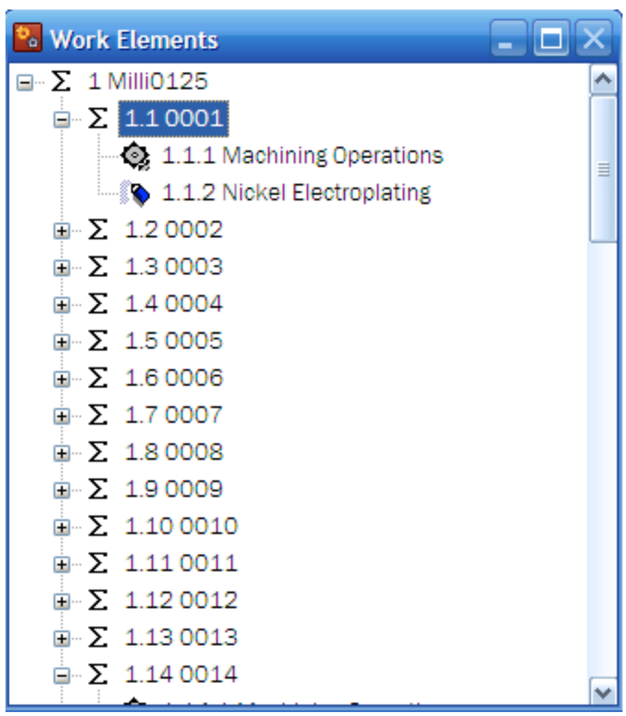


Figure 4.4.2: Create/Modify Work Elements and Work Elements Windows.

The first parameter is the Production Quantity of 20. Then Tool Steel is selected for the material. The next step is to determine the Raw Shape and its Dimensions, which is a rectangular with a length of 18 mm, a width of 12 mm and a height of 17 mm.

The Operations Parameters are considered next**.** The raw material is usually bought with a tolerance range of 0.060" to 0.125" or 1.2 mm to 3 mm larger that the final product's dimensions; therefore, the first machining step is squaring the part to required dimensions with a Radial Mill. Operation 1 and 2 Radial Mill the length from both sides to 16.78 mm; operation 3 and 4 Radial Mill the width to 15.50 mm; operation 5 End Mills the height to 10 mm. After the squaring, two boxes are machined with a Radial Mill. Operation 6 machines Box1, and operation 7, Box2. The next machining operations involve drilling. There are 7 holes in the part model; however, six of them can be drilled in pairs, and they are located on the sides of the part. Operation 8 drills three centers for the side holes; operation 9 drills four holes with a diameter of 2.31 mm; and operation 10 drills two holes with a diameter of 4.5 mm. The last hole is machined with operations 11 and 12. Operation 11 center drills the part, and operation 12, drills a 4.5 mm diameter hole. Figure 4.5 shows a picture of the Operations module for part model 0001.

OPERATIONS				
1 Squaring (Radial Mill Rough)	Rectangle	0.6100	12.0000	17.0000
2 Squaring (Radial Mill Rough)	Rectangle	0.6100	12.0000	17.0000
3 Squaring (Radial Mill Rough)	Rectangle	16.7800	0.5000	17.0000
4 Squaring (Radial Mill Rough)	Rectangle	16.7800	0.5000	17.0000
5 Squaring (End Mill Rough)	Rectangle	16.7800	11.0000	1.5000
6 Box1 (Radial Mill Rough)	Rectangle	14.4800	10.0000	9.0000
7 Box2 (Radial Mill Rough)	Rectangle	14.4800	4.1500	9.0000
8 (Drill)	Center Drill	4	0.5000	0.0120
9 (Drill)	Twist	4	3.0000	2.3100
10 (Drill)	Center Drill	3	0.0120	0.0120
11 (Drill)	Twist	3	3.0000	4.5000
Add Next Operation Here				

Figure 4.5: Operations Module for Part Model 0001.

The Tooling Cost and Set-up Cost Parameters are considered next**.** The quantity of part model 0001 is of 20 parts; therefore, Set-up Amortization and Tooling Amortization are considered in this quote. The Set-up Amortization Quantity is the number of parts that are machined in one set-up; for this estimation, the number is 20. The Tooling Amortization Quantity is the total lifetime number of parts per tool; for this case, 100 parts.

Once the model is completed, SEER-MFG calculates and outputs the estimations in a sub-window. The estimations are: cost of material, TTM per part quantity, and cost per part.

An online chronometer is used for this experiment to collect the Time-To-Quotes. See Figure 4.6. The time clock is started before the creation of the part models work element and stopped at the entry of the last parameter. The time is in minutes.

Figure 4.6: Online Stopwatch Used for Time Keeping.

4.3 Actual TTM vs. SEER-MFG's TTM

The Actual TTM vs. SEER-MFG's TTM analysis is the study between the real time-to-manufacture and the time-to-manufacture of SEER-MFG of some number of part models. This analysis is important in that it determines the accuracy of the computer system compared to the performance of the machine shop plant. In order to accomplish this comparison, MAQYPROYIND's historical parts, which have the TTM recorded, are collected.

4.3.1 Part Models

Fifty historical part models were collected for this analysis. These parts are made of a variety of materials, have different sizes and machinability, and belong to more that one customer and project. Some of the parts form an assembly for a surface finishing semi-automatic machine; others are just spare part orders.

4.3.2 Actual TTM and SEER-MFG's TTM

The actual TTM of the 50 part models was recorded by the machinists. They were instructed to record the amount of time that it takes to machine a part on the part drawing and to archive it. When the quantity of the parts is more than one, the total hours of machining time are recorded together with the total quantity. The TTM used in this experiment for part quantities greater than one is the total TTM over the quantity. The 50 part models are estimated in SEER-MFG in the same manner as described in Section 4.2.3.

4.4 Estimated TTM vs. Actual TTM vs. SEER-MFG's TTM

The relationship between traditional and SEER-MFG time-to-quote and the relationship between SEER-MFG and actual time-to-manufacture have been discussed; however, there are two more studies presented in this thesis, the relationship between the estimated TTM and the actual TTM and the relationship between the estimated TTM and SEER-MFG's TTM. These last two relationships are important in that the former evaluates the current traditional quoting system that the machine shop uses, and the latter determines how different the two quoting methods are from each other.

CHAPTER V

RESULTS

The following sections report the results for the analysis done to determine the time efficiency, and accuracy, and compares time-to-manufacture (TTM) between traditional and computer estimation systems and the actual TTM.

5.1 Timing Experiment

As mentioned in previous chapters, the traditional vs. SEER-MFG analysis determines which of the systems is more efficient. In order to determine this, seventy part models were quoted and timed for both systems. Using a spreadsheet, the percentage differences are calculated per part and averaged. The percentage was obtained by subtracting the traditional time-to-quote to SEER-MFG time-to-quote and divide it by the traditional time-to-quote for each part model involved and then taking the average of these differences.

5.1.1 Traditional vs. SEER-MFG Results

The results of the time efficiency case study indicate that the cost-estimating computer system is quicker than the traditional cost-estimating system. The difference percentage average is 10.2% for the seventy part models analyzed, and it is positive, which suggests that the traditional time-to-quote is greater by 10.2%. Equation 5.1 applies for this calculation, and Table 5.1 summarizes these results.

$$Eff_n = \frac{\sum_{n=1}^{N} \frac{(TTTQ_n - STTQ_n)}{TTTQ_n}}{N} \tag{5.1}$$

where, *Eff* = the time efficiency,

TTTQ = the traditional time-to-quote,

STTQ = SEER-MFG time-to-quote and

N = the number of part models involved.

Table 5.1: Results from SEER-MFG's Timing Experiment Compared to Traditional.

Average Time Efficiency of SEER-MFG
10.2%
Standard Deviation
18%

5.1.2 Test of Hypothesis for Timing Experiment

It is important to determine if the mean of the time efficiency experiment is significantly different on a statistical basis than zero. In order to determine this, a chi-squared test of hypothesis is employed on the data gathered. The data is organized in two categories: SEER-MFG TTQ as the observed category and traditional TTQ as the expected category. The null hypothesis states in this test that the data from both categories are equal and there is no significant difference; therefore, if the null hypothesis is rejected, then the difference between SEER-MFG TTQ and traditional TTQ is significant. The results show that chi-square is 86.22 and with a confidence of 90% and degrees of freedom equal to 69, the chi-square value from the distribution table is 89.39, and p-value is 0.0785.

According to the results of the test of hypothesis, the null hypothesis can be rejected with 92.15% confidence. Therefore, the difference between the mean of the differences in times-to-quote between traditional and automated system is statistically significant with 90% confidence.

In other words, the test proves statistically with a confidence of 90% that the difference between systems is present, and that the automated cost estimation system is faster to quote by 10.2% than MAQYPROYIND's traditional quoting with a 90% confidence.

5.1.3 Payback

Now that it has been determined that the automated cost estimation system has an advantage over the traditional system by 10.2%, the payback analysis can be completed. The other factors necessary to calculate the payback are the fixed costs of the software investment and the variable costs as time saved per part estimated. The fixed costs factors include: cost of software and cost of training, and the variable costs factors include: time efficiency factor, average time-to-quote traditionally and labor cost rate. Equation 5.3 determines fixed costs, equation 5.4 variable costs and equation 5.5 payback point.

$$FC = SC + (T \times LC_r) \tag{5.3}$$

$$VC = Eff \times \mu_{Tpp} \times LC_r \tag{5.4}$$

$$P = \frac{FC}{VC} \tag{5.5}$$

where, FC = fixed costs,

SC = software cost,

T = training time in hours,

LC_r = labor cost rate

VC = variable cost

Eff = efficiency percentage

μ_{Tpp} = mean time-to-quote per part, and

P = payback point.

The results of the payback indicate that 46,970 parts to quote per year is the point to recover costs invested in employing automated cost estimation software. Software cost and labor cost rates are not provided to protect MAQYPROYIND's proprietary information.

5.2 Accuracy Experiment

In order to determine the accuracy of MAQYPROYIND's current cost estimation system and the SEER for Manufacturing cost estimation system times-to-manufacture, both methods are studied and compared to actual TTM. Fifty part models are used in this analysis. Estimated TTM, SEER-MFG TTM and Actual TTM are recorded on a spreadsheet and analyzed.

5.2.1 Traditional TTM vs. Actual Time-To-Manufacture

The results for the traditional TTM vs. actual TTM indicate that current method of cost-estimating is 152% different than the actual times-to-manufacture. See Equation 5.3. Out of these differences, most are over-estimated. This analysis shows that there is a risk for the machine shop that may cause the loss of biddings against the competition in the market because of overestimation of projects. Table 5.2 summarizes these results.

$$Diff_n = \frac{\sum_{n=1}^{N} \left| \frac{(TTTM_n - ATTM_n)}{ATTM_n} \right|}{N} \times 100 \qquad (5.3)$$

where, $Diff_n$ = percentage difference

$TTTM$ = traditional system's time-to-manufacture

$ATTM$ = actual time-to-manufacturing, and

N = the number of parts involved in the study.

Table 5.2: Results from Traditional TTM Estimations Compared to Actual.

Mean Difference of TTM between Traditional and Actual
1.52
Standard Deviation
1.52

5.2.2 Test of Hypothesis for Traditional vs. Actual TTM

A chi-square test of hypothesis is performed to determine if there is a statistically significant difference between the traditional TTM and the actual TTM. The results of the test show a chi-square of 265.80 and with a significance of 0.05 and degrees of freedom of 49, the chi-square value from the distribution table is 70.22; therefore, the null hypothesis can be rejected with a p-value of 0 and there is a statistically significant difference between the traditional TTM and the actual TTM. In other words, the traditional estimation of time to manufacture is different when compared to the actual time-to-manufacture by 152%, and the difference between the systems is statistically proven with a confidence of 95%.

5.2.3 SEER-MFG vs. Actual Time-To-Manufacture

The analysis suggests that the estimates of the computer system differ by 22.3% to the actual historical records. The percentage difference was determined using Equation 5.4.

$$Diff_n = \frac{\sum_{n=1}^{N} \left| \frac{(STTM_n - ATTM_n)}{ATTM_n} \right|}{N} \times 100 \tag{5.4}$$

where, $STTM$ = SEER-MFG's time-to-manufacture and the other terms are as in Equation 5.3. Table 5.3 summarizes theses results.

Equation 5.4 takes the absolute value of the difference between SEER-MFG's TTM and actual's TTM; however, if the absolute value is removed from the equation and allow the negative and positive values to cancel one another, the sum of these differences is negative. This suggests that the estimation of SEER-MFG's TTM manufacture is less than the actual most of the times.

Table 5.3: Results from SEER-MFG's TTM Estimations Compared to Actual.

Mean Difference of TTM between SEER-MFG and Actual
22.3%
Standard Deviation
16%

5.2.4 Test of Hypothesis for SEER-MFG vs. Actual TTM

A chi-square test of hypothesis is also performed to show if there is a statistically significant difference between the SEER-MFG TTM and the actual TTM. The results of the test show a chi-square of 8.52 and with a significance of 0.05 and degrees of freedom of 49, and the chi-square value from the distribution table is 70.22; therefore, the null hypothesis can not be rejected with a p-value of 1. In other words, it can be stated that there is not a statistically significant difference between the SEER-MFG TTM and the actual TTM. Also, that SEER-MFG TTM is statistically proven to be close the actual TTM with a confidence of 95%.

5.3 Variability

In order to study the consistency of the traditional cost estimation method and the automated cost estimation method, the variability of the data collected is considered. The variance of the difference between the traditional TTM and the actual TTM together with the variance of the difference between the automated TTM (SEER-MFG) and the actual TTM are shown in Equations 5.5 and 5.6, and Table 5.4.

$$Var_{TvsA} = \frac{\sum_{n=1}^{N}(TTTM_n - ATTM_n)^2 - \frac{\left(\sum_{n=1}^{N}(TTTM_n - ATTM_n)\right)^2}{N}}{N-1} \tag{5.5}$$

$$Var_{SvsA} = \frac{\sum_{n=1}^{N}(STTM_n - ATTM_n)^2 - \frac{\left(\sum_{n=1}^{N}(STTM_n - ATTM_n)\right)^2}{N}}{N-1} \tag{5.6}$$

where, Var_{TvsA} = the variance of the difference between traditional and actual TTM, and

Var_{SvsA} = the variance of the difference between SEER-MFG and actual TTM.

Other variables in Equations 5.5 and 5.6 remain as previously defined.

Table 5.4: Variability of Traditional TTM Compared to Actual.

Variance of Difference of TTM between Traditional and Actual
4.53 hrs
Variance of Difference of TTM between SEER-MFG and Actual
0.49 hrs

The variance of Traditional vs. Actual TTM's is about four and a half hours. The variance of SEER-MFG vs. Actual is about half an hour. The results of the variability analysis suggest that the automated cost estimation method has a greater consistency when compared to the traditional cost estimation method; therefore, SEER for Manufacturing allows MAQYPROYIND to have more control of risk in cost estimating.

5.3.1 Test of Hypothesis for Variability

In order to test if the difference of the variances discussed in the last section is statistically significant, a hypothesis test on the ratio of the two variances is performed. Montgomery and Runger's (2006) method is used. The null hypothesis states that the variance of traditional vs. actual TTM is equal to the variance of SEER-MFG vs. actual TTM.

With a confidence of 95% and degrees of freedom of 49, the lower limit and the upper limit is 0.567 and 1.762, respectively. The test statistic, given by Equation 5.7, is 9.22. Since the test statistic value is out of the limit range, the null hypothesis can be rejected. In other words, there is a significant difference in the consistency between the traditional system and the automated system, and the automated system is more consistent.

$$f_0 = \frac{Var_{Tvs.A}}{Var_{Svs.A}} \tag{5.7}$$

Now that the averaged and standard deviations of the corresponding case studies have been reported and analyzed with consideration of its significance, some important statements and conclusions follow in the next chapter.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Future Work

This thesis has answered a number of questions, and these questions are important. It has determined the time to complete training, it has determined that SEER-MFG is faster to produce a quote than the traditional quoting system, it has determined the payback for the software implementation, it has determined that SEER can accurately model manufacturing processes, and that it is more accurate than the traditional estimation; however, this thesis has not answered all questions. One question that still exists is what it the worth of the improved accuracy and consistency?

When the issue of the worth of improved accuracy and consistency is examined, it is known that improved accuracy helps the machine shop to obtain more jobs. And if more jobs are obtained, the overhead can be spread over a larger quantity of work, allowing the machine shop to be even more competitive in the marketplace. The first part of the continuation of this study would be to determine how many more jobs would be accepted or rejected if SEER-MFG vs. traditional is used for quoting. This would involve a several year study in which data would be gather data for the traditional and SEER-MFG cases.

In addition to the issue of obtaining more jobs, it is known that more accuracy and consistency allows better control of the machine shop's performance in the market place. This means a greater avoidance of losing money, so there is less risk. Although it is possible to quantify risk as it relates to return, since risk is linked to interest rates and cost of capital, that analysis might be problematic. So instead, the number of lost jobs for traditional and SEER-MFG could be considered to find if there is a difference which can be proven statistically significant.

Additionally, when there is a bidding situation and the bid is high, the customer may never call back again, so accuracy of cost reduces the potential of losing customers. So, another part that could be considered as future study is to look at how many customers are lost using traditional vs. SEER-MFG. Once again, a statistical significant difference would be necessary to prove this point. Further, the value of marketing to gain a new customer could be found, in other words, how much effort and marketing time is required to find a new customer, because every time one customer is lost, a new customer is needed. The value of gaining a new customer is the value of losing a customer.

So if all of these factors are put together, how many more jobs can SEER-MFG win, how the risk of losing money is minimized, how the risk of losing customers do to a high bid is diminished, and results are quantified, then the question of what is the worth of improved accuracy and consistency is no longer exists; however, this is a large and extensive study which is being recommended as an extension to the current work and as a future thesis for another student. It is considered beyond the scope of this work.

6.2 Final Words

In the present economy, the investment of money must be done with caution, and extra effort is necessary to accomplish a return of investment and to stay competitive. So, cost estimation is the foundation of business effectiveness, especially in manufacturing, since the capacity of a company to remain competitive in the market and the ability to generate revenue depend on it. It is known that small manufacturing companies seem to have cost estimation difficulties that are different to the ones that large manufacturing companies have. Some of examples of these difficulties are quoting new products in a constant basis and relying mainly on machining experience to determine the cost of manufacturing. In other words, without a strong base in a cost estimation system, a manufacturing company may lose money if estimations are under the actual cost and may lose biddings if estimations are over the actual cost. Both of these eventualities pose significant threats to the existence of the business. So, accuracy is important.

However, computer systems have taken an important role in engineering and have proven to eliminate risks caused by uncertainty by using analytical and parametric expert systems. Some of the applications of expert systems discussed in this thesis were product development and concurrent engineering, manufacturing and assembly optimization, optimization of cutting parameters in machining operations and manufacturability, among others. Knowing that there have been various approaches to determine the cost of manufacture for a given part model, such as Knowledge-based, Case-based, Object-based, Agent-based, and Artificial neural networks and others, a parametric and Knowledge-based approached system was chosen to be employed by a machine shop located in Mexico. In this study, the differences between the traditional experience-based system currently employed and the automated alternative were examined, and the name of the system that was employed is SEER for Manufacture version 6.1, software which license was donated by Galorath Incorporated.

In order to prepare for the software implementation in the machine shop, software training was necessary. The training was consisted in taking a crash basic course on the software given by an expert in the software that was employed by Galorath Incorporated, and it also consisted in doing practice estimations using some part models that MAQYPROYIND had in archives. It was reported in this thesis that the training was done and completed until the time-to-quote learning curve reaches a fixed point, and the total training time was 27.08 hours. The time-to-quote of the practice models reached an average of 12.3 minutes for the last fourteen part models used. Once training was accomplished, the process to gather experimental data was begun. The data involving the traditional aspect was gathered by two machinist and quoting experts, and the data involving the automated system was gathered by the author. Data was gathered to analyze time effectiveness, accuracy and payback of the software implementation in the shop. The data from seventy part models was recorded to study the time effectiveness and payback, and the data from fifty part models was used to study the accuracy. The data was analyzed by using basic statistics, mean and standard deviation, and test of hypothesis.

Once the data was gathered and organized in spreadsheets, the statistical analysis was done. The results from the analysis indicated that the software was 10.2% faster that the traditional quoting system; however, when the payback is considered and calculated using the time efficiency factor, the payback point was still high at 46,970 parts, which means that time efficiency, though is present, is not significant. Also, the results showed that the software has an average time-to-manufacture percentage difference of 22.3% between SEER-MFG's TTM and actual TTM compared to 152% difference between the traditional and actual TTMs. This difference means that SEER-MFG is more accurate than the traditional, and this is a good justification to invest in the automated system. Also, the variability analysis showed that SEER-MFG has greater consistency than the traditional cost estimation method. The variance of the difference between the traditional and actual TTM was of 4.52 hours, and the variance of the difference between the automated and actual TTM was of 0.49 hours. To see if the variances are statistically significantly different, the variances were tested using Montgomery and Runger's

(2006) test of hypothesis method, and the results showed that there is statistically significant difference between the consistencies and variances of the traditional and automated systems; therefore, the fact that the automated system is more consistent than the traditional is a justification for MAQYPROYIND to invest in SEER-MFG.

By using an automated cost estimation system in the small machine shop, quotes can be generated 10.2% faster, but that is not a significant factor. What is significant is that substantially better accuracy and consistency can be achieved. This consideration represents an important characteristic that can dramatically help the small machine shop to remain competitive in a global economy.

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APPENDIX

APPENDIX

Data for Traditional vs. SEER-MFG TTQ

part#	Time2QuoteSeer(min)	Time2QuoteTrad(min)	Diff
0001	10.4	20	0.48
0002	8.6	10	0.14
0003	8.3	10	0.17
0004	5.8	5	-0.15
0005	4.2	5	0.17
0006	6.1	10	0.39
0007	6.2	5	-0.23
0008	4.6	5	0.08
0009	7.3	10	0.27
0010	8.7	10	0.13
0011	5.8	10	0.42
0012	6.3	10	0.37
0013	5.6	10	0.44
0014	12.0	10	-0.20
0015	13.0	10	-0.30
0016	2.5	5	0.50
0017	1.1	5	0.77
0018	7.4	5	-0.48
0019	4.9	5	0.03
0020	6.4	5	-0.29
0021	6.3	5	-0.26
0022	7.7	5	-0.53
0023	6.9	5	-0.37
0024	3.6	5	0.29
0025	13.9	15	0.07
0026	6.1	10	0.39
0027	3.4	2	-0.69
0028	3.2	3	-0.07
0029	1.9	3	0.36
0030	10.6	10	-0.06
0031	8.7	10	0.13
0032	4.9	5	0.02
0033	4.7	5	0.06
0034	5.6	5	-0.12

part#	Time2QuoteSeer(min)	Time2QuoteTrad(min)	Diff
0035	3.9	5	0.21
0036	3.9	5	0.22
0037	1.6	5	0.68
0038	8.5	5	-0.70
0039	4.0	5	0.20
0040	6.0	5	-0.20
0041	1.9	5	0.62
0042	23.9	15	-0.59
0043	2.1	10	0.80
0044	9.3	10	0.07
0045	4.1	10	0.59
0046	7.1	5	-0.41
0047	1.2	5	0.76
0048	2.4	10	0.76
0049	2.2	5	0.57
0050	1.1	5	0.78
0051	6.3	5	-0.26
0052	2.6	5	0.47
0053	5.6	5	-0.11
0054	4.2	5	0.17
0055	3.0	5	0.41
0056	7.1	10	0.29
0057	9.5	5	-0.89
0058	6.8	5	-0.37
0059	6.1	5	-0.23
0060	7.3	5	-0.45
0061	3.7	5	0.27
0062	2.1	5	0.59
0063	6.6	5	-0.32
0064	2.9	5	0.43
0065	2.9	5	0.42
0066	0.8	5	0.84
0067	4.8	5	0.04
0068	10.0	5	-1.00
0069	3.2	5	0.36
0070	4.0	5	0.21
		Average % Difference:	10.2%

Data for SEER-MFG vs. Actual TTM

Part#	SEER(hr/pt)	Actual(hr/pt)	Diff S vs. A
AB25A060	0.59	0.90	0.34
AB25A104	0.48	0.60	0.20
AB25A105	0.55	0.80	0.31
AB25A107	0.28	0.47	0.40
AB25A109	0.38	0.33	0.14
AD02A188	0.30	0.35	0.14
BARPUSHER	1.00	1.10	0.09
CYLINDERBAR	0.96	0.90	0.07
JG10A109	1.59	2.00	0.21
JG10A110	0.66	0.63	0.06
JG10A126	2.33	3.00	0.22
JG10A131	1.19	1.50	0.21
JG10A134	1.64	2.13	0.23
JG10A135	1.42	2.00	0.29
JG10A136	0.50	0.63	0.20
JG10A143	4.07	4.13	0.01
JG10A144	1.35	1.38	0.02
JG10A147	5.83	5.50	0.06
JG10A150	2.13	1.66	0.28
JG10A152	2.11	2.00	0.05
JG10A154	2.80	3.00	0.07
JG10A156	2.13	1.58	0.35
JG10A157	1.26	1.38	0.08
JG10A164	1.72	2.00	0.14
JG10A165	1.33	1.33	0.00
JG10A168	1.47	1.00	0.47
JG10A175	0.86	1.00	0.14
JG10A177	0.89	0.75	0.19
JG10A182	4.48	8.25	0.46
JG10A183	3.27	2.00	0.64
JG10A185	1.04	2.23	0.53
JG12A108	2.44	2.00	0.22
JG12A163	3.16	3.00	0.05
JG12A168	2.46	2.00	0.23

Part#	SEER(hr/pt)	Actual(hr/pt)	Diff S vs. A
JG12A172	3.86	6.92	0.44
JG12A178	0.92	0.75	0.23
JG12C104	3.24	3.00	0.08
JG12C105	2.33	3.00	0.22
JH02A380M	3.15	3.00	0.05
JH02A382	1.60	1.75	0.09
JH02A383M	3.72	3.50	0.06
JH02A384	0.40	0.55	0.27
JH02A391	1.43	1.50	0.05
JY12A045	2.15	1.50	0.43
Part C	0.3	0.625	0.52
Part E	0.41	0.63	0.34
PUSHER	3.46	4.00	0.14
QY012612	2.04	3.50	0.42
QY012612-2	2.09	3.50	0.40
QY032212	2.06	1.58	0.30
		Average Percentage Diff:	22.3%

Data for Traditional vs. Actual TTM

Part#	TTTM	Actual(hr/pt)	Diff T vs. A
AB25A060	1.38	0.90	0.54
AB25A104	0.65	0.60	0.09
AB25A105	0.80	0.80	0.00
AB25A107	1.35	0.47	1.89
AB25A109	1.29	0.33	2.88
AD02A188	1.38	0.35	2.94
BARPUSHER	3.65	1.10	2.32
CYLINDERBAR	1.76	0.90	0.96
JG10A109	2.68	2.00	0.34
JG10A110	2.88	0.63	3.62
JG10A126	5.72	3.00	0.91
JG10A131	3.94	1.50	1.63
JG10A134	2.38	2.13	0.12
JG10A135	3.29	2.00	0.65
JG10A136	3.69	0.63	4.90
JG10A143	5.04	4.13	0.22
JG10A144	6.46	1.38	3.70
JG10A147	6.70	5.50	0.22
JG10A150	2.11	1.66	0.27
JG10A152	2.46	2.00	0.23
JG10A154	2.26	3.00	0.25
JG10A156	5.82	1.58	2.69
JG10A157	1.63	1.38	0.19
JG10A164	2.80	2.00	0.40
JG10A165	2.90	1.33	1.18
JG10A168	7.53	1.00	6.53
JG10A175	2.78	1.00	1.78
JG10A177	3.94	0.75	4.25
JG10A182	10.85	8.25	0.32
JG10A183	4.98	2.00	1.49
JG10A185	5.39	2.23	1.42
JG12A108	2.54	2.00	0.27
JG12A163	10.03	3.00	2.34
JG12A168	10.03	2.00	4.02
JG12A172	10.85	6.92	0.57
JG12A178	3.59	0.75	3.79
JG12C104	-7.02	3.00	3.34
JG12C105	6.34	3.00	1.11
JH02A380M	0.60	3.00	0.80
JH02A382	2.08	1.75	0.19

JH02A383M	0.65	3.50	0.82
JH02A384	2.09	0.55	2.81
JH02A391	3.67	1.50	1.44
JY12A045	1.75	1.50	0.17
Part C	-0.96	0.625	2.54
Part E	-0.43	0.63	1.70
PUSHER	4.14	4.00	0.04
QY012612	1.96	3.50	0.44
QY012612-2	1.96	3.50	0.44
QY032212	1.14	1.58	0.28
		Average Percentage Diff:	152.0%

BIOGRAPHICAL SKETCH

Benito A. Gonzalez was born in Brownsville, Texas in 1985. Benito earned his B.S. in Engineering Physics from the University of Texas at Brownsville in 2009. He graduated with two publications in the Journal of *Physics of Fluids* as a co-author doing research in vortex suppression. In 2012, he earned his M.S. in Engineering with concentration in Manufacturing. He worked as a Graduate Assistance for the Graduate's Office Department in the University of Texas Pan American from 2009 to 2010. He has worked in the machining industry as a purchasing consultant. Benito A. Gonzalez can be reached at beno85us@yahoo.com.