A statistical based cost estimation system for plastic molded parts: A design for cost approach
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A STATISTICAL BASED COST ESTIMATION SYSTEM FOR PLASTIC MOLDED PARTS: A DESIGN FOR COST APPROACH

by

Donald W. Merino

A DISSERTATION

Submitted to the Faculty of the Stevens Institute
of Technology in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Donald W. Merino, candidate.

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ABSTRACT:

TITLE: A STATISTICAL BASED COST ESTIMATION SYSTEM FOR PLASTIC MOLDED PARTS: A DESIGN FOR COST APPROACH

This dissertation addresses the development of a method for estimating the cost of plastic injection molded parts. The method for estimating parts is based on using a modified group technology system ("MGTS"). The MGTS is based on 14 variables which represent various part and mold features. A statistical process for developing the mold cost and cycle time regression equations and the decision process used to determine the best algorthim are developed in this thesis. Additionally, an engineering economics injection molding cost model is developed. This model uses sensitivity analysis to determine areas of design emphasis.

Plastic part costs are divided into five categories: capital costs, processing costs, post-processing costs, material costs, and set-up costs. General administrative costs, sales and research costs, and tax expenses are also considered in this model. The part piece cost is calculated by adding all the costs together and dividing them by the total production volume. Earlier reported methods do not offer the ability to find the approximate total cost of a plastic part in the conceptual phase of the design. It is believed that usage of this type of model will reduce the amount of redesign required in a typical development process.

Another contribution of this thesis is the determination of the accuracy of industry estimates for making plastic injection molds and for estimating the cycle time of a part. A benchmark for individual job accuracy is developed and then used to test the theorized models against.

ACKNOWLEDGMENTS

There is an old African saying, " It takes a whole village to raise a child." I have found that the making of a Ph.D. candidate likewise takes a community of people. I am indebted to many people and organizations for their help as I pursued this research.

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A. Introduction

In his 1991 Fortune magazine article, "Japan's Smart Secret Weapon", Worthy (Worthy 1991) stated that Japan's unique cost-management system helped Japanese companies reduce costs, undersell competitors and be first to market with new products. In contrast, most US corporations employ a sequential practice of determining cost AFTER design, engineering and supplier pricing. This practice not only results in recycle and rework, but also fails to consider that cost is a driving factor in product design and engineering. (Worthy 1991)

US and world industries are undergoing a transformation in how they manage their businesses. In particular, the methodologies used in the Research, Development, Engineering and Manufacturing functions have changed significantly. Product and Process development are no longer seen as sequential activities with separate entities contributing their expertise. Now the process is often concurrent and is supported by many decision support models(Worthy 1991).

Concurrent Engineering is part of the movement to integrate the business and technical functions in industry. However, most engineers and scientists have very little business or management training or education to help them function in this new organizational paradigm. Many that do consider the application of managerial principles overlay them on engineering practices and do not use them as an integral and inseparable component of good engineering activities.

To be competitive, manufacturers and producers of goods must deliver products which meet customer requirements of cost as well as quality. Global competitors plan their new products' introductions to meet a specific cost range. This is done by setting Target Costs (Worthy, 1991). Target Costs are the costs the product must meet in order to realize a profit and create or penetrate a market. The definition of quality as meeting customers' specifications should include the price the customer is willing to pay. This approach is referred to as Design for Cost (DFC) and is practiced in a concurrent engineering context (Michaels & Wood, 1989).

Concurrent engineering utilizes multifunctional teams and a variety of models and tools to design parts. As part of my 3M fellowship, I investigated a number of best-of-breed companies that designed plastic parts. Many designers used mold filling and finite element analysis software packages to assist in the design. However, no one used a cost prediction model to assist in the design. Although much finite element analysis affords a designer a way to determine if a design meets the customer requirements of strength, a cost analysis is needed to determine if its part cost meets the customer's requirement. (Merino, 1994).

B. Need for a Cost Model

Properly functioning design teams continually assess cost tradeoffs and use this information to improve the cost estimates as the product design teams move through the product development cycle. Initial estimates developed in the conceptual design phase are updated during the definition and scoping phases of the design. There was a consensus among the designers, engineers and moldmakers worked with during this research that concluded a knowledgeable designer should routinely be able to estimate the cost of a plastic part to within +/- 30% to +/- 50% at the initial feasibility stage.

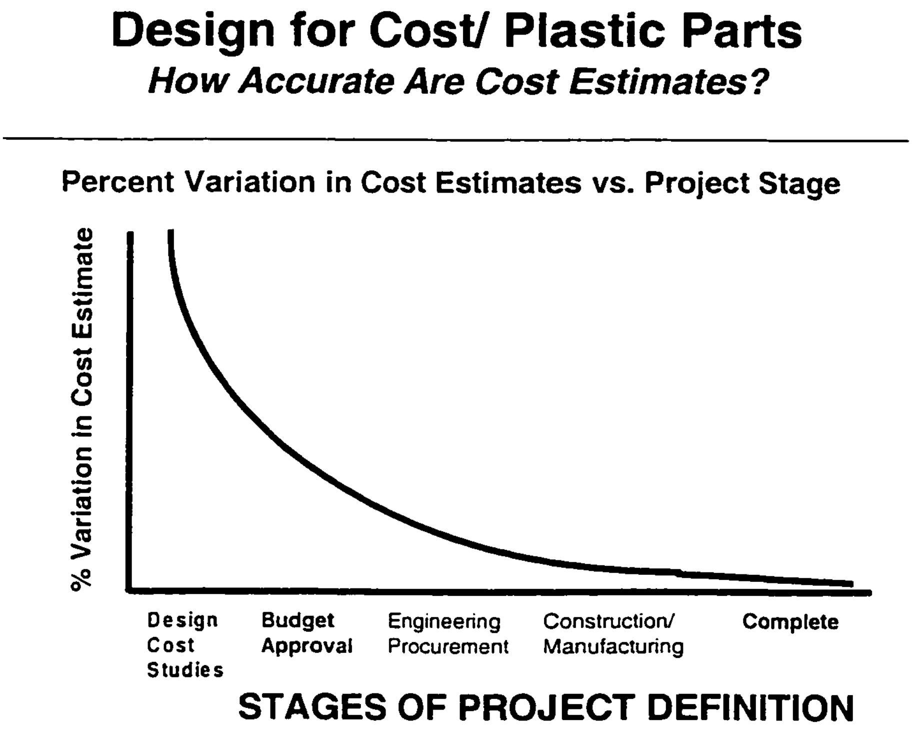

Figure I.B-1

Figure I.B-1 shows the variation in cost estimating as the project process through the various stages of development (Merino, 1994)

As the project progresses and the design team spends more time working on the product, the accuracy of the estimate can be increased by increased effort. However, while the accuracy of the cost estimate increases with time and effort , the cost to change the design also increases.

A number of companies have studied the cost to fix or correct defects at various stages of development. IBM concluded that the cost of fixing an error in R&D was $1, in manufacturing $4 and in the field $80. In a Quality Progress article an AT&T Bell Laboratory executive suggested that for their type of technology the ratios are $1 - $100 - $1000 (Mayo, 1986 and Symposium V : New Paradigms in RD & E, April 13, 1994). In either case, these studies reflect the simple fact that making changes during the early design phase is a lot less expensive than making the same changes in either manufacturing or in the field (Michaels & Wood, 1989).

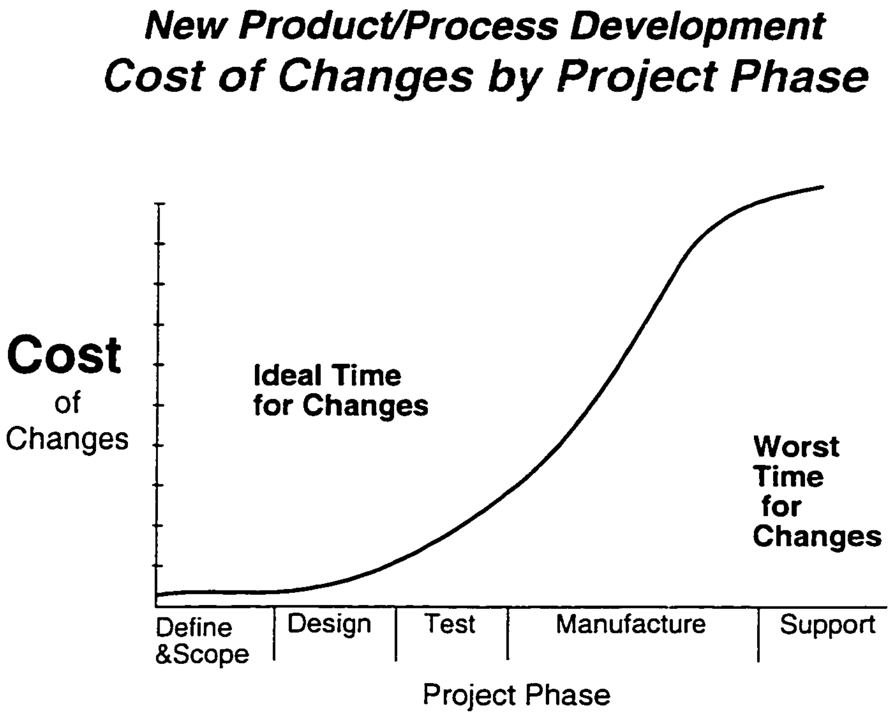

Figure I.B-2

A tenet of concurrent engineering, as opposed to the traditional sequential method, is to spend more time in the design phase when the changes are easier and less costly in order to reduce the need for change latter in the process when the cost is greater (Figure I.B-2). Many products are redesigned during the later phases of test and manufacture because it was discovered that the product costs too much. This forced redesign or rework significantly increases the product life cycle cost.

Designing products to meet a predetermined cost requires a new paradigm. In the old method of design, marketing concentrated mainly on physical product characteristics, which were converted into design and engineering characteristics on drawings. These drawings were passed to the molders and mold makers who determined the cost of the product. If the cost exceeded the acceptable cost to the customer, the product was redesigned. This sequential design process is displayed in Figure I.B-3.

In practice there are many feedback loops after the initial costing phase, or after the manufacturing phase. Each of these feedback loops costs cycle time and money. And as stated earlier, these later iterations are much more costly than getting it right the first time.

Current Sequential Decision Process for New Product Development

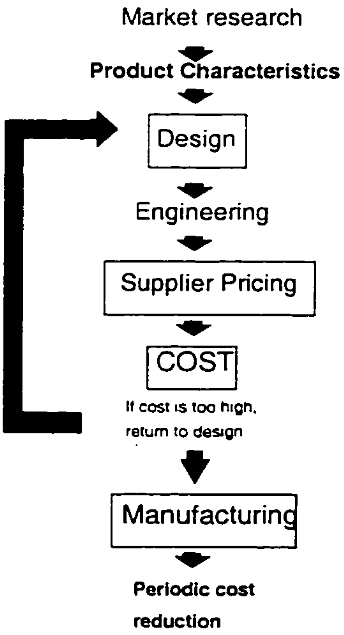

Figure I.B-3

In the new paradigm, marketing not only passes on the product characteristic , but also the cost for the product that the market will accept. Based upon this Target Cost, the design, engineering, and supplier pricing is done concurrently with the goal of meeting the customer's needs and price, (Figure I.B-4). In order to accomplish this new paradigm, it is critical to either rely on a " corporate memory" of product development costs, or develop a model to help the designers determine the critical cost tradeoff early in the design.

Concurrent Engineering Decision Process for New Product Development

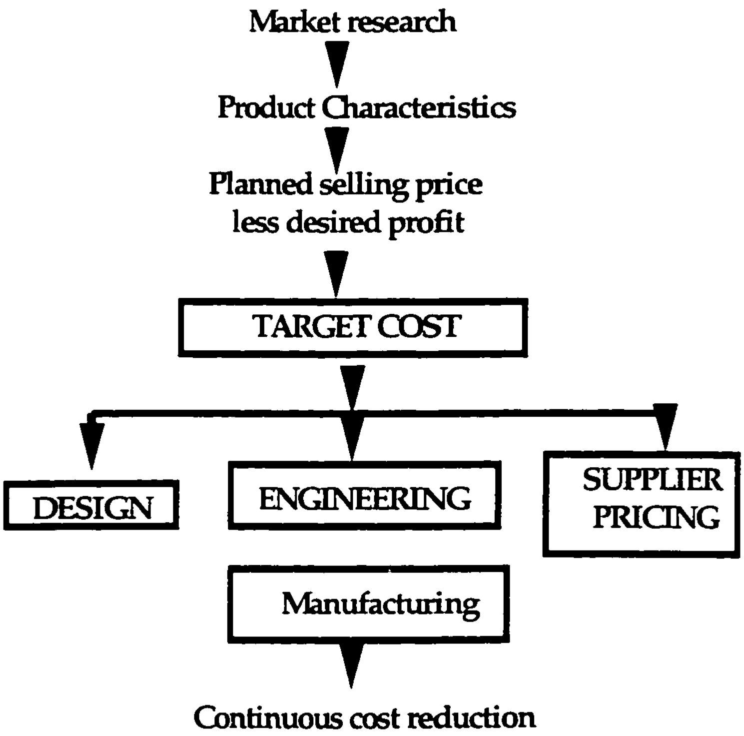

Figure I.B-4

It is assumed that the first step in the design process is a multiattribute analysis much like the popular Quality Function Deployment (QFD) method. Such analyses are used to develop the customer's requirements including both economic and non - economic attributes.

Next, at an early stage of design, an engineering economic model is proposed to determine the largest contributor to the overall costs, for example for plastic parts. This includes tooling , materials, processing, set-up, and post - processing. In later stages of the design the elements of the part cost can be sorted by their impact on the plastic part piece cost. This process uses engineering economics sensitivity analysis. The key is to determine the design features and their impact on the cost. The features that impact plastic part costs include material type, part complexity, part dimensions, wall thickness, tolerancing, etc. If the design feature/ cost impact can be determined one can develop a feature based cost model.

Finally, once the design is finished and the mold is designed, a machine based cost model can be used. The research in this dissertation concentrates on developing an engineering economics and feature based costing model.

C. Engineering Economics Methodology

An engineering economics methodology for the sensitivity analysis of the cost factors was developed as part of this research.

Engineering economics is that methodology which determines appropriate figures of merit for economic and non - economic attributes which are used to rank alternatives. Engineering Economics recognizes the Time Value of Money and the cash flows from operations. In this thesis, Engineering Economics is the methodology used to drive plastic component cost estimation models.

Plastic part costs can be divided into five categories: capital costs, material costs, processing costs, post - processing costs and set - up costs. These cost categories contain a number of variables. Some variables are unique to a single category while others affect one or more categories. Brief definitions of these costs are given in the paragraphs that follow.

- CAPITAL COSTS: The capital costs of a project consist of an initial cost representing the cost for the mold or jig. Subsequent one time costs may be incurred to replace molds, etc. . These costs are represented in the model as capital recovery costs, which are simply annualized one time costs. That is, instead of recording the first cost of the investment in the first year, it is spread out over the life of the project. Allocation for the cost of the molding machine is not found here but rather as part of the processing costs.

- MATERIAL COSTS: The cost of the raw materials required to manufacture or produce the product. These will be determined using part volumes or weights, material price per unit volume, or weight and the annual production volume.
- PROCESSING COSTS: The cost incurred to run the injection molding machine (labor, supervision, rent, utilities, amortization, etc.). These costs are based on the number of cycles per hour, the production volume and the machine rate.
- POST PROCESSING COSTS: Post - processing costs are those associated with machining and finishing operations after the part is injection molded. Examples include removing flashing, drilling holes and coating surfaces.
- SET-UP COSTS: Set-up costs are incurred in the initial set- up phases for the machinery before operations and production begin. The set-up cost will be determined on the basis of the set - up rate for the given machine size and the time required for set - up. Also determining the overall set - up cost for the productivity will be the number of such set- up cycles that would have to be carried out in one year.

- PRODUCTION VOLUME: The total number of pieces of the particular part that will be produced in a given year.

- OVERHEAD: Apart from the costs described above, there are other general administrative, sales and distribution costs that may not be directly related to production. However, in order to cover these costs, when calculating a price, an overhead cost is usually included.

D. Research Plan Description

In order to develop a cost model for plastic parts a comprehensive review of published sources was conducted. The objective was to benchmark the field in order to determine the scope and capabilities of existing costing models. Research revealed four costing models. They are:

- Poli, et al, from the University of Massachusetts (Fernandez 1987 & Kou 1990)

- IBM's Mold Cost Software (Pearce 1989)

- Menges, from the University of Aachen, Germany. (Menges 1986)

- Boothroyd & Dewhurst, Inc.'s Injection Molding Cost Estimating and Material Selection Software. (BDI 1992)

A number of mold shops were surveyed in order to assess the shop's accuracy in estimating mold costs.

A modified group technology cost model was developed to identify a coding structure for part features like molding. These codes were used to determine the cost of the part. The variables within the codes represent various mold and part features. A criterion for the group technology structure is that of being robust enough to give the cost of the mold, cycle time and material costs for the candidate part.

A statistical costing model was developed using the modified group technology system. Data from a set of best of breed companies was used.[1]

E. Significance, Implication And Utility Of The Research

The research resulted in a working computer-based model that estimates plastic part cost. The model also provides sensitivity analysis for all the major cost components. The model is consistent with industry standards and practices.

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[1] Group Technology is a system where parts are identified by a coding system that specifies features that require types of processing. Group technology is typically used for machined parts so that parts with similar codes can be processed together.

This research makes a number of key contributions to the field. First, no existing model offers the ability to determine the approximate total cost of a plastic part in the conceptual phase. Research conducted by both Pearce (Pearce 1987) and Menges (Menges 1986) results in models which first require that some degree of design already be completed, and second, offer only the approximate cost of the mold. Both methods fail to account for processing and set- up costs.

Poli (Kou 1990) on the other hand offers a relative cost method for the mold cost, processing cost and material costs. However, the relative cost ignores the time value of money and while it may have directional significance leaves out the actual cost of the part.

Finally, the Boothroyd and Dewhurst (BDI, 1992) model offers an actual cost and is the most comprehensive model so far developed but has several weaknesses, including the need for a fully designed mold in order to establish cost and a total lack of any engineering economics.

The second key contribution is the sensitivity analysis method developed using engineering economics. To date, no research has been reported utilizing this approach for the cost estimation of plastic parts.

Thirdly, the research will offer a benchmark of present industry estimating practices and accuracy. No other researcher has accomplished this.

By surveying a number of mold and molding shops an accuracy range for industry was developed as a benchmark for any models developed.

The resulting model demonstrated as a software package can be marketed to industry as a valuable tool that makes part design and costing interactive in a concurrent decision process, thereby improving the accuracy of early cost estimation of plastic components.

One of the goals in concurrent engineering is to determine the target cost at the beginning of the design cycle by examining such factors as design, engineering and supplier pricing in parallel. With the statistical cost estimation procedures developed, cost models can be developed and the concurrent engineering multifunctional team will have the ability to choose attributes and determine costs in a real-time basis without having to go through the complete designs. Hence the application of the model developed allows a part designer to change the features of the design and very quickly see the cost impact of these changes.

Use of this type of cost model in the American manufacturing industry will aid in the reduction of recycle and rework costs, thereby allowing the companies to present a product to market that will be more cost effective than competing products designed in a sequential manner.

A. Introduction

A systematic literature review was conducted to determine the prior work in the area of cost modeling for plastic injection molded parts. A number of authors have addressed cost either directly or indirectly in their writings. Typically these writings can be put into four major categories.

The first category are writers that recognize costs as an important design consideration and postulate design rules for parts to lower costs by improving part processing (i.e.: mold fill, part ejection, etc.). Glenn Beall (Beall, 1989) is an example of one such writer. While these writers offer some excellent design rules which all designers should use, they do not address cost in a comprehensive or systemic way by developing a model to determine the cost of the part.

The second group of authors describe software products used to emulate the mold process. Products like C-Mold and Moldflow are examples of such programs (Cinquegrana, 1990). These programs will allow the user to simulate the molding process to determine if the mold will fill properly or if flash will occur. These are excellent aids to the designer and can be used to determine the cycle time required by a part or the best material to mold the part. They fall short in developing a total part cost based on a comprehensive analysis of all the potential cost drivers.

The third group are software products that emulate standard estimating sheets used in many mold or molding shops. For example, Robert Beard's software program PART-COST (Beard 1992) automates present cost estimating methodologies but requires the estimator to come up with the key inputs (cycle time, mold cost, etc.). The chief benefits of this method are to organize the inputs and act as a spreadsheet to ease the calculation required to complete a quote. While this is a functional system and helps ease the burden of estimators in the field, it does not provide a comprehensive approach to costing based on the design of the part.

The final group of writers that will be described in detail below represent the best effort to date to try to integrate the design of the part and the cost in a comprehensive manner.

B. University of Massachusetts, Efforts of Poli Et al

B.1. Introduction

Corrado Poli (as reported in Otis 1989) conducted research on Design for Manufacturability (DFM) with Boothroyd and Dewhurst in the 1970s. Subsequently, he began work on an Economic Model for Injection Molding (EMIM) using group technology. This work was taken up by his student, Ricardo Fernandez (Fernandez 1987), who presented a model to produce relative costs based on features of plastic parts and the molds needed to create them. Another student, Sheng - Ming Kuo (Kuo 1990), developed a part feature methodology to predict relative cycle times for plastic part production.

B.2. Overview Of University Of Massachusetts Efforts

This chapter focuses on the history of design for manufacturing efforts at the University of Massachusetts and describes the EMIMs developed by Ricardo Fernandez (Fernandez 1987) and Sheng-Ming Kuo (Kuo 1990). Fernandez and Kuo both were graduate students at the University of Massachusetts in the 1980s under Corrado Poli. Professor Poli was one of the founders of the Design For Manufacturing field. In the late 1970s he worked with Boothroyd and Dewhurst

(Otis 1989) on the original National Science Foundation (NSF) funded design for assembly project. During the 1980s Poli dissolved the relationship with Boothroyd and Dewhurst to focus separately on Design for Manufacturing.

In the mid - 1980s Poli began to develop a variety of classification schemes for plastic injection molded parts to determine their cost. In 1985, J. Ruffo (Ruffo 1985) proposed three versions of a two digit coding system for die casting of parts. One digit was used to address mold complexity while the second digit was used to find the cycle time.

In 1986 Jitendra Divgi (Divgi 1986) extended the original work of Ruffo and determined that the factors which affect mold cost are different than the factors which affect cycle time. His project was a collaborative effort with Xerox Corporation and based on the Rank-Xerox Tool Cost Estimating Guidelines. Divgi studied only single cavity molds with two plates and a cold runner feed system. This narrow scope led some parts to qualify for more than one category, hence generating multiple costs and making redesign almost impossible. To compensate for this Divgi proposed further subdivision of mold complexity.

In 1987 Fernandez (Fernandez 1987) expanded the work of Divgi and developed a working group technology system for determining the relative mold costs of different part designs. Subsequently, Kuo (Kuo 1990) developed a group technology system to determine relative cycle times and an overall system to determine the relative total cost of a plastic part. It should be noted that much of the work accomplished for injection molding at the University of Massachusetts has been duplicated for die casting of parts and vice versa.

B.3. Mold Cost Estimating - R. Fernandez

In December 1987 Fernandez wrote "The Effect of Part Design on Tooling Cost in Injection Molding" (Fernandez 1987). In this masters thesis Fernandez describes a group technology method of coding plastic injection molded parts and then determines the relative costs of their molds. The first step in this coding system is to determine the basic shape and size of the part. Fernandez used a common technique in design for assembly by determining the parts envelope and then comparing the longest dimension (L) to the smallest dimension (H). Fernandez also used a number of other features to represent the cost drivers in his estimation model. A description of these features and their effects on mold cost follows.

B.4. Classification of Part Shape (Fernandez 1987)

Fernandez (Fernandez 1987) postulated the classification of part shape using the L/H ratio. The L/H ratio classifies a part as either flat or box shaped. Parts with an L/H greater than four are considered flat and parts with a L/H less than four are considered boxes. This ratio is critical to determine the machining time required for the part. Basically, the greater the depth and/or length, the more time it will take to machine the part. Additionally, L is used to classify the size of the part. L under 250mm is considered small, L between 250mm to 480mm is considered medium size and parts with L greater than 480mm are considered large.

B.5. Parting Line Complexity (Ruffo 1985)

Ruffo (Ruffo 1985) worked on parting line complexity. The parting line is the line where the two mold halves come together to complete the mold. The more complex this is the more costly the mold should be. To determine the parting line complexity, the first step is to determine the direction of mold closure. The direction of mold closure (or draw) helps identify the features which can be molded in the direction of mold closure. Features not in the line of draw will increase the cost of the mold. Additionally, when the direction of mold closure is determined it is important to determine the geometry of the dividing surface parting line. The parting line is defined as an imaginary surface in one or more planes, through the principal shape of the part that allows the part to be extracted from the mold. Parting lines in more than one plane will increase the cost of the part.

B.6. Part in Both Halves vs. One Half of Die (Ruffo 1985)

Ruffo (Ruffo 1985) addressed the above question of whether the die for a plastic part requires machining in one half or both halves of the die. Depending on this requirement a part is said to be moldable in one half or both halves of the die. Usually only parts with simple geometry can be molded in just one half of the die. However, if this is possible, die alignment is much easier and machining time is significantly reduced.

B.7. Undercuts (Fernandez 1987)

Fernandez (Fernandez 1987) studied internal undercuts. Internal undercuts are recessed features in a depression or projections in blind holes (not a through hole). The presence of an undercut prevents the insertion of a plug or side action to create these features. It also hinders the ejection of the part at the end of the mold cycle. To compensate for these features mechanisms like relievers, lifters or split cores are added to the mold. Their presence automatically requires the part shape to be in both halves of the die. Additionally, the complexity of the undercut will directly affect the cost of the lifter or split core design.

B.8. Side Actions (Fernandez 1987)

Fernandez (Fernandez 1987) also discussed side actions. Side actions are required when holes, slots or depressions not parallel to the line of draw are present in a part design. A side core is used to produce these types of features and must be retracted prior to the ejection of the part. Side actions are costly and have to be custom made for each design. The number of side actions are equal to the number of directions that imaginary plugs would be inserted into the part to create these features. Side action complexity is a significant cost driver. Two basic types of side action are addressed. Pin type side actions are less complex than wall type side actions (Fernandez 1987).

B.9. Cavity Detail (Fernandez 1987)

Fernandez (Fernandez 1987) addressed cavity detail. Cavity detail is a significant cost contributor, but its importance is often over-exaggerated. The complexity of cavity detail determines the additional machining and polishing time required for a part. Detail is usually in the form of ribs, bosses, holes and gussets; hence, these features will determine the cavity detail code. Cavity detail is expected to be a more significant cost driver for smaller parts, because features are more difficult to machine into very small parts.

B.10. Finish and Tolerance (Fernandez 1987):

Fernandez (Fernandez 1987) stated that surface finishes and tolerances also contribute to mold cost. Surface finish requirements need added grinding and polishing time. Texturing also requires additional machining time. The SPI-SPE (Society of the Plastic Industry -Society of Plastic Engineers) standard divides surface finished into 6 categories with SPE six (6) being the roughest and SPE one (1) being optimal grade. Tolerances are similar to finishes in as much as tight tolerances require extra costs due to multiple machining passes.

B.11. Description of Fernandez's Table (Fernandez 1987)

Once Fernandez (Fernandez 1987) determined the features with the greatest impact on mold cost, he set about determining how these features interacted to effect total mold cost. To accomplish this Fernandez created a set of 20 standardized part drawings and had these drawings quoted by three different moldshops. The estimates received from each company were compared with that company's drawings and relative changes in cost were determined. Based on these comparisons a table was created which showed the relative costs based on part and mold characteristics. This method seems to work well within a narrow family of parts.

B.12. Cycle Time Estimates - (S. M. Kuo 1990)

In 1990 Kuo wrote "A Knowledge Based System for Economical Injection Molding" (Kuo 1990). In this Ph.D. thesis Kuo describes a group technology system to determine the relative cycle time for a part and a method to determine the total relative cost of a part. Kuo assumes that the Fernandez or a similar method is used to determine the relative mold cost. Kuo notes that production rate is determined by the machine cycle time and production efficiency. The cycle time is the reciprocal of the production time. Because of this, cycle time is dependent on production efficiency and the cycle time is always greater than or equal to the machine cycle time. The difference is related to the penalties created by ejection problems caused by part geometry, tight tolerances and surface requirements.

B.13. Part Partitioning (Kou 1990)

To understand the problems associated with part geometry Kuo (Kuo 1990) introduced the concept of "part partitioning". To partition a part one must break the part into elemental plates and then apply the group technology system to the individual plates. Parts are first divided into partitionable and non-partitionable categories. Once a part has been determined to be partitionable into elemental plates the part is then sub-divided into slender and non-slender parts. If the part is a slender part the first digit depends on the lateral projections and/or ribs. For non-slender parts the first digit is determined by the presence of significant ribs or bosses. Additional divisions in these groups are based on grilled and slotted designs as well as the thickness of the ribs. The second digit is determined by the maximum thickness of the plate. The third digit is used to take into account the presence of internal threads and/or molded inserts. The fourth and fifth digit deals with the effects of surface gloss and tolerance.

Kuo's (Kuo 1990) explanation whether a part is partitionable or not is very limited. Rather, he relies on a diagram which depicts a part comprised of orthogonal slabs. A subsequent diagram "explodes" these slabs and shows that each should be thought of as an elemental plate. As an example, if a part is box-like (a cube with a hollow center) it can be partitioned so that the sides, top, and bottom of the box are viewed as elemental plates.

B.14. Slenderness (Kuo 1990)

As part of Kuo's research (Kuo 1990) he discussed slenderness. Slenderness is determined by measuring the unbent length (L) and unbent width (B) of a part. If L/B > 10 the part is slender and can be cooled quickly. Slender parts with lateral projections are difficult to fill. The "branch" can be filled if high melt temperatures are used. This results in slender parts without lateral projections having faster cycle times a slender parts with lateral projections.

B.15. Projections (Kuo 1990)

Kuo (Kuo 1990) addresses projections as a cycle time consideration. Projections are features that protrude from a part. Projections are typically considered bosses and ribs. A boss or rib can be considered significant or even another elemental plate. Significance is determined by measuring the width (b) and height (h) of the projection. This is compared to the maximum plate thickness (w). A projection is significant if $b > w$ or $3w < h < 6w$. The presence of a significant projection greatly increases the cycle time for the part.

B.16. Grilled or Slotted Parts (Kuo 1990)

A new concept introduced by Kuo (Kuo 1990) is grilled, slotted plates and frames. A plate is classified in this category if it has multiple holes, no continuous solid section greater than 20% of the projected area, and its height is equal to the wall thickness. These plates will have a faster cooling time than similar plates without these openings because of the lower weight and higher surface area in contact with the mold.

B.17. Wall Thickness (Kuo 1990)

Kuo (Kuo 1990) addresses wall thickness as a cycle time driver. It is generally agreed that wall thickness is the single most important factor affecting the cycle time of the part. Parts with thin, uniform walls solidify faster and use less material. Therefore, to lower the cost of the design, a thin, uniform wall is most desirable. It must be realized that there is a lower limit to this feature since a very thin wall will solidify so fast that the mold will not fill. Ribbing will help reduce the thickness of a part while maintaining the stiffness needed for the design.

B.18. Tolerance and Finish (Kuo 1990)

Tolerance is divided into two categories: "Difficult to Hold" and "Not Difficult to Hold" tolerances. Difficult to hold tolerances usually require 15-30% longer to cool than parts without difficult tolerances. Additionally, some materials are inadequate to hold difficult tolerances. Texturing and finish of the part also affect the cycle time. As noted above, in the mold cost segment Kuo (Kuo 1990) uses the SPI/SPE standards.

B.19. Other Features (Kuo 1990)

Kuo (Kuo 1990) also addresses other features which may affect the cycle time. Features like gear teeth, treads and living hinges increase the cycle time of the part. If these features form internal or external undercuts, the cycle time will be significantly increased. This increase is created by the presence of side actions, lifters, cams and unscrewing devices. Aside from the additional cycle time required to allow these mechanisms to operate, cooling problems often occur.

B.20 Total Cost Model - (Kuo 1990)

Kuo (Kuo 1990) also proposes a total relative cost model in his thesis. This total cost is made up of three parts: The total cost is represented by the following formula:

$$K_t = K_m + K_d + K_e \qquad (1)$$

Where,

K_t = Total Cost

K_m = Material Cost

K_d = Die Cost

K_e = Operating Cost

If K_o represents the total cost of a reference part the total relative cost,

C_r can be written as follows:

C_r = Relative Cost of Part

$$C_r = K_m/K_o + K_d/K_o + K_e/K_o \qquad (2)$$

By using the relative cost of each cost segment for the reference part, the formula can be rewritten as follows:

$$C_r = K_m/K_{mo}\ Kmo/K_o + K_d/K_{do}\ Kdo/K_o + K_e/K_{eo}\ K_{eo}/K_o \quad (3)$$

Where K_{mo}, K_{do} and K_{eo} represents the material, die and equipment costs for the reference part.

$K_{mo} = V_o K_{po}$ (4)

V_o = volume of reference part

K_{po} = the unit price of the reference material

$K_{do} = (K_{dco} + K) / N_o$ (5)

K_{dco} = die construction cost

K_{dmo} = die material cost

N_o = Number of cavities

$K_{eo} = t_o K_{ho} / (3600 N_o)$ (6)

t_o = the effective cycle time

K_{ho} = the machine rate (\$/hr)

N_o = the number of cavities

The equation (3) can be rewritten as:

$C_r = C_m f_m + C_d f_d + C_e f_e$ (7)

Where:

$C_m = K_m/K_{mo}$ represents the relative material cost.

$C_d = K_d/K_{do}$ represents the relative die cost.

$C_e = K_e/K_{eo}$ represents the relative operating costs.

$f_m = K_{mo}/K_o$ represents the % of material cost to total cost.

$f_d = K_{do}/K_o$ represents the % of die cost to total cost.

$f_e = K_{eo}/K_o$ represents the % of operating cost to total cost.

f_m, f_d, and f_e are determine based on the production volume of the part.

The reference part is a small plastic washer. Based on this reference part substitution can be made to make the equations for C_m, C_d and C_e dependent on only the values from the candidate part.

B.21. Summary

The methods described by Poli and his students represent one of the most comprehensive cost estimating methods in the published literature. Poli's students were the first to use a group technology system to identify the relevant cost drivers. Poli introduced the concept of relative costs used to delete the effects of local market conditions and labor practices. The concern over relative costs centers around the starting point used to base the cost.

For example, Fernandez used a starting point of a 10 inch plate. Because Fernandez uses this starting point it is difficult to detect the decreased machining time required for a part smaller than 10 inches. Should a washer roughly 1/2" in diameter cost the same as a 10" flat plate? Additionally, in Fernandez's method, cavity detail is based on cardinal points that are related to the size of a part. Because of this Fernandez tends to underestimate a part that has a high degree of complexity and a very small size. Both of these concerns can be addressed by either using continuous functions or at least step functions that have finer and more subdivisions.

This concern of continuous functions can be expanded to include Kuo's measurements of wall thickness. It should be noted that certain features must be measured with cardinal points. For example, the number of side actions can not be measured in anything less than integers.

Based on these concerns it seems logical that the next step in developing a group technology system is to use continuous function where appropriate. Dimension variables like length, width, wall thickness and detail can all be measured on a continuous scale. This will be one of the key differences that this author intends to base his estimating system on.

C. <u>Introduction - IBM Pearce Model</u>

IBM employee Dennis Pearce (IBM, Moldcost 1987) used regression analysis on data gathered from various IBM divisions to produce a relatively simplistic cost model for mold and processing costs called MOLDCOST. MOLDCOST gives satisfactory estimates, but is limited to parts with simple box-like shapes.

C.1. Mold Cost: (Pearce 1989)

In 1987 Dennis Pearce of IBM's Plastic Technology Center developed the MOLDCOST software program (IBM, MOLDCOST, 1987). MOLDCOST is an acronym for "More Or Less Determining Costs Of Selecting Tooling". Mr. Pearce uses this title to remind the user that this software tool is not an analytical technique, but a combination of statistical and heuristic methods (Pearce 1989).

Data for this program was developed from surveys conducted from 1984 - 1986 among IBM engineers throughout the US. The engineers, who were responsible for buying plastic molds, were given sample product drawings with accompanying cost, lead time and mold characteristics. The surveys resulted in the identification of thirty-eight parameters as possible cost drivers. The six most significant cost drivers were:

I. Number of dimensions on the print
II. Number of different surface finishes required
III. Length of part
IV. Depth of part
V. Tightest tolerance on the print
VI. Number of cavities

All of these cost drivers can be determined from the drawing except the number of cavities. MOLDCOST estimates an appropriate number of cavities based on the part size, production volume, and the desired press tonnage. (Pearce 1989).

C.2. Base Cost (Pearce 1989)

Base cost is defined as the cost to make the mold. The underlying equation of the base cost is as follows (MOLDCOST Appendix IV, Fig 14):

ln (Base Cost) = 6.510

+ 0.114 (number of cavities)

- 2.123 (tightest tolerance)

+ 0.187 (surface finishes)

+ 0.293*log (part length)

+ 0.198*log (part depth)

+ 0.412*log (dimensions)

The default value for the number of cavities in the above equation is computed from the part size and production volume inputs made earlier. This screen has a dialog box which gives the user the option to change assumptions. A 'yes' answer leads to Screen 15 (MOLDCOST Appendix IV Fig. 15) which allows the user to alter the number of cavities.

The output from the above formula is used to enter a formula that is based on the number of cavities. The formulas for the cost of multi-cavity mold decrease the cost for the additional cavities. This shows that the marginal cost for additional cavities is inversely proportional to the number of cavities. For example, the formula for a 32 cavity mold is:

BC32 = EXP(ln(bc)/1000)*100

BC = Number of cavities

MOLDCOST also gives the mold material cost. The mold material cost is based on the material selected and the size of the mold, the number of cavities and the tonnage of the press used. Unfortunately, the algorithm for mold material cost was not given (MOLDCOST Fig 16 Appendix IV).

MOLDCOST provides output of the base cost, mold material cost and the total cost. Additionally, MOLDCOST will determine the configuration of the mold. The program uses the mold material, number of cavities, number of molds, and the approximate tonnage required for this calculation.

Pearce also provides two interesting features in this program. First, the program will generate certain rules based on the underlying equations. This function is activated by using various function keys. These keys are called the what, why, and how keys. Second, the program will allow the user to configure the system to the user's personal needs. Configuration of the program usually requires the user to conduct his own statistical analysis to determine modifications to the underlying equation.

C.3. Summary:

Pearce provides a number of interesting theories in this software program. The most significant is the attempt to measure complexity by the number of dimensions. This is similar to other methods which try to count features. Also of interest are the features chosen as cost drivers. These cost drivers are similar to some of the other methods, but lack side actions and undercuts, two of the important cost drivers found in other methods.

MOLDCOST has two significant drawbacks. First, the program does not address the issues of cycle time, material costs, or total costs. Second, according to Dennis Pearce, it tends to work well only on box type parts. This seems to be consistent with other methods which try to divide parts into family groups.

D. Menges Model

Georg Menges is a German researcher who exhaustively catalogued most of the conceivable cost drivers for mold tool costs and part processing costs in his book How to Make Injection Molds (Menges 1986) The drawback to his methodology is that it is essentially a historical approach. Facts about the completed mold are key inputs; hence, the methodology is not suited for design software "what-if" scenarios.

D.1. Introduction:

In 1986, Georg Menges devoted a chapter of his book How to Make Injection Molds (Menges 1986) to a proposed cost estimating system. This work was based on an earlier thesis by Helmut Schluter RWTH (Rheinisch -Westfalisch Technische Hochschule) in Aachen (Schluter 1980). This estimating system is based on Machining and Electrode Discharge Machining (EDM) algorithms. This model requires that the mold be designed before using this system. It should be noted that the Menges method only addresses the cost of the mold and does not deal with processing costs or material costs.

Menges states that the mold cost problem for large run items is insignificant compared to the total price of the materials and processing times. In a medium run the mold cost becomes marginally significant, but in a small run the mold cost becomes the determining factor for the product process decision (Menges 1986).

The total cost for a mold is broken down into four groups. (Menges 1986) These groups are closely related to the functions of various components. The four groups are:

I. High Mold Cavity

II. Mold Base

III. Basic components

- a. Sprue and runner system
- b. Ejection system
- c. Heat Exchange system

IV. Special components

- a. Three plate molds
- b. Split cavity molds
- c. Slides
- d. Unscrewing devices

D.2. Summary:

The Menges cost estimation model is based on having relatively detailed part and mold designs. The parameters for this method can be inputted into a spreadsheet which could perform most of the calculations. For certain parameters an expert system would most likely be used to convert scoring factors into labor times or costs.

The Menges system also requires a certain degree of manufacturing or machining expertise to determine production methods. This determines the percentage of work on the part done by Electro Discharge Machining and Conventional Machining. This expertise requirement suggests that this estimating system would be more suitable for use in a tool and die shop than in a large company's design department.

Additionally, it appears that Menges assumes that the tool maker will select the optimal tool configuration and cutting path. This does not seem to be a drawback but, with the increased use of Computer Aided Design /Computer Aided Manufacturing packages, much of this information could be easily generated by the use of cutting path simulation routines. These routines would enable the tool maker to make an even more accurate estimate in roughly the same amount of time.

E. Boothroyd Dewhurst Software Model

Boothroyd Dewhurst Inc. (BDI) introduced "Injection Molding Cost Estimating and Material Selection Software" in 1992 (BDI 1992). This software was intended to assist engineers design plastic injection molded parts for ease of manufacture. A number of problems hinder the program. These include a daunting number of required input variables. Worse, many inputs must be determined from a completed design, requiring the designer to expend a significant amount of detail time on individual designs in order to generate "what-if" scenarios. Finally, like the Menges methodology, the program relies on expert mold design knowledge which cramps its utility in the hands of the part designer. One Digital Equipment Company part designer claimed that estimates generated by this software were off from actual costs by as much as 300%.

E.1. Introduction : Boothroyd / Dewhurst

The software, like other BDI programs, is designed to help engineers design parts that are easier to manufacture. This is done by giving cost estimates to the engineer based on various design variables.

Twenty design variables must be entered:

1. Material
2. Volume
3. Area
4. Length
5. Width
6. Depth
7. Maximum Thickness
8. Average Thickness

9. Tolerance
10. Appearance
11. Colored Resin
12. Texture
13. Inner surface complexity
14. Outer surface complexity
15. 2 or 3 plate molds
16. Runner System
17. Parting Line
18. Number of side cores
19. Number of lifters
20. Number of unscrewing devices

It should be noted that some of these variables require pull down menus for the calculation.

E.2. Summary: Boothroyd / Dewhurst

The program has a number of drawbacks. First, the sheer number of inputs needed suggest that there has been made very little attempt to separate the trivial from the important few. Second, the program requires a detailed design in order to determine the inputs. This forces the engineer to expend a significant amount of time on the design before analysis, making it less likely that the engineer will change the design, regardless of the results.

Additionally, the engineer must have an in - depth knowledge of the injection molding process in order to determine the part complexity. Inputs for part complexity are used to figure out the machining time of the mold insert which then is multiplied by a standard machining rate. While this is a valid method to determine the tooling cost, it appears that this method is very sensitive to differences in labor costs and manufacturing methods.

Moreover, the economic analysis is superficial at best. It only shows the basic manufacturing cost, and does not include overhead. (Perhaps the developers were targeting the engineering department to the exclusion of manufacturing and marketing.) For the program to be used by the other departments variables such as minimum annual rate of return (MARR) and time horizon must be added. For the program to be effective as a business decision tool, a graphical output package should be added as well.

While the BDI program[2] has numerous drawbacks it is one of the first commercially available Injection Molding Cost Models and has some innovative features. Both its positive and negative aspects should be analyzed more carefully.

F. Comparison of Available Economic Models for Injection Molding (EMIM) Models

The various EMIM methodologies discussed in the preceding chapters are summarized and compared here. Though no one model was accurate or complete enough for industry's purposes, the models presented by the Poli group and Boothroyd and Dewhurst represented the best overall approach.

F.1. Comparison of Models

As reported in DMI Report # :0001-V , (DMI 1992), the DMI TASK "K" TEAM made a comparison of the models found in the comprehensive literature search. Figures IIF-1 & 2 show rankings for strengths and weaknesses of the models described in the preceding chapters. The rankings employ two sets of terms: low/moderate/high and yes/no. The first set, low/moderate/high,

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[2] The software is available from Boothroyd Dewhurst, Inc., 138 Main Street, Wakefield, RI 02879 telephone (401) 783-6872 at a cost of $3750 for a site license.

indicates the degree of a particular strength or weakness that a given model has. For example, in Figure II.F-1 the Menges model ranks "high" for "Detailed Mold Design Needed". This means that the Menges model is highly dependent on inputs determined from analyzing the completed mold. The second set of rankings, yes/no, indicate whether a particular strength or weakness is present in a given mold. For example in Figure II.F-2 the Kou model is ranked "No" for "Estimates Macro Economics"; hence, the Kou model does not provide an estimate for macro economics.

As seen in Figure II.F-1 - Weakness of Existing Models, the Menges and BDI models are of limited utility to the plastic parts designer playing what-if scenarios because they require a large number of inputs, many of which require knowledge of the completed part and/or mold design. The other models are more useful in this regard, though the Pearce Model fails to cover more than a narrow family of box- shaped parts.

In Figure II.F-2 we see that the Fernandez and Kou models use feature based inputs, while the Pearce model does not. None of these models give macro economic estimates. The Fernandez model estimates mold cost and not cycle time. The Kou model reverses this, giving cycle time and not mold cost.

Figure II.F- 1: Weaknesses of Existing Models

	Fernandez	Kou	Pearce	Menges	BDI
1. Number of Inputs	**Mod.**	**Mod.**	**Low**	**High**	**High**
2. Detailed Part Design Needed	**Mod.**	**Mod.**	**Mod.**	**High**	**High**
3. Detailed Mold Design Needed	**Mod.**	**Mod.**	**Low**	**High**	**High**
4. Limited Part Applicability	**Mod.**	**Low**	**High**	**Low**	**Low**

Figure II.F-2- Comparison of EMIM Models

	Fernandez	Kou	Pearce	Menges	BDI
Feature Based Design	**High**	**High**	**Low**	**Low**	**High**
Estimates Mold Cost	**Yes**	**No**	**Yes***	**Yes**	**Yes**
Estimates Cycle Time	**No**	**Yes**	**No**	**No**	**Yes**
Estimates Macroeconomics	**No**	**No**	**No**	**No**	**Yes**
Gives accurate Estimates	**???**	**???**	**High**	**High**	**Low**

* Restricted to box-shaped parts only
Kou and Fernandez models cannot be tested because they use relative costs versus real costs.

F.2. Conclusion:

Based on observations made during field research and subsequent interviews with industry part designers, a picture of a useable cost model became apparent. A robust cost model would enable a part designer to estimate the final cost of a part with limited information. Therefore, the key cost elements should be able to be determined (processing, material, mold and set up costs) with only the features of the part being known. Additionally, the model should be comprehensive. To be comprehensive the cost element would be combined with the time value of money and production quantity estimates to give a total cost per part.

None of the models described in the proceeding chapter appears to be robust enough to meet the above requirements. The BDI and Menges models require detailed knowledge of the mold design for the part. A mold design would require an additional investment in time and money. The Kou and Fernandez models are limited because they are based on relative cost instead of real dollars and, therefore, ignore the time value of money. The Pearce model has two constraints. First, the model is only applicable to mold cost. Second , Pearce claimed in an interview that his model is tied to the narrow part family of electronic enclosures which are typically large and boxy.

The best possible combination of existing EMIMs would be to combine Kou's and Fernandez' relative cost models with the real dollar model created by Pearce.

A. Overview Of How Injection Molded Parts Are Designed and Made

A.1. Introduction

This section is devoted to a discussion of how plastic parts are typically designed and built. Understanding the present methodology will enable hypotheses to be made about the methods and tools for improving the present system and allow the creation of a new and improved design methodology that could reduce the design cycle.

A.2. Injection Molding Basics

Polymers are processed using a number of different methods. The two most common ones are injection molding and extrusion. Other methods include: liquid injection molding, reaction molding, blow molding, calending, rotational molding, transfer and compression molding. Polymers are divided into two classes: thermoset and thermoplastic resins. The following description is based on thermoplastic injection molding.

The molding machine is the key to the injection process. Typically, the granular resin is gravity fed from a hopper into the barrel where the resin is melted. The melting occurs primarily from the friction forces developed by the screw, but heat is also provided by the heater bands. Once the resin is melted, the screw rams forward forcing the resin into a mold. In the mold, the resin cools and hardens; after hardening the mold is opened and the part is ejected. While the part is cooling, the screw rotates to resupply the barrel with resin granules. (Ferguson 1989)

In a mold the sprue allows the resin to enter the mold from the nozzle located in the front of the barrel. Once in the sprue, the liquid flows into the runner system. The runner system proportions the resin and feeds cavities that form the part. The resin actually flows into the cavity through a gate. Cavities are machined into the "A" and "B" plates or inserts held in place by two plates. During the molding process the resin is usually under pressure up to 15,000 psi. This pressure requires a large clamping force. Pillars support the "B" plate during the high injection and packing pressures. This is critical because if the "B" plates deflect even a small amount, then the resin will be forced out of the cavity at the parting line causing flash which is unacceptable. Cooling is accomplished using cooling lines which are located in molding plates and at times in cavity inserts; this is used to reduce the cooling time and increase the frequency with which parts can be made. Ejection is accomplished when the mold opens, the ejector bar moves forward pushing a set of pins against the molded part forcing the part out of the mold (Ferguson 1989).

A.3. Part Design

Prior to the design of a new product, the organization must decide if the new product is necessary and what parameters or attributes the new product must satisfy in order to be successful. These parameters in turn become the design specifications and in the early feasibility stage are usually very broad and imprecise (Thayer 1944). Since plastics are primarily used to enclose or hold the functional components of a product, specifications at this stage usually do not include the selection of the plastic material. The selection of material for the enclosure is then the next step (Thayer 1944).

The selection of materials is mostly comprised of two stages. First, a material must meet the physical property requirements, dependent on the physical characteristics of the enclosure. Second, the choice must make economic sense. This requires knowledge of how the part will be processed and the cost drivers of the process (Rosato 1986).

Once a decision has been made with regard to the material, a conceptual part design is made. In this design stage, decisions about fit, form and function are made. This further quantifies the design specifications and imbeds certain rules into them. These design specifications are further defined by the material selected as well as the functional requirements of the part. Based on these specifications the part can now be designed in detail by an engineer (Rosato 1986).

How does the engineer know if the design makes economic sense? Today, the designer sends the part out for a price quote. The quote may be done by in-house experts or, more frequently, by approved vendors of the design organization. The resulting quotes are then checked to determine if the price is within the target price determined in the first stages of design and specification. If the quotes are too high, the product is redesigned. The cycle time for quote, redesign and requote is between 4 - 6 weeks depending on the complexity of the part and the company decision process (Ferguson 1989).

Once the design is finalized the part is built. In the case of proprietary/ specialized products, the molds may be made by in-house machine shops. However, especially with large companies, the job of building the mold goes to an outside vendor. The typical outside vendor is a small privately - owned business with annual sales of less than $5 million, employing less than 20 highly skilled machinists. Often the owner has had experience as a machinist (Mancino & Locurto 1992).

Once the mold builder is selected a series of negotiations take place between the designer and the vendor. This negotiation usually revolves around design changes that will make the mold easier to build and process. Negotiations may take as long as 2-3 months as the moldmaker designs the mold from the part design. Once the mold is designed, it is built by the machinists in the shop. Building the mold can take up to 6 months depending on the size of the mold. Molds that take over 2000 man-hours to build and cost over $200,000 are not uncommon. (Ferguson, 1989).

The mold is usually the responsibility of the moldmaker until the first good parts are produced at the molding site. The molding site can either be a 'captive molder' (a facility of a large company that produces molded parts) or a 'custom molder' (a company that specializes in molding parts for other organizations). A custom molder is typically a small company which has under $30 million in annual sales and employs up to 200 people. These companies are privately owned by groups of investors and run by professional managers. Molding companies have a number of plastic injection molding machines that are used to mold the parts. Usually, they also have small machine shops associated with them which are used for repairs and for building certain specialty molds (Akkad 1973).

Molding companies sometimes specialize in different product lines. It is not uncommon to find shops that specialize in medical, electronic or large consumer products. These companies are referred to as proprietary molders. In addition, some molders also offer a customer the ability to do both manual and automatic assembly as well as packaging. The molding company also estimates the cycle time of the mold. This cycle time provides the base for estimates of processing times. In some cases the molding company may bid an entire job that includes the design of the mold, the building of the mold, and the molding of the part. If volumes are very high, rather than charging the customer for the price of the mold, the molding company may amortize the cost of the mold in the part price (Akkad 1973).

B. SURVEY OF NJ MOLD SHOPS

B.1. Introduction

In 1992, DMI hired two co-op undergraduate Engineering Management students , S. Mancino and R. Locurto, to work with Dr. D. N. Merino, Principal Investigator and D. W. Merino, then a DMI Resident Engineer. The work these students did for DMI was included in their Engineering Management Senior Design Course. What follows are edited excerpts from their Senior Design Report. (Mancino & Locurto 1992)

One of the senior design project's tasks was to describe a typical New Jersey mold tool shop. A total of 12 shops out of 71 New Jersey moldmakers were visited and surveyed. The shops were divided into 4 categories based on dollar amounts of sales. The four categories were:

- Less than $1 Million
- Between $1 Million and $5 Million
- Between $5 Million and $10 Million
- Greater than $10 Million

The population was obtained from *The New Jersey Plastics Industry Directory (1991)*, published by the Polymer Processing Institute at Stevens

Institute of Technology. This publication lists companies in the Plastics Industry in New Jersey and lets the companies identify themselves by their specialty. Seventy-one (71) companies had identified themselves as moldmakers. From this listing, three companies from each of the four groups were selected at random to comprise a stratified sample of the moldmakers in New Jersey. The following is a breakdown of the mold making industry:

Table III.B-1 NJ Moldmaking Statistics

Sales Category	Population	Percent of Total Population	Sample Size	Percent of Total Sample
≤ $1M	22	31%	3	25%
>$1 to ≤ $5M	22	31%	3	25%
>$5 to ≤ $10M	12	17%	3	25%
> $10M	15	21%	3	25%
Totals	71	100%	12	100%

(Source: NJ Plastics Industry Directory)

Based on the surveys, various aspects of the shops were studied including labor rates, estimation accuracies (reported), bid differences, mold design and shop identification.

B.2. Estimation

Based on the results of the survey, over 85 percent of all the mold shops used manual custom forms to estimate the cost of building a tool. Based on the survey, eighty - three (83) percent (10 of 12 mold shops) claim that they can estimate the cost of a tool 80 percent of the time within ± 20 percent. The following table shows the reported labor rates of the shops.

Table III.B-2 Labor rates for NJ mold shops

Shop Size	Direct Labor Rate , ($/ Hr.)			Average ($/ Hr.)
	Shop a	Shop b	Shop c	
≤ $1M	45	60	40	48.33
>$1 to ≤ $5M	45	50	40	45.00
>$5 to ≤ $10M	37	42	45	41.33
> $10M	50	45	50	48.33

(Source: Survey by Mancino/Locurto 1992)

The next step was to take a sample part and determine the bid range. A "pull through cap" made by GTE, a small part with moderate detail, was chosen. A "pull through cap" is a part used to terminate wire in a connector. A part drawing was given to each of the 12 mold shops and a cost estimate for a 4-cavity mold for a production volume of 500,000 parts was requested. The results are shown on the following page.

Table III.B-3 Mold estimates from NJ mold shops

Shop Size	Estimate for the Mold			Average
	a	b	c	
≤ $1M	$12,500	$16,000	$17,900	$15,460
>$1 to ≤ $5M	$18,000	$28,900	$19,000	$21,960
>$5 to ≤ $10M	$18,000	$19,500	$22,000	$19,830
> $10M	$15,000	$10,500	$16,000	$13,830

(Source: Survey by Mancino/Locurto 1992)

Based on these results, the labor rate ranged between $37/hour and $60/hour with a mean of $45.66/hour compared to estimates which ranged from $10,500 to $28,900 with a mean of $17,770.

B.3. Description Of Mold Shops (Mancino & Locurto 1992)

Based on the survey, 67 percent of the small shops (≤ $1 Million in annual sale) have been in business less than 10 years, while the larger shops have been in business for more than 20 years. In addition, only 33 percent of the small shops are corporations while the rest are sole proprietorships. In contrast, all of the larger shops are corporations. Mancino & Locurto observed that as the size of the company increased, it became more likely that the company would also be involved in actually manufacturing injection molding parts. These shops will be referred to as combination shops - shops that combine mold making and injection molding.

B.4. Survey Findings

Mancino and Locurto made a number of statements based on the results of the survey:

- As a tool shop's annual sales increase, the difference between sales for the tool division and the total annual sales increases, which seems to indicate that as annual sales increase, the shops diversify.

- The percentage of tool maintenance and repairs increase with annual sales. There are greater profits and fewer risks involved with injection molding than in mold-making. In addition, as the annual sales increase, the number of new molds constructed is seen to decrease.

- The primary business groups for New Jersey moldmakers are the electrical/electronics and medical/health care industries. These industries account for 50 percent of the new molds built by New Jersey shops.

B.5. Comparison Of NJ Survey To 3M Shops

New Jersey and Minnesota have major concentrations of plastic moldmaking and injection molding shops. Comparing the three 3M shops later discussed in sections IV-VI indicates that the 3M shops were similar in size and structure to those in NJ.

C. Determining The Accuracy Of Industry Estimates For Cost

C.1. Overview

The objective of this research was to determine the accuracy of forecasts for making plastic injection molds prepared by reliable mold-making shops . This study analyzes the difference between the mold shop estimates of man hours or costs versus the actual man hours or costs expended in making a plastic injection mold.

The analysis was broken down into two parts. Part I analyzed the individual job accuracy. Based on the Mancino & Locurto study and confirmed in interviews with the 5 mold shop estimators visited during the author's 3M fellowship, these industry professionals believed that they could estimate a mold's cost within ± 20% , 80% of the time. Based on these interviews the author assumed that the distribution of estimates would be normal, but that this assumption needed to be tested. The accuracy or percentage error is determined by the following formula :

$$\text{Accuracy or Percentage Error} = \frac{(\text{Estimated Job Size} - \text{Actual Job Size})}{\text{Actual Job Size}} \times 100$$

Part II analyzed the overall shop accuracy. It was hypothesized that, on average, there would be no difference between the estimated and actual mold costs. This hypothesis implies that the estimates and actuals are equal and come from the same population.

It is assumed that over time a shop must have an average estimate close to the actual cost if it is to continue to operate. That is, under-estimating over time will not allow a shop to cover the costs to make molds and may eventually drive the company out of the mold making business. Over-estimating, on the other hand, would invite competition and reduce the volume of molds produced, thus potentially straining a company's ability to continue to make molds.

C.2. Method and Sample

During the summer of 1992 research was conducted to determine the accuracy of mold shop estimates. This effort began with the authors visiting five mold shops. These shops were selected from the 3M "approved" vendors list, a list compiled by 3M's purchasing department based upon successful completion of past jobs within time , budget and quality guideline as set forth by 3M. In 1992 3M had only 15 moldshops that qualified as approved vendors; additional, Dr. Dennis Ferguson, Senior Engineer in 3M's manufacturing research division and a 20-year veteran of working with mold makers and molders on key 3M manufacturing projects, assisted in the selection of the mold shops. Having worked with all 15 mold shops and numerous others over his career, Dr. Ferguson felt that 5 were clearly the "best of the breed". Of the 5 shops visited only 3 had data available and were willing to participate in the study.

C.2.a. Description of Studied Shops

The first shop, A, is a small privately owned shop in Minnesota. Shop A had approximately 2000 square feet of manufacturing space and 10 workers. Equipment in this shop consisted of modern machines mostly less than 5 years old. This included both wire and CNC EDM machines as well as numerous multi-axis CNC vertical milling machines. This shop produced production quality tooling for numerous OEMs, including 3M. Shop A specialized in small, highly detailed molds for the electronics industry.

The estimates in this shop are performed by the owner, a moldmaker with 30+ years of experience in the mold making industry. He felt that he estimated jobs within ±20% of the actual cost 80% of the time. Interestingly, the owner had a very strong wage incentive program that, he claimed, worked very well. He offered the machinists a 50% split of the profits for the difference between the estimated and actual manufacturing time. Sixty-six jobs completed between 1988 and 1992 were examined. They represented all of the new molds built for Shop A during this time period.

The second shop, B, was a small, privately owned shop in Michigan. Shop B had approximately 3000 square feet of manufacturing space and 20 workers. Equipment in the shop was not very modern and consisted of 20 - 30 year old manual Bridgeport Milling machines. Shop B specialized in prototype tooling for short run part production. This shop constructed the majority of molds from aluminum. The molds were then used to make molded parts. This occurred in a small area of the factory that had 3 injection molding machines.

In this organization a job is estimated by two employees, the experienced mold maker and one engineer. The final estimate was determined based on a consensus between the two.

They believed they could estimate to within ±20% of the actual costs. Once the bid is accepted, the job is passed to a machinist who is responsible for fabricating the part and getting it running on the molding machine. One hundred fifty-nine jobs completed between 1986 and 1992 were examined and represent the majority of new mold builds for Shop B during this time period.

Selection of the jobs was based on having sufficient data that is, the original estimate was available as well as the final cost.

The third shop, C, was a combination mold maker and molding shop in Minnesota. Shop C made the vast majority of its sales from processing plastic parts but also made molds in its own mold shop for proprietary small electronic bobbins molds.

The mold estimating for Shop C was accomplished by a mold estimating group that consisted of former mold makers and other laborers. Each member of the group was responsible for the estimate of the particular job. This was then passed to the group leader for approval. In the majority of cases the group leader approved the estimate. In cases where the group leader disagreed with the estimate, he would reestimate the cost. Based on discussions with the estimating group they individually and collectively felt that they could estimate a job to within ±20% of the actual cost.

The estimating group estimated the cost of molds made in - house, the cost for molds that would be made by mold shop vendors and made estimates on the weight of the part and the cycle time for the injection molding process. They had no stake in the profitability of the individual orders. Sixty-seven randomly selected jobs completed between 1984 and 1992 were examined and represent the majority of bobbins made during that time period.

C.3. Correlation Between Invoice and Actual Cost

C.3.a. Objective

This research was undertaken to determine if invoice prices of a mold could be used as a measure of mold cost. This is important because the mold shop studies used slightly different measure, for estimated and actual cost.

The three mold shops used were the same three that were previously described. The following definitions are required to understand the data provided by the shops:

C.3.b. Definition Of Terms

The mold refers to the injection molding tool and includes the mold base, all fixtures such as pins, side actions, etc. and the cavities that will give the part shape.

Material cost includes the mold base, pins, etc. as well as the metal block and associated consumable tools (drill bits, broaches, etc.) that will be used to make the mold.

Burdened labor rate is the wage paid to the worker including benefits and an overhead charge for the operation and capital recovery for machinery that the machinist uses to build the mold.

The invoice price is the dollar amount the mold shop vendor charges for the mold and the price paid by the mold shop customer.

The estimated man hours is the number of hours that the mold shop estimated it would take to complete the mold. The estimated man hours can typically be found by taking the invoice price and subtracting the material cost estimate. The result represents the dollar amount of labor estimated. This amount divided by an average burdened labor rate determines the estimated man hours required to complete the mold.

The actual man hours reflect the actual amount of time required to complete a job. The actual man hours were determined by reviewing the billing log which detailed the man hours of labor for each worker billed to the job.

The actual cost is a function of the man hour expended on the job multiplied by the burdened labor rate plus the material cost.

The estimated man hours are multiplied by the burdened labor rate to determine the labor cost. This cost is the major share of the total estimate or invoice price. The following formula is typically used to find the invoice price:

$$\text{Invoice price} = (\text{Est. Man-hours} \times \text{Burdened Labor Rate} + \text{Material Costs}) \times \text{Overhead Rate} \times \text{Profit Margin}$$

Labor costs account for approximately 75% to 90% of the total cost, material costs are usually 5 to 10 times less than the labor cost and the charge for special operations is usually 5 to 10 times less than the material costs. Therefore, the first term dominates and the estimated man hours are seen to be proportional to the invoice price.

The same is true for actual man hours and actual cost. However, in this case material cost estimates are more accurate. As many mold shops use standardized mold bases bought from vendor catalogs, the material price is a well-known variable. Therefore, actual cost is found to be closely related to the actual man hours expended on the job.

C.3.c. Methodology

To test whether a relationship between invoice price and labor costs exists regression analysis was used. Regression analysis determines the relationship between two variables (see Appendix III). The two variables are the invoice price (estimate) and the total cost (actual). It is assumed that the relationship between these two variables is linear because in an ideal shop the difference would be a constant profit margin. Microsoft Excel's statistical package was used to conduct the analysis.

C.3.d. Hypothesis

The hypothesis is that the invoice price of the mold is directly related to the actual cost of the mold. If a relationship exists between these two variables then the invoice price can be used as the dependent variable in a cost model. Regression analysis was used to determine whether a relationship existed. A "good" relationship will be said to exist if 70% of the variation can be explained. This translates into a Coefficient of Determination or R^2 >70%. An R^2 of greater than 70% yields a correlation coefficient of R of > 80%.

Unfortunately, the data available for the three different shops contain differing information. Therefore, a structured approach was used to determine if a relationship existed between the invoice price and the actual cost.

C.3.e. Analysis Of Collected Data

The first step to determine if a relationship exists is to examine the data from the three mold shops. Shop A's data consisted of the invoice price, the estimated hours, estimated material cost and the actual man hours expended. The 66 data points described in C.2.a were used. The estimated hours were found by subtracting the material cost estimate from the invoice price and dividing the result by the burdened labor rate.

Shop B's data consisted of the estimated hours as found on the bid estimating sheet and the actual hours. The 159 data points described in C.2.a. were used.

Shop C's data consisted of the invoice price and the actual cost. Shop C's data was presented in this manner because Shop C was a combination molding house and mold maker. As a larger company, Shop C had a group of estimators who estimated the price of the mold. This then became the invoice price to the customer. Once the estimate was made, the mold shop sent the mold out for quote on non-proprietary jobs. If the job was for a proprietary product, the mold was then made in - house or passed to a further subset of vendors. In this case the actual cost was then billed back to Shop C. The data used in the analysis of Shop C were from proprietary jobs. The 67 data points described in C.2a. were used for Shop C. A summary of the data is presented below:

Table III.C-1. Summary of Data Collected by Shop

Shop	Invoice Price	Est. Hours	Act. Hours	Actual Cost
A	X	x	X	-
B	-	x	X	-
C	X	-	-	X

(x = data available; - = data not available)

Based on the above data sets the invoice price can be regressed against actual cost in the case of Shop C.

In the case of shops A and B, the relationship between the estimated hours and the actual hours must first be analyzed. The estimated hours will be regressed against the actual hours. Since the estimated hours are directly related to the invoice price estimate and the actual hours are directly related to the actual cost, the results will be used to make an inference between the invoice price and the actual cost.

C.3.f. Results of Experiments

Statistics for the data were computed using the methodology found in the Appendices (Morrison 1990).

Table III.C-2. Price vs. Cost and Estimated vs. Actual hours:

Results of Statistical analysis

Shop	Invoice Price	Est. Hours	Act. Hours	Actual Cost	R^2 Coef. of Det.	R Corr. Coef.
A	-	x	x	-	76.3%	87.3
B	-	x	x	-	71.9%	84.8
C	x	-	-	x	80.0%	89.4

All the R^2 were found to be greater than the hypothesis of 70% set in C.3.e. and Shop C had the highest R^2 with 80%. Based on the results for shops A and B it can be determined that a good correlation between estimated and actual hours exists. Based on the postulate that estimated hours are proportional to invoice price and that actual cost is proportional to the actual man hours, it can be inferred that invoice price is proportional to actual cost. This is supported by the results for Shop C which show an even higher correlation between the invoice price and the actual cost than the estimated vs. actual man hours.

C.3.g. Conclusion

The results of the experiment indicate that there is a good relationship between the invoice price and the actual cost. The results for Shop C strongly support this conclusion. The results from shops A and B also meet the decision criteria and support this conclusion.

However, it was somewhat surprising that the results from Shop C were much better than the results for either shop A or B since data from Shop C consisted of the invoice price and actual cost. It might have been expected that greater error would have been introduced into a comparison based on the material and outside processing costs variation.

C.4. Individual Job Accuracy

C.4.a. Objective

The objective of this research was to determine the accuracy of individual mold estimates prepared by three plastic injection molding (PIM) mold makers. For Shops A and B the estimated accuracy was tested by studying the actual versus estimated man hours required to make the mold. For Shop C the estimated accuracy was tested by studying the actual versus estimated costs required to make the mold.

C.4.b. Methodology

A statistical analysis was performed using the standard deviation of the percent Error. The standard deviation is a measure of variation and can be used to determine how accurate individual forecasts are. (Refer to Appendix III for further explanation of statistical methods.)

C.4.c. Hypotheses

1. Based on the discussions the author, D. W. Merino, had with the 5 mold maker PIM tool makers discussed in C.2. and the survey by Mancino and Locurto of NJ PIM mold makers, it is hypothesized that a capable PIM tool maker will be able to estimate actual costs within ±20% on 80% of all jobs. Since the results in C.3 show that the estimated and actual man hours have a <u>high correlation</u> (> 70%) with the estimated and actual costs for Shops A and B, the same estimate percentages as above are assumed.

Assuming a normal distribution, the hypothesis that a good mold shop can estimate actual job costs within ±20%, 80% of the time is equivalent to 1.28 standard deviations. If the accuracy is ±20% then, $1.28\sigma = 20\%$ or $1.0\sigma = 15.6\%$.

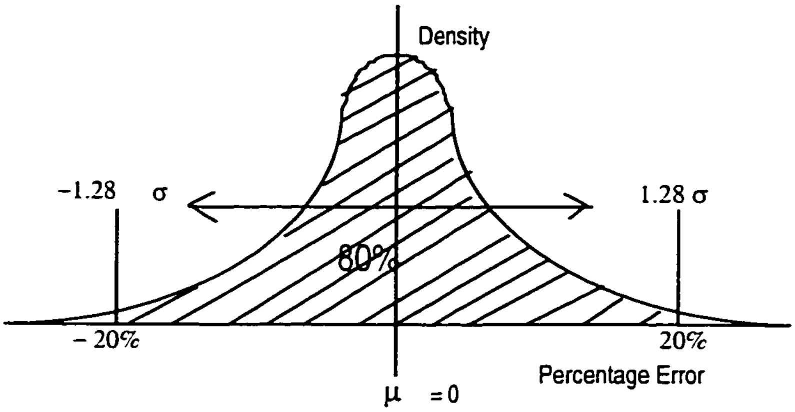


Figure III.C-1 Normal Curve for Mold Estimates

Therefore, the hypothesis will be rejected if s > 15.6%.

2. Another way of testing the hypothesis that moldmakers can estimate actual job costs, by +/- 20%, 80 % of the time, is to take a sample of completed jobs and determine what percent of the jobs were estimated within +/- 20%. If the percentage is less than 80%, then the hypothesis is disproved.
3. It was hypothesized that the percent error is dependent on the size of the job. To test this hypothesis, regression analysis was used. A Coefficient of Determination (R^2) of at least 70% is used to indicate a "good" correlation between the size of the job and percent error.
4. It was assumed that the percent error distribution would be normal. To test this hypothesis the data was plotted on a Q-Q plot and visually inspected. This is found on Section C.4.f.

C.4.d. Experiment

The data for Shop A, B and C consisted of 66, 159, and 67 jobs respectively. The various hypotheses were tested using the following descriptive statistics:

- *Standard Deviation* of the percent Error (σ)
- *Coefficient of Determination* (R^2)

  (percent variation experienced)
- *Q - Q plot*

The methodologies used in performing these statistics are given in Appendix III

C.4.e. Results of Experiment

Table III.C-3. Individual Job Accuracy:

Results of Statistical Analysis for Hypothesis 1 and 2

Hypothesis 2: -20% error $\leq$ 80 % of jobs $\leq$ 20% error.

Percent Error	Shop A N=66	Shop B n-159	Shop C n-67
Hypothesis 1	S.D. ≤ 15.6%	S.D.≤ 15.6%	S.D.≤ 15.6%
S.D. of percent Error	79.1%	57.0%	26.9%
Conclusion	Reject	Reject	Reject

Hypothesis 2: -20% error ≤ 80 % of jobs ≤ 20% error.

Percent Error	Shop A	Shop B	Shop C
Percent of job with error between +/- 20%	47.0%	28.3%	55.2%
Conclusion	Reject	Reject	Reject

Table III.C-4. Individual Job Accuracy:

Results of Statistical Analysis for Hypothesis 3.

percent Error	Shop A	Shop B	Shop C
Hypothesis 2	$R^2 \geq .70$	$R^2 \geq .70$	$R^2 \geq .70$
R^2	.02	.14	.06
Conclusion	Reject	Reject	Reject

Shop A

One standard deviation for the percent error of Shop A was 79.1 percent. This value is over five times greater than the hypothesized standard deviation of 15.6% for a well run mold shop. Therefore, one rejects hypothesis 1. Also, since only 47% of the jobs were estimated within +/- 20%, then one rejects hypothesis 2. The R^2 value of 2% shows very little correlation between the percent error and the actual man hours. Therefore, one rejects hypothesis 3.

Shop B

Shop B had a one standard deviation for the percent error of 57.0 percent. This value is over three times greater than the hypothesized standard deviation of 15.6%. Therefore, one rejects hypothesis 1. Also, since only 28.3% of the jobs were within 20% of the estimated cost, then one rejects hypothesis 2. The R^2 value of 14% does not meet hypothesized minimum value of 70%. Therefore, one rejects hypothesis 3.

Shop C

One standard deviation for the percent error of Shop C was 26.9%. This value is about two times greater than the hypothesized standard deviation of 15.6%. Therefore, one rejects hypothesis 1. Also, since 55.2% of the jobs were estimates with less than 20% error, then one rejects hypothesis 2. The R^2 value of 6% does not meet the hypothesized minimum value of 70%. Therefore, one rejects hypothesis 3.

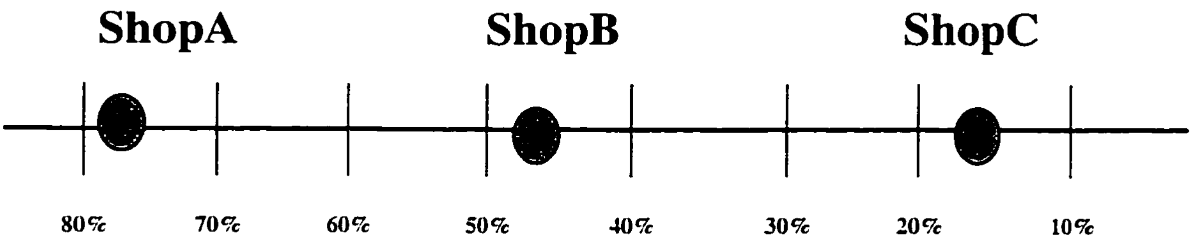
C.4.f. Conclusion

The results of the statistical analysis performed on the three mold shops show that none of the three shops' individual job accuracy approached the accuracy which they - or industry in general - believed were their performance and/or industry norms. The standard deviation for all the shops was significantly higher than the hypothesized population standard deviation of 15.6% for the percent error. Also, none of the shops estimated 80% of the jobs within +/- 20%. In fact, the best shop only estimated slightly more than half of its jobs within +/-20%.

The standard deviation for Shop C, although still high, was considerably lower than those for the other two shops. This could be due to the fact that all of Shop C's data was for the same type of part in which the estimators have significant experience. But insufficient data or testing was done to examine this point. In fact, the standard deviation for other types of parts from Shop C was considerably higher; 42.73%. From this result it might be inferred that if a mold shop specializes in one type of mold making, it will be able to estimate with a lower standard deviation than one which makes a wide range of molds. Here, too, insufficient data or testing was done to validate this partial conclusion.

A pair of summary charts showing the shops' accuracy at 1 standard deviation and the percent of jobs estimated within +/- 20% is provided below and can be used as a benchmark.

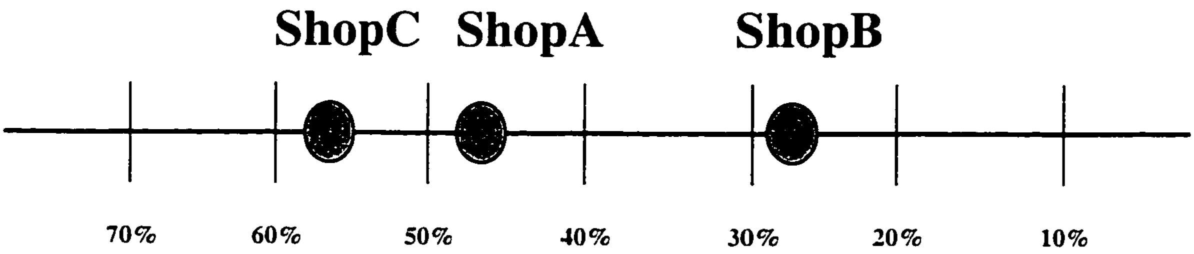
Dot Plot of Mold Estimate Accuracy (Standard Deviation)



Standard Deviation of Percentage Error Estimates

Figure III.C-2

Dot Plot of Mold Estimate Accuracy (Percent of jobs within +/- 20%)



Percent of Samples Jobs with Accuracy within +/- 20%

Figure III.C-3

The Q-Q plots below appear to be roughly normally distributed.

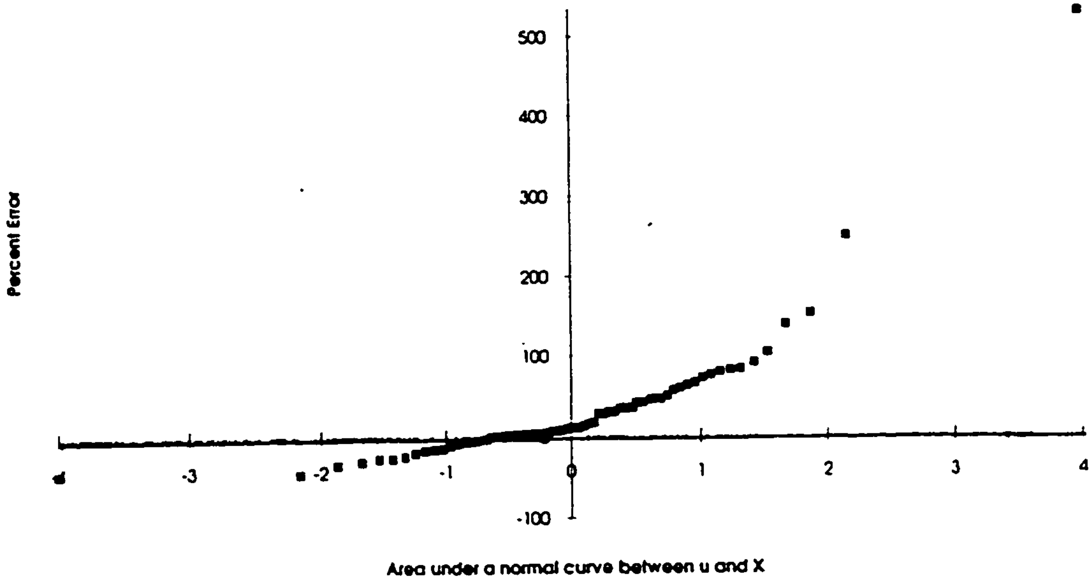

Q-Q Plot for Shop A

Figure III.C-4

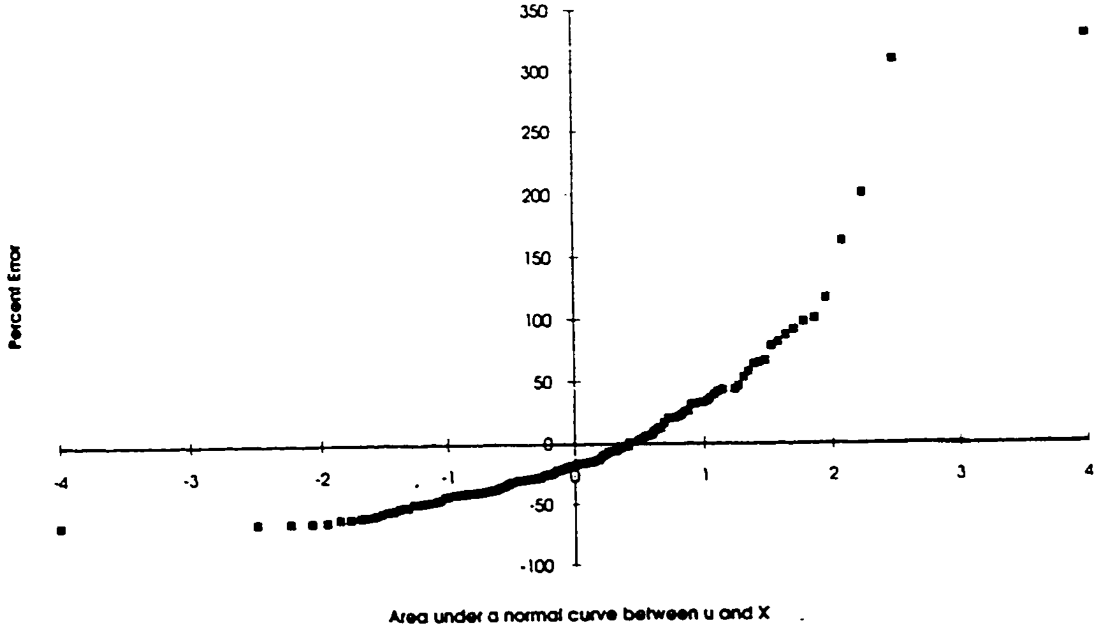

Q-Q Plot for Shop B

Figure III.C-5

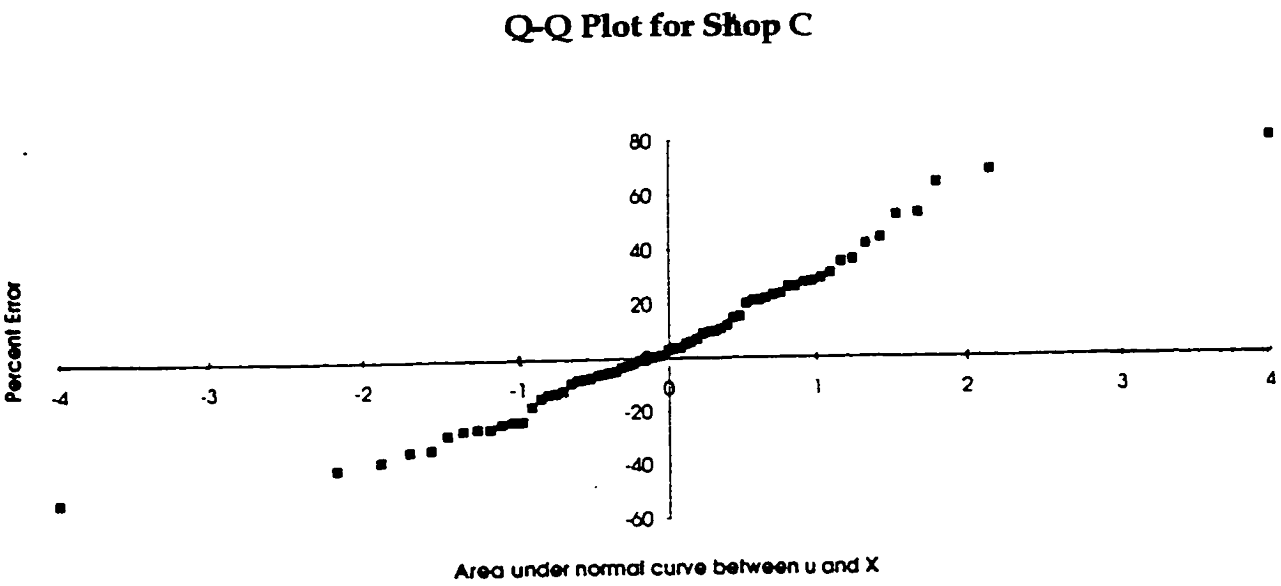


Figure III.C-6

The results of the regression analysis show that there was no acceptable correlation between the percent error and the actual man hours or actual costs for either of the three shops. If, in fact, a correlation had been found between the percent error and the size of the job, a transformation of the data would have been necessary in order to normalize the data.

C.5. Overall Average Shop Accuracy

C.5.a. Objective

Since in section C.4 we showed that estimate accuracy is not as precise as people within the industry believed, it would be of interest to determine how accurate shops are at estimating over time. It is also of interest to determine if any systematic error exists.

The objective of this experiment was to determine the overall average shop accuracy for three plastic injection molding (PIM) moldmakers in estimating the costs of jobs. For shops A and B the estimated accuracy was tested by studying the actual versus estimated man hours required to make the mold. For Shop C the estimated accuracy was tested by studying the actual versus estimated costs required to make the mold.

C.5.b. Methodology

A statistical analysis was performed to determine whether the overall average of all estimates was the same or different from the overall average of the actual costs. (Refer to Appendix III for further explanation of statistical methods.)

C.5.c. Hypothesis

It was hypothesized that, on average, the percent difference between the estimated and actual mold cost over time would be equal to zero. This meant that both the actual and the estimated mold cost were from the same population. A 95% confidence level was assumed. Thus, a two tailed t-test with a 5% significance level (α=.05) was used.

Expressed symbolically:

H_O: $\mu = 0$

μ = percent difference between estimated actual jobs.

Since the same data as in Part C is being used, it is not necessary to perform another regression analysis of the percent error vs. actual man hours or costs. The regression analysis performed earlier showed no correlation between the two variables.

C.5.d. Experiment

The data for Shop A, B and C consisted of 66, 159, and 67 jobs, respectively. The hypotheses were tested using the following descriptive statistics:

- *Mean* of the percent Error (μ)
- *Median* of the percent Error (M)

The methodologies used are given in Appendix III.

C.5.e. Results of Experiment

Table III.C-5

Overall Average Shop Accuracy: Results of Statistical Analysis

percent Error	Shop A	Shop B	Shop C
Hypothesis	$\mu=0$	$\mu=0$	$\mu=0$
DOF	65	158	66
$S_{\bar{x}}$	9.811	4.534	3.311
$\bar{x}$	32.9%	-4.3%	5.5%
t (calc)	3.35	-.948	1.66
t (tab)	±2.00	±1.96	±2.00
Conclusion	Reject	Accept	Accept

Shop A

This shop had a sample <u>mean</u> of percent difference between actual and estimated job cost of 32.9% and Standard Deviation of 79.1%. Since $t_{(calc)}$ (3.35) falls outside of $t_{(tab)}$ (±2.00), the hypothesis is rejected and it appears that on average Shop A overestimates the man hours required to make a PIM mold as compared to the hypothesized well run PIM moldmaker.

Shop B

Shop B had a sample mean of -4.3% and a Standard Deviation of 57%. Since $t_{(calc)}$ (-.948) falls within $t_{(tab)}$ (±1.96), the null hypothesis is accepted and it is concluded that on average Shop B correctly estimates the man hours required to make a PIM mold as compared to the hypothesized well run PIM moldmaker.

Shop C

In this shop the sample mean was 5.5% and Standard Deviation of 26.9%. Since, $t_{(calc)}$ (1.66) falls within $t_{(tab)}$ (±2.00), the null hypothesis is accepted. Thus, on average, Shop C correctly estimates the man hours required to make a PIM mold as compared to the hypothesized well run PIM moldmaker.

C.5.f. Conclusion

The results of the experiment on Shop B and Shop C indicate that over time these companies estimate close to the actual job costs. While not perfect, the averages of the differences between actual results and estimates are reasonably close to zero. This result is consistent with expectations for an established plastic injection mold maker and shows no systematic error. To remain in business over time, the overall average estimate must be close to the average actuals.

Otherwise, the company would lose money on underestimates or lose sales because of overestimated bids.

The results of the experiment on Shop A indicate that this shop greatly overestimated man hour requirements and that possible systematic error exists for Shop A.

But , even if a 32.9% systematic overestimating error existed for Shop A , it would not affect the conclusion in C.3.e. because that conclusion was based on a 1 σ distribution of the percent error.

Normally these results would be surprising given that Shop A bids in a competitive market which should penalize chronic overbidding. However, further inquiry revealed that Shop A used a wage incentive program. This program works by splitting the money saved in beating the estimated man hours between the machinist and the shop. Assuming that Shop A's bids are not higher than its competitors on a relative cost basis, further research may need to show that this type of incentive program does not affect the shop's competitiveness.

D. Determining the Accuracy of Molding Cycle Time Forecasts

D.1. Overview

The objective of this research was to determine the accuracy of cycle time estimates for plastic injection molded parts during the molding process. This study analyzes the difference between the molding shops' estimates of cycle times versus the actual cycle times.

The analysis was broken down into two parts. Part I analyzed the individual job accuracy. Five molding shops were visited, their selection is discussed in D.2. During the visits the person in charge at estimating was interviewed. These estimators felt that their estimation process yielded an accuracy of ±15%, 80% of the time. The accuracy or percentage error is determined by the following formula:

$$\text{Accuracy or Percent error} = \frac{(\text{Estimated Cycle Time} - \text{Actual Cycle Time})}{\text{Actual Cycle Time}} \times 100$$

The data is assumed to be normally distributed, but this must be tested. Part II analyzed the overall average shop accuracy.

D.2. Sources of Data

During the summer of 1992 research was conducted to determine the accuracy of plastic injection molding shop estimates. This effort began with the author visiting five injection molding shops. These molding shops were approved 3M vendors and represented approximately 1/10 of 3M's total approved injection shop vendors. Selection of molding shop was the same as discussed in C.2. Only two of the 5 shops had data and were willing to participate in the study. Cycle time is the time needed to close the mold, inject the material, let the material cure, open the mold and eject the part.

The first molding shop was a large combination moldmaker and molding shop in Minnesota. Shop C's sales were approximately $40 million. The vast majority of its sales are from processing plastic parts. It specializes in producing small electronic bobbins. This is the same Shop C from section C but, for this analysis the injection molding group data was studied instead of the mold making group data.

Cycle times for Shop C were estimated by a mold estimating group that consisted of former moldmakers and laborers who believe that their estimates of cycle times are within ±15%, 80% of the time. The estimators are an independent group who have no stake in the profitability of the individual jobs. Cycle times for these jobs were expressed in shots/hour[1]. Three hundred fourteen (314) jobs

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[1] Shots/ Hour= [seconds/shot]*[1hour/3600 sec.]; conversely, seconds/shot=1/[shots/hour]*[1 hour/3600 sec.]

including bobbins and non-Bobbins data completed between 1984 and 1992 were examined.

The second molding shop was a small privately owned shop in Minnesota. Shop D's sales were approximately $15 million per year. This shop did not specialize in any one part, but rather molded for a wide range of products.

Cycle times for Shop D were estimated by the Director of Marketing and his staff of four. The Director of Marketing was a part owner of the company. This group also felt that its estimates of cycle times were within ±15%, 80% of the time. Cycle times for these jobs are expressed in seconds/shots. Examined were 103 jobs completed between 1990 and 1992.

D.3. Individual Job Accuracy for Cycle Time Estimates

D.3.a. Objective

The objective of this experiment was to determine the accuracy of individual cycle time estimates from two well run plastic injection molding shops. For both shops C and D the estimated accuracy was tested by studying the actual versus estimated cycle times required for each job.

D.3.b. Methodology

A statistical analysis was performed on the percent error to determine the standard deviation. The standard deviation is a measure of variation and can be used to determine the accuracy of individual forecasts. Refer to Appendix III for further explanation of statistical methods.

D.3.c. Hypothesis

1. Based on the discussion the author had with plastic injection molding shops, it was hypothesized that a good molding shop will be able to estimate actual cycle times within ±15% on 80% of all jobs.

Assuming a normal distribution, the estimate that a molding shop can estimate actual cycle times 80% of the time is equivalent to 1.5 standard deviations. If the accuracy is ± 15% then, $1.28\sigma = \pm 15\%$ or $1.0\sigma = \pm 11.7\%$.

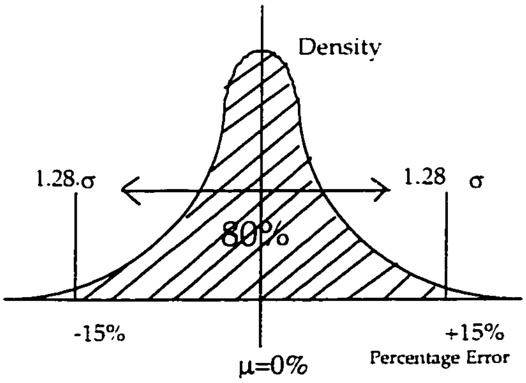


Figure III.D-1. Normal Curve for Cycle Time Estimates

Thus in conclusion, a good molding shop should be able to estimate actual cycle times where one standard deviation is less than or equal to ±11.7% (e.g. $1\sigma \leq \pm 11.7\%$).

2. Another way of testing the hypothesis that molders can estimate actual cycle time within +/- 15% 80% of the time, is to take a sample of jobs from a molder and determine what percentage of the jobs were estimated within +/- 15%. If the percentage is less than 80%, then the hypothesis is disproved.

3. It was assumed that the percent error is dependent on the size of the job. The graph of the percent error vs the actual cycle times would lead to conclude that this hypothesis is true. To test this hypothesis, regression analysis was used. It was hypothesized that a coefficient of Determination (R^2) of at least 70% would indicate a " good" correlation between the two variables. It was assumed that the percent error distribution would be normal. To test this hypothesis, the data was plotted on a Q-Q plot and then visually inspected.

4. It was assumed that the percent error distribution would be normal. To test this, the data was plotted on a Q-Q plot and visually inspected. The results of which are found in Section D.3.f.

D.3.d. Experiment

The data for shops C and D consisted of 314 and 103 jobs, respectively. In addition, a combined analysis was performed for shops C and D which consisted of 417 jobs. The hypotheses were tested using the following statistical methods:

- *Standard Deviation* of the percent Error (σ)
- *Coefficient of Determination* (R^2)
  (percent variation experienced)
- *Q-Q plot*

The methodologies used in performing these methods are given in Appendix III.

D.3.e. Results of Experiment

Table III.D-1. Individual Job Accuracy:
Results of Statistical Analysis for Hypothesis 1 & 2

	Shop C n= 314	Shop D n=103
Hypothesis 1	σ ≤ ±11.7%	σ ≤ ±11.7%
σ of percent error	25.0%	12.9%
Conclusion	Reject	Reject

Hypothesis 2: -15% error $\leq$ 80% of jobs $\leq$ 15% error

	Shop C	Shop D
Percent of jobs with error between +/- 15%	44.6%	83.5%
Conclusion	Reject	Accept

Table III.D-2 Individual Job Accuracy:

Results of Statistical Analysis for Hypothesis 3

percent Error	Shop C	Shop D
Hypothesis ii	$R^2 \geq .70$	$R^2 \geq .70$
R^2	.28	.12
Conclusion	Reject	Reject

Shop C

One standard deviation forthe percent error of Shop C was 25.0%. This value is two and a half times greater that the hypothesized standard deviation of 11.7% for the perfect molding shop. Therefore, one rejects hypothesis 1. Since only 44.6% of the jobs were estimated within +/- 15% of the actual cycle time, one should reject hypothesis 2. The R^2 value of 28% shows very little correlation between the percent error and the actual cycle times. Therefore, hypothesis 3 is rejected.

Shop D

One standard deviation for the percent error of Shop D was 12.9%. This value is close to the hypothesized value of 11.7%. Since 83.5% of the jobs were estiamted within +/- 15% of the actual cycle time, one should accept hypothesis 2. However, the R^2 value of 12% does not meet the hypothesized value of 70%. Therefore, hypothesis 3 is rejected.

D.3.f. Conclusion

The statistical analysis of the two molding shops showed one poor and one fair estimator of the cycle times for individual parts. One standard deviation for Shop C was significantly higher than the hypothesized population standard deviation of 11.7% for the percent error. One standard deviation for Shop D, although still higher than 11.7%, was considerably lower than Shop C and close to the hypothesized value. Also, Shop D did estimate over 80% of its cycle times with +/- 15%.

The analysis indicates that Shop D was much better than Shop C. Further inquiries were made to explain why Shop D was better than Shop C. It was found that the estimates for Shop D were prepared by a person with many years of experience who was part owner of the company. Apparently , in contrast, Shop C's estimates were done by a group of trained estimators without financial stake in the process, in contrast to Shop D.

A pair of summary charts showing the Shop Accuracy at one standard deviation and the percent of jobs estimated within +/- 15% is provided next and can be used as a benchmark

Dot Plot of Mold Estimate Accuracy (Standard Deviation)

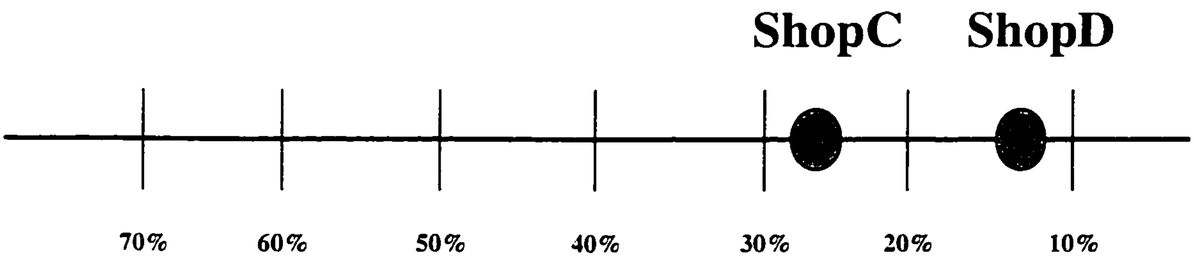


Figure III.D-2

Dot Plot of Cycle Time Estimate Accuracy (Percent of jobs within +/- 15%)

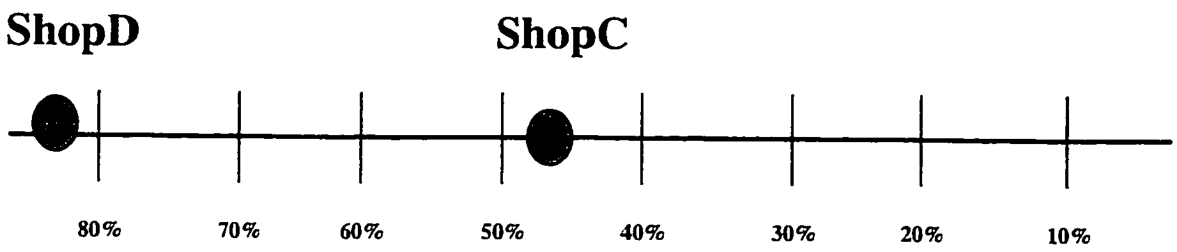


Figure III.D-3

Dot Plot of Mold Estimate Accuracy (Percent of jobs within +/- 20%)

The Q-Q plot below appears to be roughly normally distributed.

Q-Q Plot for Shop C Cycle Time

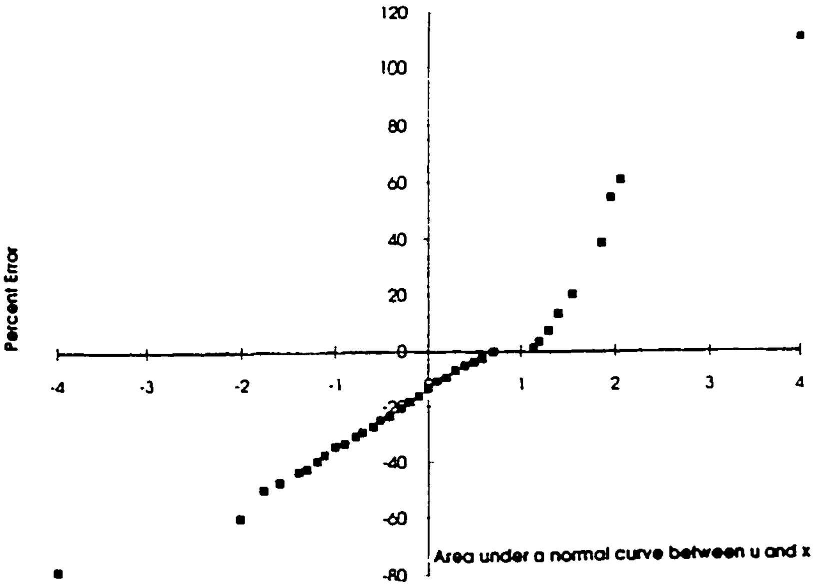
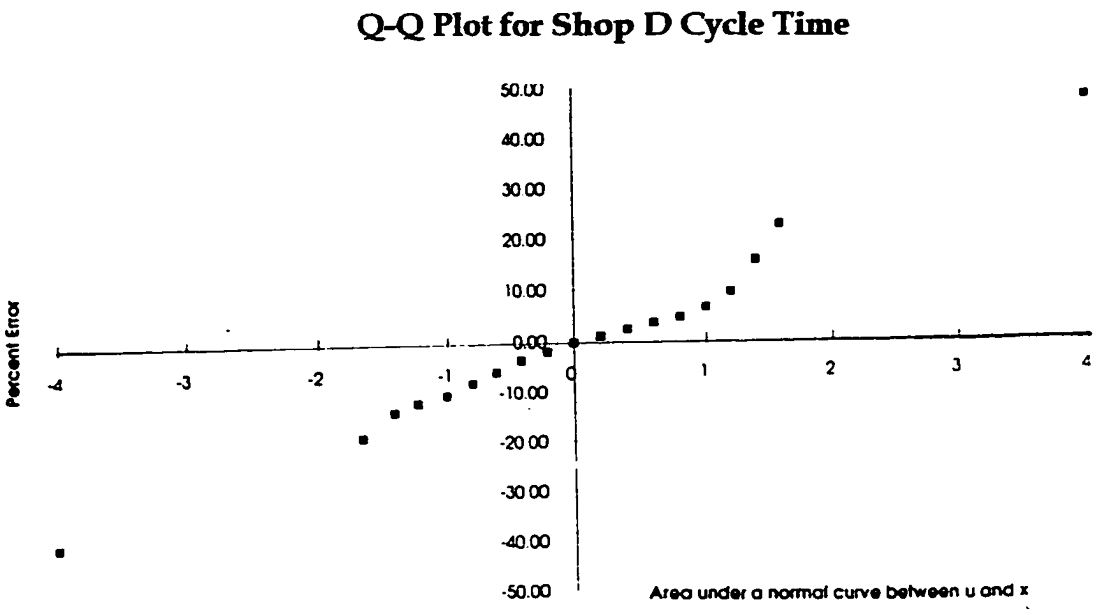


Figure III.D-4



Q-Q Plot for Shop D Cycle Time

Figure III.D-5

The results of the regression analysis show that there is no acceptable correlation between the percent error and the actual cycle times for either of the two shops. If a correlation had been found between these two variables, a transformation of the data would have been necessary in order to normalize the data.

D.4. Overall Shop Average Accuracy

D.4.a. Objective

The objective of this experiment was to determine the overall average shop accuracy of two well run plastic injection molding shops in estimating cycle times. For Shops C and D the estimated accuracy was tested by studying the average actual versus the average estimated cycle times required to produce the part. The combined data for shops C and D was analyzed as well.

D.4.b. Methodology

A statistical analysis was performed to determine whether the overall average of all estimates was the same or different from the overall average of the actual cycle times. Refer to Appendix III for further explanation of statistical methods.

D.4.c. Hypothesis

It was hypothesized that on average there would be no percent difference over time between the estimated and actual cycle times. This meant that both the actual and the estimated cycle times were from the same population. A 95% confidence level was assumed. Thus, a two tailed t-test with a 5% significance level (α=.05) was used.

Expressed symbolically:

$H_O: \mu = 0$

D.4.d. Experiment

The data for shops C and D consisted of 314 and 103 jobs, respectively.

The hypotheses were tested using the following statistical methods:

- *Mean* of the percent Error (μ)
- *Median* of the percent Error (M)
- *Standard Error* of the percent Error ($\sigma_{\bar{x}}$)

The methodologies used are given in Appendix III.

D.4.e. Results of Experiment

Table III.D-3

Overall Average Shop Accuracy: Results of Statistical Analysis

Percent Error	Shop C	Shop D
Hypothesis	μ=0	μ=0
DOF	314	103
$\sigma_{\bar{x}}$	1.41	1.27
$\bar{x}$	-13.8%	-0.8%
t(calc)	-9.79	-0.63
t(tab)	±1.96	±1.96
Conclusion	Reject	Accept

Shop C

This shop had a sample mean of -13.8%, and Standard Deviation of 25%. Since t(calc) (-0.63) falls within t(tab) (±1.96) the hypothesis is accepted and it is concluded that on average Shop C underestimates the cycle time to mold plastic parts compared to the hypothesized well run Plastic Injection Molder.

Shop D

Shop D had a sample mean of -.8% and Standard Deviation of 12.9%. Since t(calc) (-9.79) falls outside of t(tab) (±1.96) the hypothesis is accepted and it is concluded that on average Shop D correctly estimates the cycle time to mold plastic parts compared to the hypothesized well run Plastic Injection Molder.

E.4.f. Conclusion

The results of the analysis performed on each shop produce two different results. The results of the experiment on Shop C indicate that this shop underestimated the cycle time requirements, while the results for Shop D show that this shop was on average able to estimate within the limits hypothesized for a perfect plastic injection molding shop. Again, one may ask if Shop D was able to provide better estimates due not only to the experience of the estimator, but also due to his personal interest in the well being of the company. Unfortunately, insufficient data or analysis is available to make a conclusion at this point.

A. Overview

The modified group technology costing model was first proposed in a 1991/92 DMI project report (Merino, Merino, 1991) as a possible improvement to existing models. This improved model incorporates a wider range of plastic parts than existing based models and is designed to account for complexity, size, and detail with greater sensitivity.

A fourteen variable modified group technology system was proposed for testing. These variables represent various part and mold features. The group technology structure needs to be robust enough to give the cost of the mold, cycle time and material costs for the candidate part. This section describes the method used by the author to build and test the model.

B. Introduction

The process cycle beginning with the design of a plastic part, through mold construction and part production lends itself to various types of costing models. Machine time approaches are potentially the most accurate, but rely on data taken from the completed mold design. Hence, machine time approaches are incompatible with design software what-if scenarios. In contrast, a feature based costing model can assign a group technology code to a plastic part design and correlate this code to cost. It is thought that this approach is compatible with an easy to use plastic part design software.

Since the goal of Design for Cost is to make cost interactive with the design of a plastic part, it was decided to use a modified group technology that related to design features of plastic parts. Additionally, it was recognized that the Time Value of Money also needed to be included in a model. The research presented in Chapter II has shown that the existing cost models do not combine these two elements. Because of this deficiency, the development of a cost model that related to the features of the part and the Time Value of Money was developed. The following chapter will show the development of a Modified Group Technology that will determine the cost of two of the key variables in Plastic Part costs - mold cost and cycle time. Latter chapters will show how these variables can be used to drive a larger model that will capture the manufacturing costs for plastic parts.

Long range research goals may include producing a mold design/machine-tooling software package which will analyze a CAD rendering of a mold design and generate commands to an automated mold tool shop to manufacture the mold. This would be optimal for a machine time based cost model.

Fernandez noted problems connected with developing a model which predicts real costs and avoided them by developing a model which gives relative costs. However, even with this approach, the Fernandez model fails to accommodate a broad number of parts (Fernandez 1987).

It appeared that development of a universal model which found cost (relative or real) for any plastic part in any market was overly broad. The research presented in this chapter was focused on families of parts produced by a single company or a single division of a large company. In this way a series of costing model databases were to be constructed for given part families that account for a company's particular market conditions as well as the unique capabilities (expertise, tooling) of its plastic injection molding tool vendors. It is believed that such a model will give the best possible cost estimation accuracy in real dollars for a given family of parts.

Since the cost model is being developed with the corporate part designer in mind, the output of the costing model should be the cost from the factory, not the actual cost of constructing the mold. Since industry practice is to charge the customer based on the estimate, the costing model will be constructed using estimated costs. Since estimated mold costs and actual mold costs show a strong correlation, then actual costs could be used to develop the model.

C. Proposed Group Technology

In order to meet industry's costing model requirements, a fourteen variable group technology costing model is proposed for testing. These variables are based on an analysis of the best features of existing costing models, after discussions on cost estimation with actual customers at a number of mold shops that were visited.

The proposed costing model uses the following fourteen variables:

1.. Part Family
2. Length
3. Width
4. Depth
5. Percent of Prism Volume
6. Number of Dimensions
7. Maximum Wall Thickness
8. Number of Side Actions
9. Undercut Complexity
10. Parting Line Complexity
11. Tightest Tolerance
12. Finish
13. Material
14. Number of Cavities

These variables represent various part and mold features. The following is a description of each of the proposed variables.

Part Family

The part family variable will be used to separate parts into similar fit, form and function groups. This division will enable a breakdown of the parts into groups of similar size and shape . Some examples of part family types are electrical connectors, computer enclosures, and gears. These part families will initially be based on data gathered at various companies.

Length, Width and Depth

The next three variables are the dimensional variables. These will be used to determine the impact of the mold base, mold material, and machining time. The moldbase is the piece of metal used to mount the mold. Based on observations of mold estimators at work, it appears that the longest length and depth drives the metal block size that is to be used for the mold. In addition, the size of the insert and the number of cavities will drive the size of the mold base.

These three dimensions also drive the machine time required for the part. It is important to measure these three variables since inaccuracies in total volume may lead to incorrect machining times, (Menges 1986). For example, two parts with the same area will have different machining times depending on the depth of the part. The greater the depth the more machining time is required.

Percent of Prism Used

The concept of "prism" was originally described by Boothroyd and Dewhurst (Boothroyd and Dewhurst 1983). They defined "prism" as the rectangular prism with the smallest length, width, and depth that would enclose the part. "Percent of prism used" is defined as the volume of the part divided by the prism volume. The "percent of prism used" should correlate closely with mold machining time, part cycle time, and part material cost.

Consider a plate part and a frame part. They are identical except for the hole in the center of the frame. The two parts have the same overall length, width, and depth, so their molds could be machined from metal blocks of the same size. However, the "percent of prism used" is greater for the plate than for the frame, hence a greater machining time is predicted for the plate mold. Hence, we see that the "percent of prism used" correlates to machining time.

Also, the smaller the "percent of prism used", the greater the surface area of the part in contact with the mold relative to volume. In the previous example, the frame with its hollow center has the greater cooling surface as predicted by smaller percent of prism used. Greater cooling surface area implies faster cooling time, which implies faster cycle time. Hence, "percent of prism used" should be inversely related to cooling time. Part volume can be computed by multiplying percent of prism used times prism volume. Part volume multiplied by the material per unit volume cost yields the material cost to make a given part.

Number of Dimensions

The number of dimensions will be used to determine part geometry complexity, hence mold complexity and cost. This should be a significant improvement over most existing cost models, which measure part complexity in terms of the number of certain features present. These features are usually narrowly defined as ribs, bosses, gussets and holes. Some classes of parts do not have these features. For example, O-rings have varying degrees of complexity as measured by the number of dimensions but lack the standard features which define complexity in most existing cost modules.

Maximum Wall Thickness

The maximum wall thickness variable will be used to help determine the cycle time of the part, assuming that thicker walls require longer cooling times. The cooling time for multi-wall parts is usually constrained by the thickest wall. This variable, coupled with the material selected, should account for most of the cycle time required.

Number of Side Actions

The side action variable is a discrete function from 0 to 4 and measures the number of side actions used in the mold. Side actions increase the cost of the die and may also increase the cycle time.

Undercut Complexity

The undercut variable is also a discrete function that will be used to measure complexity of the undercuts. To deal with undercuts a tool builder must install cams, lifters or split cores. These additions are very expensive and add greatly to the die costs. Cams, lifters, side actions and split cores all must be retracted prior to part ejection. This action usually increases cycle times.

Parting Line Geometry

Many designers will change the parting line geometry to eliminate the need for the above mechanisms. These changes will bring about different problems and change the cost. For example, a planar parting line is much easier to align than a non-planar parting line. During the field research conducted at 3M the author noticed that some parts had varying parting line complexity. Therefore, this coding system will use a larger range for measurement of this cost driver.

Tolerances

Tolerances will be measured by using the net difference. This means that a tolerance of ±0.20 inches would be 0.40 inches and a tolerance of +0.25/-0.15 inches would receive the same score. The tolerance variable is used to determine machining difficulty. In some cases tight tolerances cause cycle time to increase, especially when the working die is used as a shrink tool by allowing the part to shrink to shape as it is cooling in the die . This practice can increase the cycle time by 200-300% and is very inefficient. The parts molded by this method should normally be redesigned or molded in an off-line shrink fitting die to cool the part.

Finish

Finishes will be measured using the standard SPI-SPE rating system. Additionally, another variable might be added to count the number of different finishes on the part. Poli's method uses finishes to help find the die costs (Fernandez 1987). Pearce points out that the addition of different finishes on a part significantly increases the part cost (Pearce 1989).

Material Code

The last input made by the user to the model will be the material code. The material code will be used to determine the material cost as well as the processing costs. The thermal conductivity of a material may be used as the material code.

D. Technology Systems Data Description

D.1. Overview

A major research objective was to further develop mold and processing costs algorithms. To accomplish this goal DMI's Technology Transfer activity and 3M agreed to jointly fund a 3M fellow to study families of injection molded parts. Data was gathered during the summer of 1992 from a 3M vendor. The data collected was analyzed using the Modified Group Technology System (MGTS) proposed in Section C to represent features that would correlate to the cost of the injection mold and molding cycle time.

D.2. Objective

This research was undertaken to determine the degree of correlation between the attributes of the proposed Modified Group Technology System

(MGTS), the cost of the mold, and the molding cycle time. First an MGTS was proposed. Data was then gathered from a 3M vendor.

D.3. Mold Cost Data

The first data set was comprised of a family of parts. This was necessary because if the MGTS is unworkable for a family of parts then it would be impossible to extend it for plastic injection molded parts in general.

The MGTS used for defining the independent variables in the mold cost model is described in Section C. To develop this model the author gathered data on 110 parts. These parts were taken from the electronics industry and represent small electronic bobbins and connectors. This family of parts can be defined by the variables found in Table IV.D-1 and used in the model. It should be noted that the initial results use 111 parts. However, one part was disqualified due to a transcription error. This was part # 4595, a 12 cavity mold costing $5845, a significantly low cost suggesting a transcription error. Note, the actual data can be found in Appendix VIII.

Table IV.D-1. Variation of Attribute Values[3]

Variable	High Value	Low Value	Mean Value	Std Dev.
Continuous Variables:				
Mold Cost	$57,402	$2,025	$14,508	$11,322
Length	3.54"	0.27"	1.18"	0.61"
Width	2.57"	0.16"	0.92"	0.54"
Depth	1.81"	0.09"	0.64"	0.35"
Dimensions	117	5	46	29
Closest Tolerance per part	0.01"	0.0004"	0.0035"	0.0017"
Tolerance	10	0.394	3.45	1.718
Wall Thickness	0.4″	0.01″	0.067″	0.056″
Material Code	9.6	4.5	6.18	0.7

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[3] See Appendix VIII for raw data

Discrete Variables:

Side Actions	1	0	0.03	0.16
Cavities	16	1	5	3
Wall Thickness	0.4″			
Undercut	5	0	4.86	0.81
Parting Line	1	2	1.019	0.09

Note: These parts are all from the same part family and had the same finish.

The variables for mold cost, cavities, dimensions and closest tolerance seem to cover the vast majority of injection molded parts in general. The size (length, depth and width) and side action variables are limited to a smaller subset of plastic injection molded parts. It is estimated that these variables cover approximately 30% of all parts.

D.4. Molding Cycle Time Data

The same parts described in Section D.3 were also used to develop the cycle time model. This family of parts can be defined in terms of the variables found in Table IV.D-2.

Table IV.D-2. Variation of Attribute Variables (Full Set)[4]

Variable	High Value	Low Value	Mean Value	Std Dev.
Shots per hour	830	160	425.85	150.30
Wall Thickness	0.4"	0.01"	0.07"	0.06"
Length	3.54"	0.27"	1.18"	0.61"
Width	2.57"	0.16"	0.92"	0.54"
Depth	1.81"	0.09"	0.64"	0.35"
Material Code	9.6	4.5	6.18	0.7
% Short Fiber Fill	33%	0%	12.5%	14.2%
Percent Prism	25%	1.2%	9.02%	5.53%

It was noted that in this group of variables, there is a wide variation in cycle time. Since part number 4900 and 4899 were duplicate points 4900 was dropped. The resulting database had 109 parts and was defined by this new table values.

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[4] See Appendix VIII for raw data

D.5. Methodology

D.5.a. Applying the PPI to Create Constant Dollars

In order to avoid bias of the statistical analysis the variable must be in a consistent form for analysis. In this case, the dependent variable is mold cost, with different years. Thus, a consistent plane of reference must be selected. 1992 dollars were selected as the constant dollar basis.

Therefore, all the 110 mold costs were expressed in 1992 dollars. This was accomplished by applying a factor which represents the Producers Price Index (PPI) for mold shops. The Department of Labor's Bureau of Statistics' annual report has a category for capital equipment and a subcategory for Tools, Dies, Jigs, Fixtures and Industrial Molds. It was decided that this would be the category to use to find the proper factors. Data in this subcategory begins in 1985 and is not tabulated monthly. This presented a problem since the yearly subcategory PPIs are published approximately 2-3 years after the end of the year studied. Therefore, the larger Capital Goods for Manufacturing category had to be used to estimate the PPI for the subcategory.

The method involved finding the percentage change in the larger category and then multiplying this by the sub category's PPI.

The following formula shows the method:

$$\frac{\text{PPI Main Group 19XX +1}}{\text{PPI Main Group 19XX}} \times \text{PPI Subgroup 19XX} = \text{PPI Subgroup 19XX + 1}$$

The following chart represents the PPIs used to determine the 1992 dollars for the mold.

Table IV.D-3. PPI by Year - U.S. Bureau of Labor Statistics

Year	PPI
1980	1.50
1981	1.36
1982	1.28
1983	1.25
1984	1.22
1985	1.19
1986	1.17
1987	1.15
1988	1.12
1989	1.09
1990	1.04
1991	1.01
1992	1.00

D.6. Statistical Methods

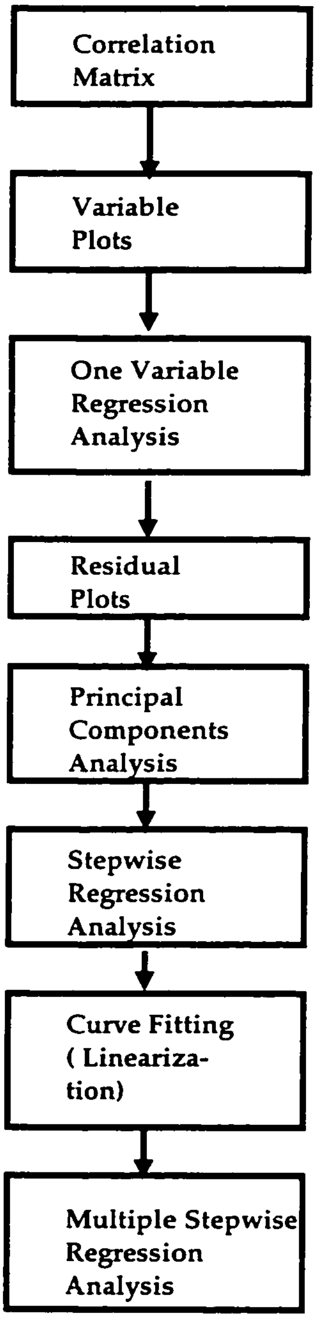
The field of statistics has many tools and methods that a researcher can use to make inferences from the data. The key is to choose tools that form a logical path. Other paths may produce similar results. In addition, the answer should not be path dependent. A block diagram of the decision process for the determination of the cost and cycle time algorithm is provided on the following page.

Figure IV.D-1. Statistical Process for developing a Mold Cost / Cycle Time Regression Equation

OBJECTIVE:

1. Determine which MGTS variables are significant. Rank order MGTS Variables using correlation Coefficients (r). The higher the r, the more important.
2. Check for linearity. Visually look at the data and determine if the data is linear or curvilinear. If it might be linear do Step 3 - 6. If obviously curvilinear, skip to Step 7.
3. Find Linear Function (y= mx + b) and coefficient of determination, R^2 for each variable. The higher the R^2, the better the linear relationship. This should further determine which functions are linear and which are not.
4. Determine if a nonlinear function exists. Visually check the plot of the residual to determine if a pattern can be found.
5. Reduce the number of variables by reducing cross correlations. Use resulting Rotation Matrix to transform the data.
6. Determine impact of variables in a multiple linear relationship. Try to produce the highest R^2 with the smallest number of variables.
7. Determine functions to linearize variable. Analyze the plots and make estimates of possible functions. Next, determine the R^2 of the resulting functions and use the functions with the highest R^2 for the next step.
8. Determine formula for multiple linearized variables. Try to produce the highest R^2 with the smallest variables.

METHODOLOGY:



A number of different statistical methods were used to make inferences about the data. All methods were performed using the SAS or SPSS computer package. First, a correlation matrix was used to determine which of the 14 variables correlated best to the dependent variables (Mold Cost & Cycle Time). Variables with higher correlation coefficients were judged to be more important than the rest. An explanation of correlation matric can be found in Appendix III.

Next, variable plots were used to determine if the relationships were linear or curvilinear. This methodology was used along with one variable regression analysis and residual plots. Linearity was determined by visually inspecting the plot of the data. In addition, the R^2 found during the regression analysis was used to rank the variables by linearity with higher R^2 representing greater linearity. Lastly, the residual plot was visually analyzed to determine if an underlining pattern existed that might relate to a possible function. An explanation of these three methods can be found in Appendix III.

The next step was to use principal components analysis to determine if a transformation existed that would easily explain the data, and to minimize or eliminate variable interdependence. The rotation matrix which was weighted was used to determine if it was worthwhile to pursue the rotation. A detailed explanation of principal components analysis can be found in Appendix III.

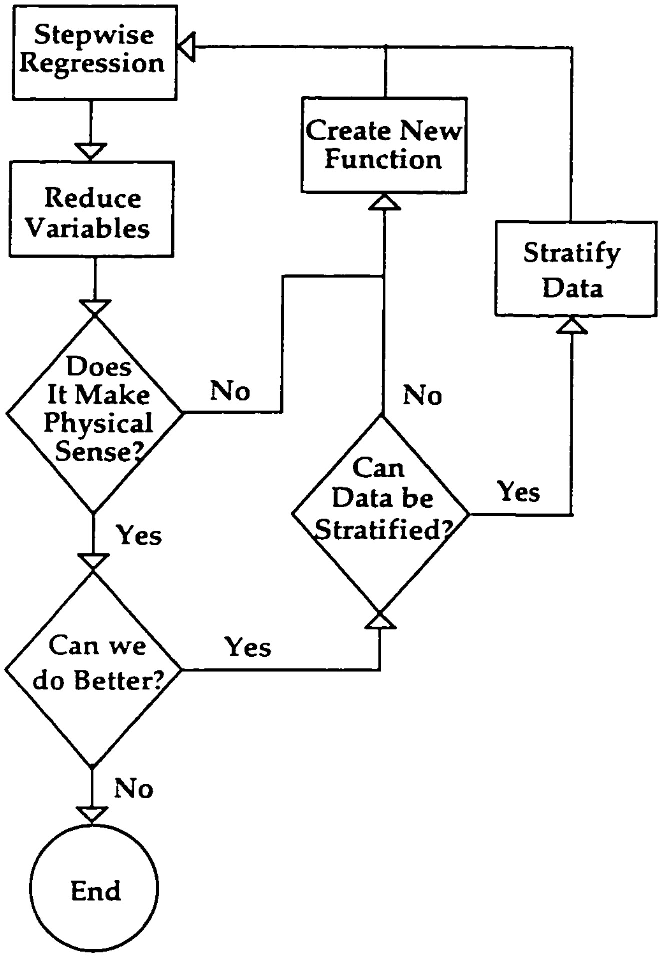
To determine if the transformations found, after completion of principal components analysis were useful, a stepwise regression was performed on both the transformed and untransformed data. The key to the stepwise regression is to get the highest R^2 with the lowest number of variables, separating the vital few from the trivial many. An explanation of stepwise regression can also be found in Appendix III.

Upon completion of the preceding steps linearization of the data was attempted. To accomplish this, a number of functions were applied to the independent variables. The variables were then plotted against the dependent variable (Mold Cost). Also regression analysis was performed and residual plots were studied. A visual observation was first made and a resulting function hypothesized. This function was then plotted and regressed against the dependent variable. The higher the R^2, the better the function linearized the data. An explanation of linearization can be found in Appendix III.

Once the variables were linearized a stepwise regression was again performed to determine the resulting function. This was plotted and the residuals were studied to determine if further transformations needed to be performed. Again, the key to this step is to get the highest R^2 with the lowest number of variables. After the R^2 was found, a check was made to determine if the resulting function made physical sense. If the resulting function made no physical sense then a different transformation was used to find a new R. The following chart provides a block diagram of the decision process that was used to determined to the best Mold Cost or Cycle Time algorithm:

Figure IV.D-2. Decision Process for Selecting a Mold Cost or Cycle Time Algorithm

METHODOLOGY: OBJECTIVE:



1. Determine the best fit or the highest R^2.

2. Rule of Parsimony. Reduce function to the vital few instead of the trivial many.

3. Check to see if the resulting function makes physical sense.

4. Can a different transformation be used and a better R^2.

5. Can the data be stratified?

E. Developing a Mold Cost Algorithm Using a Modified Group Technology System

E.1. Analysis Of Data Collected

E.1.a. Correlation Matrix

Table IV.E-1. Correlation Coefficients (R) of Selected MGTS Variables versus Cost in order of importance

Independent Variable	Correlation Coefficient
Dimensions vs. Cost	R = 0.66
Cavities vs. Cost	R = 0.57
Percent Prism vs. Cost	R = 0.35
Side Actions vs. Cost	R = 0.24
Depth vs. Cost	R = 0.26
Length vs. Cost	R = 0.20
Tolerance vs. Cost	R = 0.07
Width vs. Cost	R = 0.03

As stated above the first step was to create a correlation matrix. In this step, the independent variables which are defined in the MGTS are correlated to the dependent variable - mold cost. The result of the correlation matrix is a series of correlation coefficients (R). These show not only the correlation of the independent and dependent variables, but also the cross correlations between the independent variables. Table IVE-1 summarizes the results of the independent vs. dependent variables on the following page.

Based on these results it was determined by inspection that the most important variables in the determination of cost will be dimensions, followed by cavities. Dimensions represents a measurement of complexity and cavities are a multiplier of complexity. Other variables in order of importance are, percent prism, side actions, and depth. Length, tolerance and width were also reported because they have a physical relationship to cost.

The second part of the correlation matrix shows the cross correlations of the top three variables.

Table IV.E-2. Cross Correlation Coefficients for Top Three Variables

	Correlation Coefficient		
Independent Variable	**Dimensions:**	**Cavities:**	**Percent Prism:**
Dimensions	R= 1.00	R= 0.16	R= 0.20
Cavities	R= 0.16	R= 1.00	R=0.33
Percent Prism	R= 0.20	R= 0.33	R= 1.00
Side Actions	R= 0.06	R= - 0.08	R= - 0.16
Depth	R= 0.51	R= - 0.10	R= - 0.22
Length	R= 0.17	R= - 0.28	R= - 0.19
Tolerance	R= 0.08	R= - 0.09	R= - 0.14
Width vs. Dimensions	R= 0.18	R= - 0.23	R= - 0.01

The illustrations shown on the previous page indicate a very high cross correlation between depth tolerance and dimensions. When developing functions to linearize variables attempts should be made to concatenate variables with lower correlations together to get a composite function as new variable. For example, functions with cavities and dimensions will be tried as well as functions with percent prism and length, width and depth.

E.1.b. Principal Components Analysis

Next, a principal components analysis was performed. A principal components analysis is an attempt to minimize the number of variables needed to explain the data. This is done by finding the eigenvectors that represent the rotation of the original matrix that will produce a diagonalized matrix. The eigenvectors are weighted to show the effect each variable has on the overall data.

The resulting rotation matrix is shown below:

Table IV.E-3. Eigenvectors for Principal Components Analysis

Variable / Princ. Comp.	#1	#2	#3	#4
Cavity	0	0.27	0.95	0
Length	0	0	0	0.13
Prism	0	.95	-0.28	0
Dimension	1.00	0	0	0
Tolerance	0	0	0	0.97
Undercut	0	0	0	-0.12
Total Proportional Weight of Eigenvector	0.95	0.03	0.01	0.003

As the table shows 95% of the expected change can be found by just using the dimension variable. Based on the results of the principal components analysis it was determined that any chosen rotation would not have a significant result on the data and the resulting regression analysis. Thus, principal components analysis was not be used further in this analysis.

E.1.c. Regression Analysis

Next, regression analysis was performed on the individual variables to determine the coefficient of determination or R^2 as well as the linear relationship between the independent variable and the dependent variable.

The following summarizes the results:

Table IV.E-4.

Coefficient of Determination (R^2) for Selected MGTS Variables vs. Mold Cost

Variable (Symbol)	R^2
Dimensions (Dim)	0.45
Cavity (Cav)	0.25
Percent Prism (Prism)	0.09
Side Action (Side)	0.06
Undercut (U/C)	0.06
Wall Thickness (Wall)	0.05
Depth (D)	0.05
Length (L)	0.03
Tolerance (Tol)	0.02
Width (W)	0.01

Based on this analysis it was concluded that dimension and cavities have the most importance or impact on the cost of a mold.

E.1.d. Stepwise Multiple Regression of Independent Variables on Mold Cost

Next, a stepwise multiple regression was performed utilizing the above variables. This was performed to develop a formula based on a linear model. This table shows the R^2 of the independent variables related to the dependent variable (cost). The results are summarized on the following page.

Table IV.E-5. Multiple Stepwise Regression based on Linear Assumption

Variables	R^2	Change
Dim	0.44	-
Dim & Cav	0.60	0.16
Dim, Cav & Side	0.66	0.06
Dim, Cav, Side & Length	0.70	0.04
Dim, Cav, Side, Length & Depth	0.72	0.02
Dim, Cav, Side, L, D & Width	0.727	0.007
Dim, Cav, Side, L,D,W and Tolerance	0.731	0.002

E.1.e. Initial Results

The result was the following formula based on the 7 variables.

Mold Cost (1992$s) = -7297 + 281*Dim + 1592*Cav + 9507*Side Action + 7578*Length - 10679* Depth - 2835*Width + 468*Tolerance

This formula meets the requirement for a relationship that meets the R^2 goal of greater than 70% but presents a number of problems. First, the signs of three variables make no physical sense. An increase in either width or depth will increase the cost of the mold since more volume will need to removed therefore taking more time to machine and increasing cost. In addition, the tolerance variable should have a negative effect since a larger tolerance will decrease cost and very tight tolerances tend to increase costs. Because of this and the desire to gain a high R^2 it was determined that a number of transformations would be tried based on the physics of the problems and the variable plots. Applying the Rule of Parsimony would mean that the last two variables would be left out of the resulting equations since they add very little to the overall R^2.

E.1.f. Transformed Regression Analysis

Numerous transformations were performed on the data. The five transformations and the side action variables in Table IVE-6 seem to best describe the process. These transformations were used as the dependent variable and a regression analysis was performed with cost as the independent variable. The results are provided below:

Table IV.E-6. Coefficient of Determination (R^2) for Transformed MGTS Variables

Transformation	Symbol	R2
√(Cavity * Dimension)	U	0.76
√(Width * Dim) * % Prism	V	0.40
√(Depth * Dim) * % Prism	W	0.33
Side Actions	X	0.07
√Length * Depth	Y	0.04
Tolerance / Length	Z	0.03

The first transformation [√(Cavity * Dimension)] is hypothesized as a representation of complexity. The next two transformations [√(Width * Dim) * % Prism, √(Depth * Dim) * % Prism] are hypothesized to represent the volume of material and difficulty required to remove the material. The number of side actions represents an average cost for a side action. The √Length * Depth transformation is hypothesized to represent the cost of the mold base which is dependent on the size of the cavity. The last transformation is hypothesized to represent the cost for tight tolerance for parts. This variable is dependent on not only the tolerance but also the overall length. This is summarized in the table below:

Table IV.E-7. Physical Description of the Transformed Variables

Variables:	Transformation	Physical Description
U	√(Cavity * Dimension)	Complexity
V	√(Width * Dim) * % Prism	Volume and Difficulty to Remove
W	√(Depth * Dim) * % Prism	Volume and Difficulty to Remove
X	Side Actions	Average Cost of a Side Action
Y	Tolerance / Length	Cost of Tight Tolerance
Z	√Length * Depth	Cost of the Mold Base

E.1.g. Stepwise Regression with Transformed Variables

These transformations were then used to conduct a multiple regression. The results of the multiple regression are found below:

Table IV.E-8. Multiple Stepwise Regression based on Transformed Variables

Variables	R^2	Change
U	0.76	-
U & V	0.78	0.02
U, V & X	0.82	0.04
U, V, X & Y	0.822	0.002
U, V, X, Y & W	0.823	0.001
U, V, X, Y, & Z	0.823	0.000

Once again, applying the Rule of Parsimony means that the last two variables would be left out of the resulting equations since they add very little to the overall R^2.

The resulting equation would then be:

Mold Cost (1992 $s) = - 4993

+ 1135 * √(Cavity * Dimension)

+ 12266 * Side Action

+ 54 * (√(Width * Dim) * % Prism)

+ 1358 * √(Length * Depth)

E.2. Applicability Of Mold Cost Model

The cost algorithm found above is applicable to the range of parts found in Table 1. This includes parts with high complexity in the small to medium size range. This model should work fairly well over the full range of parts discussed in the table. In addition, this model should extend past the boundaries established in the first table. None of the variables used in the model will increase exponentially as the size of the part increases.

Other variables tried in the above model included variables that were higher order polynomials. One of the variables tried was length^2. This variable proved to have a greater impact than any other variable tried. But, while the R^2 improved this variable was not very stable as the length increased. For example, if the length increased from 1 to 10 inches the cost variable would increase by a factor of 100. This was unacceptable and as a result this variable had to be bypassed.

These formulas have not yet been tested on other groups of parts, both inside and outside the window of parts used in the analysis.

F. Developing a Cycle Time Algorithm Using Modified Group Technology Systems

F.1. Analysis Of Data Collected

F.1.a. Correlation Matrix

As stated above the first step was to create a correlation matrix. In this step the independent variables which are defined in the MGTS are correlated to the dependent variable - cycle time. The result of the correlation matrix is a series of correlation coefficients. These show not only the correlation of the independent and dependent variables, but also the cross correlations between the independent variables. The results of the independent vs. dependent variables are summarized on the following page.

Table IV.F-1. Correlation Coefficients for MGTS variables - in order of importance

Independent Variable	Correlation Coefficients
Percentage of Fill vs. Shots per Hour	R = 0.72
Width vs. Shots per Hour	R = -0.57
Length vs. Shots per Hour	R =- 0.56
Depth vs. Shots per Hour	R = -0.46
Wall Thickness vs. Shots per Hour	R = -0.41
Percent Prism vs. Shots per Hour	R = -0.07
Thermal Conductivity vs. Shots per Hour	R = -0.03

Based on these results it was determined that the most important variables in the determination of cycle time are percentage of fill width and length. The percentage of short fiber fill acts as an insulator. As the percentage increases, these parts shrink less and can be ejected faster. Surprisingly, both wall thickness and thermal conductivity correlated less well than expected to the cycle time.

The second part of the correlation matrix shows the cross correlations of the top three variables.

Table IV.F-2. Cross Correlation Coefficients

Variable	vs. Percent of Fill	vs. Width	vs. Length
Percentage of Fill	R = 1.00	R = -0.48	R = -0.52
Width	R =- 0.48	R = 1.00	R = 0.82
Length	R = -0.52	R = 0.82	R = 1.00
Depth	R = -0.41	R = 0.53	R = 0.57
Wall Thickness	R = -0.40	R = 0.31	R = 0.23
Percent Prism	R =- 0.01	R = 0.01	R = -0.17
Thermal Conductivity	R = -0.18	R = -0.01	R = -0.071

F.1.b. Regression Analysis

Next, regression analysis was performed on the individual variables to determine the R^2 as well as the linear relationship between the independent variables and the dependent variable.

The following summarizes the results:

Table IV.F-3. Coefficient of Determination (R^2) for selected MGTS variables vs. cycle time

Variable (Symbol)	R^2
Percentage of Fill (Fill)	0.50
Width (W)	0.33
Length (L)	0.29
Depth (D)	0.20
Wall Thickness (Thick)	0.16
Dimensions (Dim)	0.04
Percent Prism (Prism)	0.02
Thermal Conductivity (TC)	0
Cavities (Cav)	0

F.1.c. Stepwise Multiple Regression

A stepwise multiple regression was then conducted using the above variables. This was performed to determine a formula based on a linear model. This model shows the interrelationships of the independent variables and dependent variable. The results are summarized on the following page.

Table IV.F-4. Multiple Stepwise Regression of Untransformed Variables

Variables	R2	Change
Fill	0.50	
Fill & W	0.56	0.06
Fill, W & Cav	0.57	0.01
Fill, W, Cav & Thick	0.58	0.01

F.1.d. Initial Results

The result was the following formula based on the 4 variables:

Shots per Hour = 475 + (5.6 * Fill) - (4.6 * Cav.) - (286 * Thick) - (84 * W)

However, this formula did not meet the requirement for a relationship that meets the R^2 goal of greater than 70%. To attain a higher R^2 of over 70%, a number of transformations were tried, based on the physics of the problems and the variable plots.

F.1.e. Transformation (One Dimensional Heat Conduction Equation)

Numerous transformations of the data were tried. Five transformations seem to best describe the process. These transformations were then used as the independent variable and regressed against the dependent variable. The results are provided below:

Table IV.F-5:

Transformed Variables

Transformation	Symbol	R2
1/(1-Fill)	Nonfill	0.50
Length * Width* Depth * % Prism	Volume	0.28
Depth ^{2}/ TC	Heattran	0.19
Length - Depth	Flatness	0.11
Length/ ((1-Fill) * Thick)	Lovert	0.10

Table IV.F-6:

Physical Description of Transformed Variables

Var.	Transformation	Physical Descriptions
Nonfill	1/ (1-Fill)	Measure of Fiberfill
Volume	Length * Width * Depth* % Prism	Shot size
Heattran	Depth ^{2} / TC	Cooling Time
Flatness	L-D	Flatness of part
Lovert	Length/ ((1-Fill) * Thick)	Cooling Area

The heat transformation was derived by looking at a one dimensional heat conduction equation [Dewhurst/ Archer 1987]

$\rho\, C_p\, (\partial T/\partial t) = K\, (\partial^2 T/\partial x^2)$ where

x = coordinate distance from center of wall

T = temperature

t = time

K = coefficient of thermal conductivity

C_p = Specific Heat Coefficient

ρ = density

The above equation is often simplified to the following:

$\partial T/\partial t = \alpha\, \partial^2 T/\partial x^2$ where $\alpha = K/(\rho * C_p)$

If metal plates are assumed to be perfectly conducting, the boundary value solution can be expressed in the following series.

$$\frac{T - T_m}{T_i - T_m} = \frac{4}{\pi}\sum_{n=0}^{\infty}\frac{-1^n}{2n+1}e^{\frac{-(2n+1)^2\pi^2\alpha}{h^2}}\cos\frac{(2n+1)\pi x}{h}$$

where $T_i =$ initial uniform temperature,

$T_m =$ temperature of the metal plates

$h =$ distance of the plates

Based on this equation a number of authors, including Dewhurst and Archer, suggest a truncated solution where the cooling time is the point when the highest temperature in the mold equals the heat distortion temperature (T_x). (Dewhurst / Archer 1987) Thus, if $h = h_{max}$, $x = h_{max}/2$, $T = T_x$ and only the first part of the equation is used the resulting equation is:

$$\text{Cooling time} = -\frac{h_{max}^2}{\pi^2\alpha}\ln\frac{\pi(T_x - T_m)}{4(T_i - T_m)}$$

By assuming a mean value of T_x, T_m, and T_i the formula can be further reduced to:

Cooling time = $(\psi h_{max}^2)/(\pi^2\alpha)$ where ψ = cooling coefficient that can be estimated by using statistical analysis.

Based on this a transformation should be a function of the part thickness divided by a measure of thermal conductivity. Therefore, the heat transformation

Depth ^{2} / TC is a representation of the cooling time for a three dimensional cube.

F.1.f. Stepwise Regression with Transformed Variables

These transformations were then used to conduct a multiple regression.

The results of the multiple regression are found on the next page:

Table IV.F-7.

Multiple Stepwise Regression for Transformed Variables

Variables	R^2	Change
Non – fill	0.50	
Non - Fill & Volume	0.59	0.09
Non - Fill, Volume & Lovert	0.62	0.02
Non - Fill, Volume, Lovert, Length	0.63	0.01
Fill, Volume, Lovert, Length, Cav.	0.64	0.1

The resulting formula is :

Shots per Hour = 96-(3.5 * Cav) - (55.5 * Length) + (1.9 * Lovert) +(327 * Nonfill) - (3.2 * Volume)

While this formula does not quite reach the R^2 goal of 70%, it appears to make good physical sense. As the volume, length and cavities increase, the shots per hour decrease because filling the mold is harder. As the amount of fill increases, the part will solidify quicker with less shrink and can be ejected quicker. As the Lovert increases the cooling area increases and the part cools faster increasing the shots per hour.

F.1.g. Data Stratification

1. Review of the data indicated that possible subsets of data existed based on part geometry. This resulted in the division of the data into two groups based on Length / Depth. Poli et. al. (Kou, 1990) describe the L/H ratio[5] as a critical ratio that describes if the part is flat or box-shaped. Poli's research used a L/H ratio of 3, based on the data gathered and analyzed the L/H appears to be approximately 2.25.

The first group had 81 data points while the second group had only 28. The variations in the first group of variables are found in the following table:

Table IVF-8.

Variation of Attribute Variable (First Stratification) L/D < 2.25

Variable	High Value	Low Value	Mean Value	Std Dev.
Shots per Hour	800	160	432.5	150.5
Wall Thickness	0.4"	0.01"	0.07"	0.06"
Length	2.24"	0.27"	1.05"	0.46"
Width	1.91"	0.25"	0.84"	0.39"
Depth	1.81"	0.20"	0.72"	0.33"
Thermal Conductivity	9.6	4.5	6.19	0.75
% Short Fiber Fill	33%	0%	12.75%	14.01%
Percent Prism	25%	1.2%	9.12%	5.68%

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[5] Poli uses h as a measure of depth while in this work it is referred to as depth.

Table IV.F-9:

Variation of Attribute Variable (Second Stratification) L/D $\geq$ 2.25

Variable	High Value	Low Value	Mean Value	Std Dev.
Shots per Hour	830	225	406.7	150.7
Wall Thickness	0.13"	0.02"	0.05"	0.03"
Length	3.54"	0.3"	1.57"	0.83"
Width	2.57"	0.16"	1.16"	0.8"
Depth	1.53"	0.089"	0.42"	0.32"
Thermal Conductivity	8.1	5.3	6.15	0.57
% Short Fiber Fill	33%	0%	11.8%	14.9%
Percent Prism	19.6%	1.5%	8.7%	5.2%

Since the part family selected was for smaller parts the data is split into two groups. The first group contains smaller, more dense parts where the driving variable should be the transformation Depth^2 /TC, which would represent the cooling time of the part. In this group cooling would not be driven by the wall thickness, but rather by the depth of the part.

The second group of parts represents thinner parts that should be driven by the wall thickness or filling time.

F.1.h. Transformed Regression Analysis with Stratified Data

The transformations discussed above were used to conduct a multiple regression for the two groups. The results of the multiple regression for the first group are found below:

Table IV.F-10.

Stepwise Regression of Transformed Variables

(First Stratification) L/D< 2.25

Variables	R^2	Change
Nonfill	0.48	--
Nonfill & Heattran	0.57	0.09
Nonfill, Heattran & Lovert	0.61	0.04
Nonfill, Heattran, Lovert, & Volume	0.62	0.01
Nonfill, Heattran, Lovert, Volume, & Width	0.64	0.02

The resulting formula was:

Shots per Hour = -54.9 - (731.6 * Heat tran) +(2.2 * Lovert) + (361.9 * Nonfill) - (3.6 * Volume) + (134.6 * Width)

This formula did not meet the requirement for R^2 but made good physical sense. As the depth of the part increases, Heattran increases resulting in longer cooling time or fewer shots per hour. Similarly, as Lovert and Width increase, more cooling area is available, the part cools faster and shots per hour increase. Nonfill and Volume follow the same pattern as described in F.1.f. The only problem is the negative constant, but since Nonfill is always greater than or equal to 1, the result of the constant and Nonfill cannot be zero. Additionally, for the variable ranges described by these parts, shots per hour are always positive. The second group was analyzed by using the above transformations with the following results.

Table IV.F-11. Stepwise Regression of Transformed Variables (2nd Stratification) L/D ≥ 2.25

Variables	R^2	Change
Flatness	0.56	--
Flatness & Lovert	0.72	0.16
Flatness, Lovert & Volume	0.75	0.03

The resulting formula is:

Shots per hour = 524 - (183.2 * Flatness) + (3.2 * Lovert) - (3.4 * Volume)

This formula met the R^2 requirements but had only three variables since the data set was very small. Naturally, if more data for these type of parts is used the results would be more robust. However, this result should serve to give an order of magnitude estimate and be relatively correct.

A. Injection Molding Cost Breakdown Structure

A.1. Introduction

As previously described, engineering economics is the methodology used to decide among competing alternatives. Engineering economics uses the time value of money to amortize capital investments. Since the plastic injection molded part cost problem required an initial capital investment, it is a prime candidate for this type of analysis. By using the amortized cost of the mold, setup, annual and operating costs, plus tax considerations of making the part, an equivalent uniform annual cost can be found. This cost can be used in conjunction with the production volume to determine the average cost of a part each year of the project.

A.2. Definition Of Terms

A.2.a. Cash Flow Analysis

The selection process for capital facilities is based on estimates for future cash flows. Positive cash flows arise when revenues (sales) and borrowings exceed expenses. Negative cash flows occur from expenses, repayment of debt, and 'first cost' or 'investment cost' exceeding income. Cash flow analysis includes the estimation of such cash flows.

A.2.b. Time Horizon

The time or planning horizon is simply an estimate of the length of the operational time period for the project under study. Before undertaking any economic study, a planning horizon must be determined. This is especially important in analyses that compare two alternative investments, because if the planning horizons for the two alternatives differ, special measures must be taken to ensure a common planning horizon. For most studies the useful life of the asset is taken as the planning horizon.

A.2.c. Depreciation

Often the capital cost of an asset is expensed or depreciated over its estimated useful life. Depreciation can be used for most tangible property, such as buildings and equipment, although not for non-depreciable property such as land. The IRS mandated Modified Accelerated Cost Recovery System (MACRS) is used for most studies. Other depreciation methods, such as straight-line, are used for screening and feasibility analyses.

A.3. Introduction to Design for Cost (DFC)

Delivering products that meet customer requirements of cost and quality is a key goal of concurrent engineering. Global competitors target new products to be delivered to the market within a specified cost range. Design team members use a variety of tools to meet customer requirements of quality and cost. The purpose of the model is to use engineering economic sensitivity analysis to determine areas of design emphasis and provide design team members with a new tool.

Good design teams continually evaluate cost - benefit tradeoffs and use the information to improve cost estimates throughout the product development cycle. Initial cost estimates are developed in the conceptual design phase and updated during the definition and scoping phases. This process continues through the design and manufacturing phases of the product development cycle.

The engineering economics model deals with the effects of volume, capital outlays, rate of return, time value of money, project lives, and other factors that will affect the decisions regarding part design, cavity selection and production. "What-if" sensitivity analysis allows the user to evaluate a large number of scenarios in an efficient manner to determine the best life cycle cost for the product.

A.4. Identification Of Costs And Other Terms

As previously stated, plastic-part costs can be divided into five categories. These are capital costs, material costs, processing costs, post-processing costs and set-up costs. These are described in earlier sections of the report.

B. Pro forma Plastic Part Economic Model

B.1. Introduction

The model proposes an engineering economics methodology for the sensitivity analysis of cost factors with respect to design and provides an early determination of part cost range. Sensitivity analysis is important so that design and management emphasis can be placed in areas that will have the greatest impact on the overall cost.

As stated earlier, plastic-part costs can be divided into five categories. The five categories are capital costs, processing costs, material costs, set-up costs and post processing costs. These cost categories are the ones that have been used in the economic model under development.

Each of the cost categories is found to be dependent on certain variables. The variables are summarized in the following table. Some variables are unique to the to one category while others affect more than one.

Cost Categories

Table V.B-1.

Capital Cost	Material Cost	Processing Cost	Post Processing Cost	Setup Cost
Mold Cost	Production Volume	Production Volume	Jig Cost	Setup Rate
Jig Cost	Material Price	Time Horizon	Cycle Frequency	Setup Time
Time Horizon	Part Volume	Cycle Frequency	Machine Rate	
		Machine Rate		

Inflation and the MARR (Minimum Attractive Rate of Return) generally affect all of the cost categories.

B.2. Capital Costs

The capital costs of a project consist of an initial or periodic cost representing the cost for the mold or jig. These costs are represented in the model as first time investment costs which are converted to capital recovery (CR) costs. Capital recovery costs are annualized one-time costs, spread out over the life of the project. They are annuities (A).

B.3. Material Costs

Material costs were determined using the following formula:

Material Cost = (Part Weight) x (Material Price per unit weight) x (Production Volume)

B.4. Processing Costs

Processing costs are defined as the cost incurred to run the injection molding machine. These costs are based on the number of cycles per hour, machine rates and production volume. To determine the size of the required machine, the project area of the part was examined and the following formula was utilized (Dym 1983):

Projected Area = # of Cavities x Projected Area of Cavities

For example, in the case of a handheld calculator, a number of assumptions were made. First it was assumed that the part basically had 2 halves and that both had approximately the same projected area - 36 in^2 (9 in x 4 in). Clamp tonnage was then calculated as follows:

Clamp Tonnage = 1.33 x Projected Area x 5 $tons/in^2$

The 1.33 factor is a safety factor that attempts to include runners and gates and the 5 tons/in^2 (tsi) was found in a 1983 article by Joseph B. Dym (Dym 1983) in which a range of 2-5 tsi was recommended with low viscous materials using the higher values. As it is considered good engineering practice to use conservative estimates, especially in initial design phases, the 5 tsi value was used.

Clamp tonnage was then used to find the hourly rate published every quarter in *Plastics Technology*[*]. In this example the projected area was 72 in^2 which resulted in the use of a 500 ton machine found to have an hourly cost rate of $56.94.

The cycle frequency was determined by Dym using parts per hour vs. part thickness graph. However, the cycle can be determined by other methods like the one described in the previous chapter. With all the variables having been determined the processing cost was calculated using the following equation:

Processing Cost = [Production Volume/Cycle Time] x Hourly Rate

B.5. Setup Costs

Setup costs were determined by first finding the setup rate for the given machine size. This too was found in the quarterly survey published by *Plastics*

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[*] Bill Communications, Inc. Publisher

Technology. Continuing with the above example, a 500 ton machine was determined to have a setup rate of $210. In addition it was assumed, based on experience of the operator, that the setup rate would approximately be 12 hours per run. In this example, assuming the customer required two deliveries per year, the setup time will be 24 hours per year. Therefore setup costs are calculated as follows:

Setup Cost per Machine = Setup Rate x Setup Time

B.6. <u>Post Processing Costs</u>

Post processing costs consist of the capital cost to set up a jig and secondary operations cost for processing the parts. Secondary operations costs are calculated as follows:

Secondary Processing Cost = [Production Volume/Cycle Time] x Hourly Rate

B.7. <u>General Administrative And Sales And Research Costs</u>

An accepted industry method to account for overhead costs is to use a percentage of the total direct costs. In the pricing model, general administrative costs were taken at 20% of total direct costs and sales and research costs were taken at 15%. These percentages can be varied depending upon the scope of the design project economics. If costs at the factory door are desired, the percentage will be less than costs at the divisional or corporate level. These rates will be company or user specific.

B.8. Tax Expenses

For a preliminary after-tax analysis, assuming a fixed tax rate and straight-line depreciation for all depreciable assets, tax expenses for the project can be estimated using the following formula:

$$TE = t\ ((CR - (Dt)/(1 - t)) - (Dt)$$

where TE= Total Tax Expense

t = the combined tax rate

CR = the capital recovery

D = the depreciation expense

This was found by using the Standard Income Statement Format found in most engineering economic texts (Lang/Merino 1993);

where: X = the Operating Income Before Tax

Cr = the Capital Recovery Factor (A/P, i , N)

Where: A= Annuity, P= Initial / Capital Cost,

i= % per period and N = period

P = the Initial Capital Investment

$(X-D)$ = the Net Income Before Tax

$(X-D)t$ = the Tax paid

Therefore, for $NPV = 0$,

$$[(X-D) - (X-D)t] + D = CR + TE$$

Where:

$[(X-D) - (X-D)t] + D$ is the Net Cash Flow after Tax

By rearranging terms:

$$X = \frac{CR + Dt}{1-t}$$

But, this includes Capital Recovery and Tax Expense. The variables can be separated where:

$$X = CR + [t((CR - Dt)/(1+t)) - Dt]$$

Here the first term is the Capital Recovery and the second term is the Tax Expense.

B.9. Piece Cost

Piece cost was simply calculated by adding all the costs - direct, general administrative, sales and research, capital recovery and taxes - and dividing it by the total production volume. For the pricing model no markup is assumed and price is equal to piece cost.

B.10. Summary

The Engineering Economics Model can be summarized as follows:

Year 1 2 3 ... N

B.10.a Direct Costs

(Material Cost) x $(1 + f)^0 = M.C._1$ ...... $M.C._n$ = Material Cost $(1+f)^{n-1}$

(Processing Cost) x $(1 + f)^0 = P.C._1$ ... $P.C._n$ = Processing Cost $(1+f)^{n-1}$

(Set up Cost) x $(1 + f)^0 = S.C._1$ .... $S.C._n$ = Set up Cost $(1+f)^{n-1}$

(Post- Proc Cost) x$(1 + f)^0 = P.P.C._1$ ... $P.P.C._n$ = Post Proc Cost $(1+f)^{n-1}$

Total Direct Cost $= M.C._1 + P.C._1 + S.C._1 + P.P.C._1 = T.D.C._1$

B.10.b. Overhead

General Administrative Cost $= T.D.C._i \times G\&A\ \% = G\&A_i$

Sales and Research Cost $= T.D.C._i \times SRA\ \% = SRA_i$

Total Cash Cost $= T.D.C._i + G\&A_i + SRA_i = TCC.$

B.10.c. Pricing Model:

Capital Recovery Cost $= P(A/P,i,N) = CRC$

Tax Expense $= t \times \{ [CRC - (D) \times (t)]/(1 - t)] - (D) \times (t) = TE$

Total Annual Cost $= TCC + CRC + TE = TAC$

Piece Cost $= (TAC)/(\text{Annual Volume})$

A. Testing the Model

There are significant problems testing a cost model because the two best tests are generally not attractive to prospective industry users. The best test would be that the cost model improves design based on a direct comparison of design groups. That is, to have two groups of engineers design the same part. One group would be the control group and would not use the cost model. The other group, the test group, would design the part with the aid of the cost model presented in this research. In this scenario man-hours and costs of both groups would be tracked as well as the success in the marketplace of these two products. Based on these statistics one could draw a conclusion of the usefulness of this model. However, the extremely high cost of this type of test means that corporate sponsorship is unlikely. Companies would rather assume that the model is effective and start using it. The model is presently under evaluation at Allied Signal, Becton Dickinson and 3M.

A second test could be an accuracy test. Here the cost would be estimated during the various design stages by the model. After the design was complete and the part was put into production the data would be gathered by the company's cost accountants/ cost engineers. These collected costs could then be compared to the model's estimate. An attempt was made to find a corporate sponsor for this test. However, all companies that were approached were very concerned about the cost of the tests and the proprietary nature of their cost accounting systems. Therefore, this approach was unsuccessful.

Accordingly, a third test was devised. First, assuming that given the true cost of capital, material, processing and setup, the engineering methodology would provide an accuracy cost to recover the capital and pay the taxes associated with the project. This is a reasonable assumption due to the longevity of engineering economic theory and the wide acceptance of time value of money in the corporate sector. If this assumption is granted the next step is to test the inputs for the engineering economic calculations. These inputs are the endogenous variables found by the sub-model for mold cost and cycle time.

Ideally, this test would have a number of control parts where the mold cost and the cycle time are already known. Unfortunately, this data was extremely hard to find in the field. The model developed was based on 110 parts made over a five year period; while these parts could have been subdivided into a group for model regression and a test group, this was not done because of concern that the significance of the model developed would be significantly degraded if data points were removed from the set, due to the large number of variables used in the regression analysis.

The research completed by Mancino and Locurto (Mancino & Locurto 1992) provided one opportunity to test the model against a single reference point. Mancino and Locurto used a pull through cap (in Figure VI.A.1) to obtain estimates from 12 mold shops. The average estimate for a 4 cavity mold was \$17,775 and the standard deviation was \$4,680. One could reasonably say that, if the model described in the research was within the range of one standard deviation - between \$13,095 and \$22,455, then the mold cost equation is accurate. In fact, for this type of part, the mold cost equation estimates a cost of \$18,437, a difference of only \$662. However, this is only one point of data and the accuracy assumption can not be expanded to include all types of parts or all moldmakers.

Two industry partners (IBM and 3M) were willing to provide old data from parts already designed to be used for testing. The first data set was 4 parts, with 16 individual molds from 3M's telecommunication division. The parts are electrical connectors from a similar family as the parts used to develop the mold cost model. This data resulted in 16 test points for the mold cost and cycle time models. Based on the 16 points, the average percent different of the actual mold cost versus the estimated mold costs was –0.78% and the standard deviation was 27.98%. The Q-Q plot shows an approximate standard distribution. Compared to the industry goal of a 15.6% standard deviation described in chapter III, the 27.98% standard deviation is significantly greater. Yet, compared to the three mold shops described in Chapter III, a standard deviation of 27.98% is better than 2 of the 3 shops and comparable to the best shop studied that had a standard deviation of 26.9%.

A possible explanation for this standard error may be the fact that the molds were match sets. In match sets the cap mold and the jacket mold are required to make the part. Since 3M's policy is to have the same shop make both molds when the 2 parts are used to make the same parts it is possible that the mold shop may have averaged the total price of both mold for the job. This would reduce the price on the more costly mold and increase the price on the less expensive mold. A study on the 8 pairs of molds renders an average percent error of -1% and a standard deviation of 8%, much better than industry goals and far better that the best mold shop. Unfortunately, we do not know if the mold maker averages the prices of the mold pairs.

Of interest were some of the anomalies in the test data set. First, the 12-cavity mold for Cap A was more expensive than the three 16-cavity molds of the same part. The same was true for Jacket A. While physically this makes very little sense there are two potential explanations. First, we may be seeing a learning curve effect in these parts. Learning Curve theory states that as the number of units in production increases the time required to make the units decrease. In this case, the learning curve effect may be greater than the effect of four extra cavities. The second possible explanation is that the mold shop was willing to cut the price on the subsequent mold based on the size of the program. The part represented here is produced in very large quantities of greater than 500 million parts per year. Therefore, a moldmaker could make a decision to reduce the price because of the number of molds required to produce the amount of parts required.

The cycle time was also tested against the same parts. The 16 parts cycle time was compared to the estimated cycle time. In this test the average cycle time difference was 9.86% and the standard deviation was 13.94 %. The high average difference leads one to believe that a systematic error may be present. The low standard deviation is very encouraging and is close to the industry goal of 11.7% and as good as the best shop studied (12.9%). The systemic error is troubling, but might be explained as the sampling error since there are only 4 basic designs being studied in this test. It is interesting to note that as expected, the number of cavities has no affect on the cycle times , but one wonders if that is not related to the overall factory set-up.

Both of these examples represent an effort to test the cycle time and mold cost model and are not as exhaustive as might be desired. Unfortunately, no further cycle time estimates were available for testing. A set of 83 data points of IBM molds made between 1986 and 1987 were available from Dennis Pearce, the developer of the MoldCost model. No part drawings were available. However, the raw data used to develop MoldCost was available. These test parts were not within the same part family as the parts used for the model and were outside the relevant range model. Therefore, a test of the model was attempted based upon a series of assumptions. Two key variables were missing, the side actions and the present prism of the part Therefore, it was decided for testing purposes only to ignore the side action variable and assume that all parts had a 33% prism. Based on the assumptions the average percent error between the actual mold cost and the estimated mold cost was -7.67% and the standard deviation was 37.31% the Q-Q plot shows that the percentage error had a roughly standard distribution . Compared to the mold shops these estimated with limited data available were better than 2 of the 3 mold shops who made their estimations with full part drawing and access to the engineers that designed these parts.

Based on these two tests one can say that the mold cost model can estimate as well as industry for both inside and outside the relevant range of the parts used to derive the model.

Dot Plot of Mold Estimate Accuracies

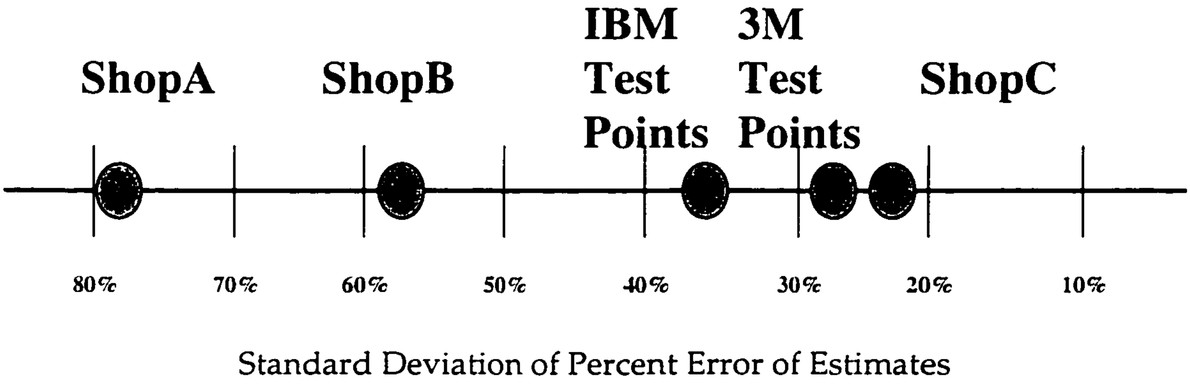


Figure VI.A-1

For the Cycle time, The test shows that the model may have a systemic error, but has almost the same variability as the present molder studies. More testing needs to be done on the cycle time model with a set of more diverse parts.

Dot Plot of Cycle Time Estimate Accuracies

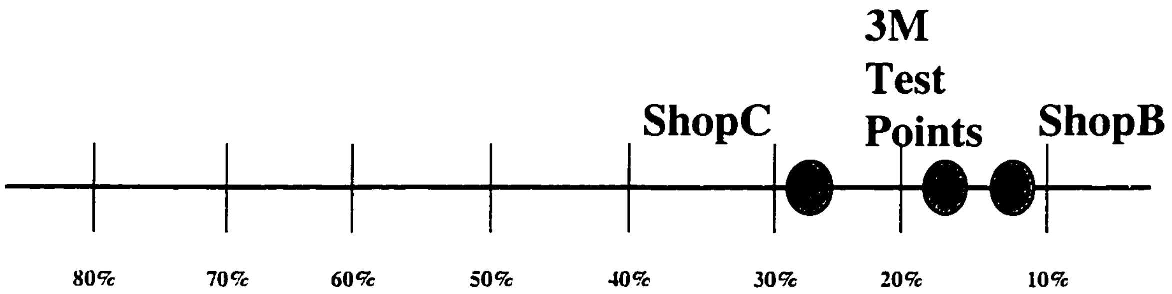
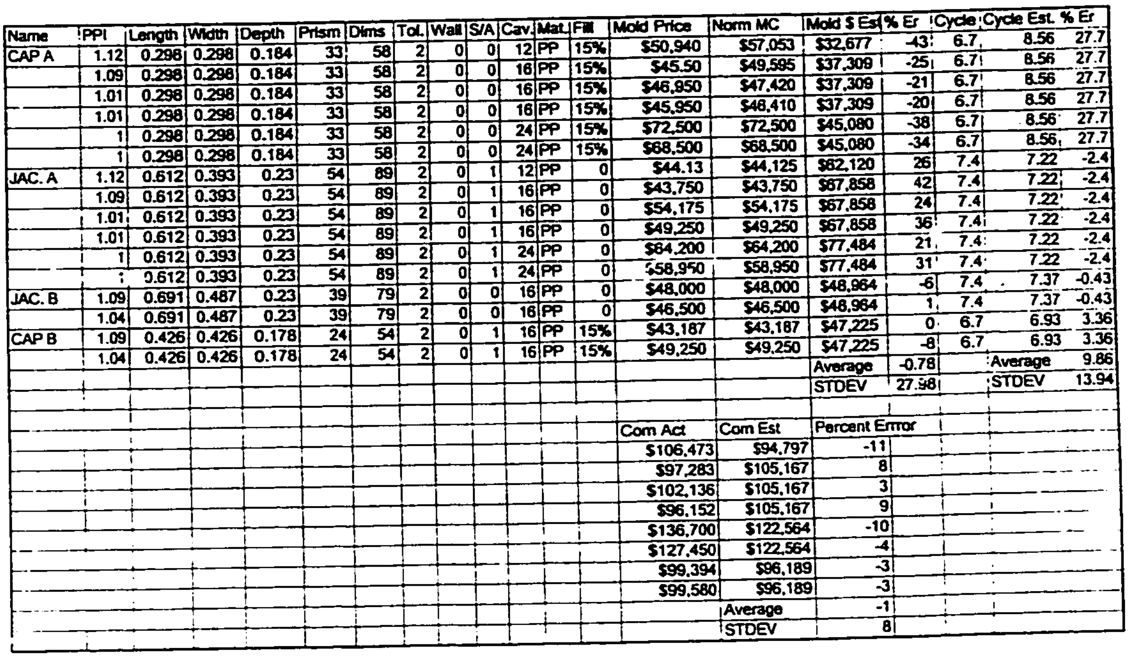


Figure VI.A-2

3M Test Points



Name	PPI	Length	Width	Depth	Prism	Dims	Tol.	Wall	S/A	Cav.	Mat.	Fill	Mold Price	Norm MC	Mold $ Est	% Er	Cycle	Cycle Est.	% Er
CAP A	1.12	0.298	0.298	0.184	33	58	2	0	0	12	PP	15%	$50,940	$57,053	$32,677	-43	6.7	8.56	27.7
	1.09	0.298	0.298	0.184	33	58	2	0	0	16	PP	15%	$45.50	$49,595	$37,309	-25	6.7	8.56	27.7
	1.01	0.298	0.298	0.184	33	58	2	0	0	16	PP	15%	$46,950	$47,420	$37,309	-21	6.7	8.56	27.7
	1.01	0.298	0.298	0.184	33	58	2	0	0	16	PP	15%	$45,950	$48,410	$37,309	-20	6.7	8.56	27.7
	1	0.298	0.298	0.184	33	58	2	0	0	24	PP	15%	$72,500	$72,500	$45,080	-38	6.7	8.56	27.7
	1	0.298	0.298	0.184	33	58	2	0	0	24	PP	15%	$68,500	$68,500	$45,080	-34	6.7	8.56	27.7
JAC. A	1.12	0.612	0.393	0.23	54	89	2	0	1	12	PP	0	$44.13	$44,125	$82,120	26	7.4	7.22	-2.4
	1.09	0.612	0.393	0.23	54	89	2	0	1	16	PP	0	$43,750	$43,750	$67,858	42	7.4	7.22	-2.4
	1.01	0.612	0.393	0.23	54	89	2	0	1	16	PP	0	$54,175	$54,175	$67,858	24	7.4	7.22	-2.4
	1.01	0.612	0.393	0.23	54	89	2	0	1	16	PP	0	$49,250	$49,250	$67,858	36	7.4	7.22	-2.4
	1	0.612	0.393	0.23	54	89	2	0	1	24	PP	0	$64,200	$64,200	$77,484	21	7.4	7.22	-2.4
	1	0.612	0.393	0.23	54	89	2	0	1	24	PP	0	$58,950	$58,950	$77,484	31	7.4	7.22	-2.4
JAC. B	1.09	0.691	0.487	0.23	39	79	2	0	0	16	PP	0	$48,000	$48,000	$48,964	-6	7.4	7.37	-0.43
	1.04	0.691	0.487	0.23	39	79	2	0	0	16	PP	0	$46,500	$46,500	$48,964	1	7.4	7.37	-0.43
CAP B	1.09	0.426	0.426	0.178	24	54	2	0	1	16	PP	15%	$43,187	$43,187	$47,225	0	6.7	6.93	3.36
	1.04	0.426	0.426	0.178	24	54	2	0	1	16	PP	15%	$49,250	$49,250	$47,225	-8	6.7	6.93	3.36
															Average	-0.78		Average	9.86
															STDEV	27.98		STDEV	13.94

Com Act	Com Est	Percent Error
$106,473	$94,797	-11
$97,283	$105,167	8
$102,136	$105,167	3
$96,152	$105,167	9
$136,700	$122,564	-10
$127,450	$122,564	-4
$99,394	$96,189	-3
$99,580	$96,189	-3
	Average	-1
	STDEV	8

Table VI.A-1

IBM Test Data Points

P/N	CAV	TOL	LEN.	WID.	DEP.	DIMS	COST	Norm	Mold Est.	% Er
		in mm	in mm	in mm	in mm		86-87			
1	1	0.15	174.5	63	1.6	42	$11,876	$14,132	$21,444	52
3	4	0.15	78	21.5	28	30	$17,575	$20,914	$18,828	-10
4	1	0.15	300	280	20	80	$37,000	$44,030	$82,219	41
5	1	0.2	328	321.5	17	40	$28,600	$34,034	$46,282	36
6	1	0.05	276.5	121.3	23.8	160	$47,000	$55,930	$82,959	13
7	1	0.05	343.5	194.8	85.3	330	$111,500	$132,685	$114,425	-14
8	1	0.1	355	281.1	314.5	520	$258,000	$307,020	$173,937	-43
9	1	0.1	355	291.8	247	415	$151,500	$180,285	$157,004	-13
10	1	0.1	303	247	39.8	415	$86,880	$103,387	$137,204	33
11	4	0.1	75	17	16.3	56	$42,000	$49,980	$24,773	-60
12	1	0.03	382	75	24	175	$40,390	$48,064	$55,513	15
13	1	0.1	358	72	10.2	165	$34,950	$41,590	$51,347	23
14	2	0.1	67.4	19	7.3	21	$10,830	$12,888	$10,611	-18
15	1	0.05	110.2	73.9	25	51	$16,150	$19,219	$27,628	44
16	1	0.1	293.6	209	63	190	$51,900	$61,761	$88,383	43
17	[illegible]	0.13	264.7	191.2	17	63	$32,000	$38,080	$46,409	22
1[illegible]	2	0.03	137.9	8.2	9	39	$13,000	$15,470	$13,020	-16
19	2	0.05	27	20	7.3	37	$11,000	$13,090	$15,140	16
20	1	0.05	310	292.7	133.5	335	$115,000	$136,850	$137,377	0
21	1	0.2	307.2	290	250.5	265	$115,000	$136,850	$128,334	-8
22	2	0.05	78	12	22.5	27	$14,000	$16,660	$11,952	-28
23	1	0.03	285.5	125.8	18.3	180	$61,000	$72,590	$67,306	-7
24	1	0.15	302	294.5	31	85	$45,800	$54,502	$66,587	22
25	1	0.25	300.5	141	25	18	$18,000	$21,420	$22,289	4
26	1	0.03	219	219	23	135	$33,000	$39,270	$72,786	85
27	1	0.06	148	130.7	20	100	$38,000	$45,220	$49,689	10
28	1	0.13	276.5	127.8	14.7	110	$41,000	$48,790	$52,243	7
29	1	0.1	283.5	127.8	16.3	35	$55,000	$65,450	$29,220	-55
30	1	0.1	328	314.4	95.5	320	$109,000	$129,710	$136,925	6
31	2	0.2	318	89.2	30	75	$35,000	$41,650	$43,050	3
32	2	0.1	43	43	15.5	22	$16,000	$19,040	$14,791	-22
33	2	0.2	176	46.8	48	34	$31,500	$37,485	$23,281	-38
34	1	0.1	296.3	134	60	120	$45,000	$53,550	$59,406	11
35	1	0.1	326.4	313.2	278.3	375	$160,000	$190,400	$154,276	-19
36	1	0.1	196.8	113.7	14.8	95	$27,170	$32,332	$45,703	41
37	2	0.1	42.4	13.2	7.4	36	$21,380	$25,442	$12,293	-48
38	4	0.2	27.9	15.8	4.5	19	$9,475	$11,275	$11,627	3
39	2	0.08	54.7	19.2	7.3	49	$16,965	$20,188	$18,157	-10
40	4	0.1	165.5	50	11.5	28	$24,500	$29,155	$22,581	-23
41	4	0.15	73	34	11.4	52	$20,000	$23,800	$27,786	17
42	4	0.1	165.5	24	11.5	28	$21,500	$25,585	$18,517	-28
43	4	0.03	28	18	21.5	28	$16,500	$19,635	$15,495	-21
44	4	0.03	56.7	28	18	28	$20,000	$23,800	$17,483	-27
45	2	0.05	105	105	25	36	$25,730	$30,619	$29,116	-5
46	2	0.07	67.5	50	19.7	64	$17,764	$21,139	$29,799	41
47	1	0.2	308	285	53.5	125	$33,408	$39,753	$78,913	99
48	2	0.08	452.6	83.9	13.4	106	$35,700	$42,483	$49,041	15
49	2	0.07	462.4	83.9	8.9	170	$99,700	$118,643	$61,593	-48
50	4	0.05	310.2	83.9	11.1	160	$61,057	$72,658	$67,825	-7
51	4	0.1	33	33	14	29	$19,900	$23,681	$19,319	-18
52	1	0.04	211.5	83.9	13.4	104	$34,500	$41,055	$42,457	3
53	1	0.04	211.5	83.9	11.5	30	$21,500	$25,585	$21,600	-16
54	1	0.07	17.3	17.3	24.2	22	$13,500	$16,065	$8,323	-48
55	1	0.06	25.9	25.9	17.8	27	$15,250	$18,148	$11,403	-37
56	1	0.05	302	83.9	13.4	95	$36,500	$43,435	$52,100	20
57	4	0.03	160	85	19	106	$76,500	$91,035	$54,888	-40
58	4	0.04	160	85	6	72	$30,300	$36,057	$43,586	21
59	4	0.04	159.4	149.4	9	133	$73,400	$87,346	$73,053	-16
60	4	0.03	159.4	155.4	19	255	$94,500	$112,455	$104,584	-7
61	2	0.01	1	0.9	1.1	12	$11,308	$13,457	$1,785	-87
62	4	0.02	1.3	0.9	1.9	18	$23,400	$27,466	$6,145	-78
63	2	0.05	446.6	59	17	57	$72,500	$86,275	$32,289	-63
64	1	0.1	60.1	18.2	18.5	43	$20,700	$24,633	$14,124	-43
65	1	0.1	361	65	57	168	$57,900	$68,901	$54,337	-21
66	4	0.03	80	34	3	31	$21,800	$25,942	$19,953	-23
67	1	0.1	541.2	130.3	11.4	44	$34,400	$40,936	$33,508	-18
68	1	0.1	577.6	134.6	79.8	86	$43,100	$51,289	$55,053	7
69	1	0.1	584.2	139.7	64.5	93	$54,600	$64,974	$56,633	-13
70	1	0.02	227.5	160	80	210	$61,800	$73,542	$83,480	14
71	2	0.05	129	114	60	105	$39,500	$47,005	$54,843	17
72	2	0.1	331	52.3	51	47	$58,700	$69,853	$30,488	-56
73	2	0.05	290.2	56.2	12.9	17	$84,000	$99,960	$15,825	-84
74	2	0.05	321	175	49	65	$131,000	$155,890	$59,635	-62
75	2	0.06	403	326.7	50.7	385	$175,000	$208,250	$155,414	-25
76	2	0.07	505.9	70.5	64.8	196	$151,000	$179,690	$68,723	-62
77	2	0.1	442.4	216.1	98.8	248	$166,000	$197,540	$112,884	-43
78	2	0.1	291.2	63.5	108	75	$113,000	$134,470	$42,790	-68
79	2	0.03	129.5	86.5	35	195	$10,000	$119,000	$66,942	-44
80	2	0.03	185.1	81	17.8	311	$109,000	$129,710	$82,502	-36
81*	1	0.07	555	326.7	55.7	394	$74,000	$88,060	$153,793	75
82*	1	0.1	443.2	54	100	90	$41,000	$48,790	$41,680	-15
83*	1	0.07	504	117.8	64.6	198	$48,500	$57,715	$74,640	29
84*	1	0.08	442.4	216.1	90	255	$58,000	$69,020	$106,802	55
									Average	-7.67
* MOLDS BUILT IN PORTUGAL						STDEV	37.31			

Table VI.A-2

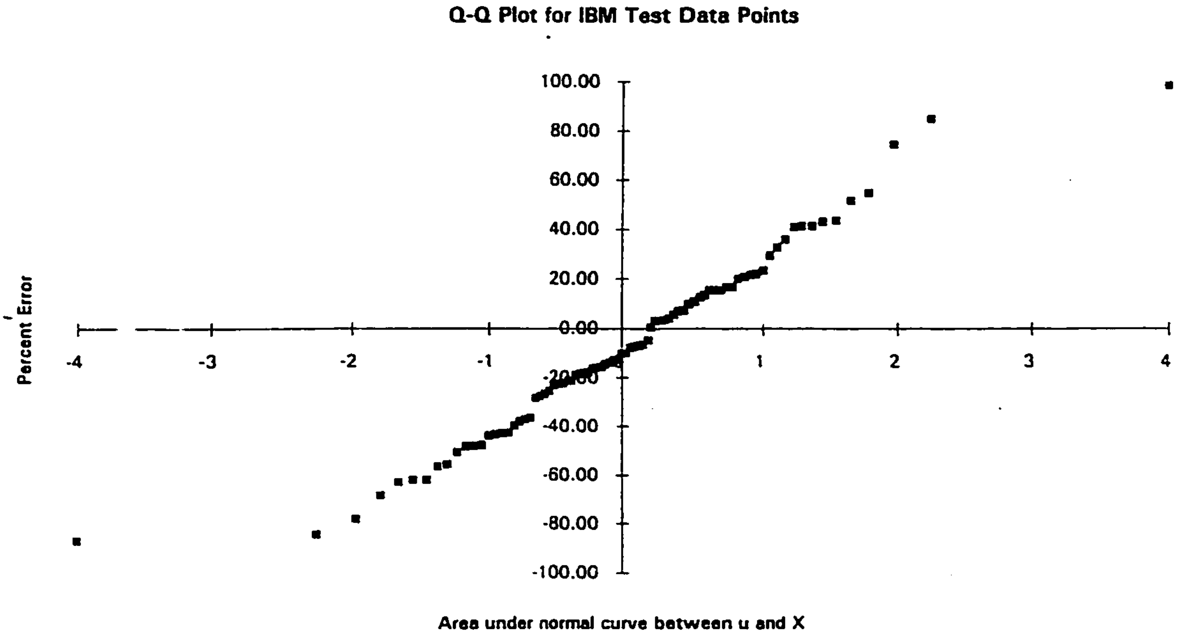

Q-Q Plot for IBM Test Data Points
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
Percent Error
-4
-3
-2
-1
1
2
3
4
Area under normal curve between u and X

Figure VI.A-3.

Another test that was needed was a cycle time estimate, but the cycle time was not estimated by molding shops for the pull through cap like the mold cost was. Therefore, as a proof of concept we can try to show that the model will not exceed the theoretical minimum cycle time based on the one dimensional heat transfer equation derived in chapter V. The one dimensional heat transfer equation represents the most idealized model for potential cycle time. In this model the injection and ejection occur instantaneously before and after the cooling cycle. In reality, this is never the case. In some instances the injection/ejection phase can be longer than the cooling phase alone.

The other idealization of the one dimensional heat transfer model is related to boundary conditions. Here it is assumed that the mold plates / boundaries will remain at a constant temperature. In reality for small and intricate parts the boundaries run considerably hotter than the rest of the mold plate due to poor heat transfer in these regions. This leads to a longer cycle time than if the part had boundaries with a constant and predictable temperature. In the case of the pull through cap the cycle time found by the model was 429 shots per hour compared to the 884 shots per hour found by the one dimensional heat transfer equation. This is a result that one would expect from an accurate model where the cycle time would not exceed the calculated cooling time. Unfortunately this is not an exhaustive test and is of limited use.

B. Potential Impact on the Design Process

It is expected that the model described in this thesis could be used to affect a change in the method plastic parts are designed. Presently, the plastic part is designed based on perceived market need or engineering need. In the case of engineering need a more complex product is conceived in marketing. Within this product component parts are needed. In either case these parts are to be designed and the process to make these parts determined.

In the concurrent design process the marketing department will pass along perceived customer needs. These may include fit, form and function of the part and should include a target price that the market is willing to pay. In either the simple or more complex case, the designer first needs to develop a design that will meet the engineering requirement for the customer. These may include strength, impact, accessibility etc. as well as the required fit, form and function.

Once a potential solution is developed, typically with a concept drawing, the engineer could use this model in a number of ways. First if this model is used in conjunction with other similar models for different processes, the engineer could input estimates for the various input parameters and determine the design processes that would result in the least cost. Since many of the input parameters like the number of parts made per year and the product life are estimates, the best that can be expected is that these model could point designers to a smaller domain of potential processes. As of yet, similar models for different processes do not appear to be readily available.

Second, assuming that it has already been decided to use plastic injection molding to make the part, the model would be used by the designer after the initial concept drawing to determine the key cost drivers of the design. Using estimates for the key variables it can be decided which of the cost categories drive the cost. This analysis will provide the designer with a better idea if the part cost is driven by the mold price, the cycle time or material cost. Based on this the designer will know where to focus his/her attention in the detailed design.

As a management tool the cost model could be used to determine the overall sensitivity of the variable. In this case a range of estimates are used for the design variables. The high and low costs for each variable can be determined if all other variable estimates are held constant. Based on the cost differences caused by the uncertainty of the estimates, a rank order of variable with the highest impact can be determined. This will help management decide where to invest time and attention.

As the detailed design progresses the designer can use the model to further refine the cost estimates by examining the variables using sensitivity analysis to determine the marginal sensitivity of the variables. This is done by changing variables a small amount while holding all other costs constant. The marginal sensitivity can also be ranked and will help the designer decide where to focus time and attention to further reduce the cost of the part. The marginal sensitivity indicates the change in part cost based on a fixed change in the input parameter- usually 10%. The gross sensitivity indicates the change in part cost over the range for that variable - which could be very small or very large.

The above method described differs from the present method of design where the designer will usually use rules of thumb or past experience to determine which process should be used and where the design emphasis should be placed. Additionally, since the designer may or may not have the ability to estimate the part cost, the entire design may have to be detailed prior to estimates from the moldmaker and molder. If the price is too high for the market then the part needs to be redesigned. This requires rework which will drive the cost of the product up. Unfortunately, this cost is not built into the estimate of the part as a separate cost, but rather is included in the overhead rate.

C. Conclusion:

A number of conclusions about plastic part manufacture can be drawn from this research. First, a number of metrics for the benchmarking of the moldmaking industry can be made. These metrics include the accuracy of estimating an individual job, a metric for overall shop accuracy over time, and lastly, the correlation of the invoice and actual cost for mold making. Combined, these will characterize and benchmark the estimating practices of this industry.

Second, are some metrics related to the molding industry. These include the job to job estimating accuracy of cycle time which is the key cost variable of the piece part cost molding, as well as the overall shop accuracy.

Third, we can show a clear methodology for the development of a mold cost model. This methodology can be replicated by other researchers for different industries or within the injection molding industry as part families change or technology changes.

Fourth, we can show a methodology for the development of a cycle time model. This method can be repeated for different shops or a different family of parts.

Fifth, an engineering economics frame work is proposed. This framework, tied to the previously mentioned models, will give plastic part designers the ability to determine the life cycle manufacturing cost of a plastic part. This model will also give designers the ability to find the sensitivity of various designs missing design variables and give engineers and managers the ability to better focus the design effort.

D. Benchmarking of Mold Estimating Practices

Based on the research presented one can conclusively say that moldmakers do not, as they believe, estimate mold costs within +/- 20%, 80% of the time. In fact , moldmakers have a wide variation in their ability to estimate the cost of the mold depending on experience, job difficulty, familiarity with the part and other factors.

As for the overall shop accuracy over time, the results are mixed. Two of the three shops studied showed an average overall shop accuracy over time close to zero. This is consistent with the expectation that a plastic injection moldmaker would need to estimate the costs accurately over time. The third (shop A) consistently over-bid jobs. Based on this data alone it is difficult to draw a conclusion. Shop A's sales could be on the decline leading to eventual changes in bidding practice. Another possibility is that Shop A could be a very efficient shop and the market place may be rewarding Shop A for this. Data was not collected to either prove or disprove these theories.

Lastly, one can conclude that there is a strong relationship between invoice price and actual cost. Based on this, one can then conclude that invoice price may be used as the dependent variable in a statistical analysis.

E. Benchmarking of Cycle Time Estimating Practices

Similarly, based on the research presented one can conclusively say that molders do not estimate cycle time within +/- 15%, 80% of the time. As with costs, molders' ability to estimate cycle time varies widely.

As for the overall shop accuracy over time the results are mixed. The results of the experiments indicate that plastic injection molding shops estimate cycle time fairly close to their acceptable regions. While not acceptable, the averages of their estimates are close to zero. This result is consistent with expectations for an established injection mold shop.

F. Future Research:

From this research, there are a number of areas to be further explored. Clearly, more testing of the model needs to be completed. There are three main tests that should be accomplished on this model. First, an attempt should be made to prove that a cost model used in the design process is a tool that will increase the efficiency of the design process. To accomplish this the model should be tested using a statistically significant number of design teams. Ideally the design teams would be divided into two groups, the first group designing parts without the aid of the economic model and the second group the test group using the model. Through direct comparison of time and money spent by each group, a determination of the effectiveness of the cost model could be made.

The second type of testing would be accuracy testing. This could be done in two ways. First a statistically significant set of design teams could be observed. At predetermined points during the design the observer could determine the cost of the part from the model while the design team estimates the cost of the part using traditional methods. Upon completion, the parts cost would be determined by the actual costs received from the vendors or in - house service providers. The estimates made by the model would be compared to the estimates using traditional methods and to the actual costs found at the end of the design. A simpler test for accuracy would be to obtain parts where the full cost is known or were the mold capital cost and cycle time is known and then test the model against these parts. Based on the results, an average percent of error and the standard deviation for the test could be compared to the results found in chapter III and a judgment could be made on the accuracy of the model.

The second line of research would be to build better mold and cycle time models. First, the methodologies described in chapter IV should be used to find new algorithms for the mold cost and cycle time of different families of parts. The parts presented in the research represent small electrical / electronic parts. It would be of interest to find out if the parts produced by Ford Motors or Rubbermaid - the makers of large size parts - would be similar. Additionally, as the methodology is run on other families of parts, a better and more comprehensive model for injection mold would be developed.

A modification of this avenue of research would be to take the methodology and try to apply it to other mold - based manufacturing methods. Here the mold cost model would probably use the same variables, but the cycle time variables may need to be modified to accurately reflect the time drivers of the selected process.

Moreover, additional research could be done with the models actually developed, particularly as to the effects of the cavity side action interaction. Intuitively one would suspect that the cavity/side action interaction would be of a similar nature as the dimension/cavity interaction. However, the data set used in this research had very few parts that had multiple cavities and side actions.

Similarly, the cycle time model should be reviewed in a number of places. The actual cycle time of the part has a great deal to do with individual ability, in that some of the variation seen on the cycle time model has do to with less than optimal molding set up. It may be that the number of parts in the run is directly proportional to the amount of effort to optimize the cycle. Therefore, in a short run of parts the set-up person may only optimize the molding machine settings to get acceptable parts at a reasonable cycle time. For a longer run of the same part the setup person may spend a longer time and reduce the cycle time by 25-

30%. Since a customer molder data was used approximately 90% of the parts were short run (<100,000) (Fergusson 1992).

Lastly, research should be done to use the cost estimation model as the basis of a plastic shop floor planning model. By using the cost model as a basis, a linear programming solution to the shop floor loading problem can be developed.

In conclusion, more actual practitioners should publish the successes and failures in developing cost estimation models. Unfortunately, almost all the published literature is authored by academicians whose focus is on the physics of the injection molded part cost problem and usually provides only anecdotal data to show the effectiveness of their model. To improve estimating ability and make Design for Cost a reality, companies must know how others are solving "real" problems and the limitations of these techniques.

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"Part Cost"

1992

1992: LITERATURE SEARCH SUMMARY

A. Purpose Of Search:

The purpose of this literature search was to determine the published body of knowledge in the field of cost estimation for plastic injection molding parts. This including mold tool costs, materials cost, and part production costs.

B. Literature Search Results:

A total of 110 articles were identified in the literature search. 18 articles had specific mention of EMIM software or methodologies. The remaining articles covered general methods of cost estimation in manufacturing, rules for mold design, and aspects of plastic part production. Reference lists in chronological and alphabetical order by author's last name are provided in Appendices 1 & 2. An annotated bibliography was provided in Appendix 3. Various analyses of the search were conducted including key words (Appendix 5), key authors (Appendix 6), and key journals (Appendix 7).

C. Key Word Analysis:

Of the 110 articles found in the literature search, 18 contained in-depth discussions of EMIM methodologies or computer software. A key word analysis was conducted on these 18 "on-target" articles. The analysis indicates that the most frequently used key words were:

	No. of Articles
Plastics	5
Computer Software	3
Cost Accounting	2
Computers	2
Mathematical Techniques	2

Plastics with five mentions is the most frequently occurring key word. Computer software (3 mentions) was next. Of these key words, plastics was used in the literature search as a search word. Computer software will be incorporated in future searches as a search term.

Cost accounting, computers, and mathematical techniques each occurred twice as key words. None of these terms were used as search terms in the literature search. Future searches will include these terms.

In addition, the term die was found once as a key word and should be used in future searches in combination with the term mold.

D. Key Authors

The most frequently occurring authors in the literature search were:

	All Articles	18 on Target
	# of Articles	# of Articles
Poli, Corrado	22	2
Wilder, Robert	8	0
Dewhurst, Peter	3	0
Divgi, Jitendra	3	0
Kou, Sheng-Ming	2	2*
Rosato, D.V.	2	0
Scheurmann, H.	2	2
Akkad, Manoj	1	1
Evans, Colin	1	1
Fernandez, Ricardo	1	1
Foy, Francis R.	1	1
Hancock, F.J.	1	1
Joohnson, John	1	1
Kammlade, John	1	1
Praveen, Khullar	1	1
Kim, S.G.	1	1
Larson, H.R.	1	1
Pearce, Dennis	1	1
Santos, J.F.	1	1
Walsh, K.B.A.	1	1
Zenger, David	1	1

Co-authored with Poli

Corrado Poli has contributed heavily to the EMIM field and he is the most frequently occurring author in the literature search with 22 articles, two of which specifically mention EMIMs. Due to his prominence in the EMIM field, a search under his name was conducted. Robert Wilder is the second most frequently occurring author with 8 articles, though none mention EMIMs specifically. Kou and Scheuermann each appear twice as authors of articles specifically mentioning EMIMs.

E. Key Journal:

A key journal analysis was performed on the articles identified in the literature search. The journals appearing most frequently are listed below:

	All Articles	**18 On- target**
	No.	**No.**
Modem Plastics	12	0
University of Massachusetts\Amherst	5	2
Dissertation Abstracts International	5	3
47th Annual Technical Conference of SPE	4	3
Plastics World	3	0
Plastverarbeiter	3	1

The search was conducted on the following databases accessed through the Stevens Institute of Technology Library:

(1) <u>Compendex:</u>

Compendex plus provides coverage of the world's significant engineering and technical literature. Subject coverage includes but is not limited to the various disciplines of engineering, applied physics, electronics and instrumentation, light and optical technologies, and other areas of significant technology. Compendex Plus contains references to and abstract from journals, technical reports, books, proceedings and conference papers, and more. Publications from around the world are indexed including approximately 4,500 journals and 2,000 conferences per year.

(2) <u>Dissertations Abstracts:</u>

Dissertation Abstracts is a definitive subject, title, and author guide to virtually every American dissertation accepted at an accredited institution since 1861, when academic doctoral degrees were first granted in the United States. In addition, citations for thousands of Canadian dissertations, and an increasing number of papers accepted abroad, are included in the database. Professional and honorary degrees are not included. All subject areas are covered. Abstracts are included for a large majority of the degrees granted after January 1980.

British and European dissertations are included in the database from January 1988 forward. In addition, abstracts are included for Masters Abstracts from Spring 1988 to the present.

F. Key Word Analysis

Of the 110 articles found in the literature search, 18 contained in-depth discussions of EMIM methodologies or computer software. Figures A5- 1-4 show a key word analysis conducted on these 18 "on-target" articles. The analysis indicates that the most frequently used key words were:

	Instances:
Plastics	5
Computer Software	3
Cost Accounting	2
Computers	2
Mathematical Techniques	2

Of the five most frequently used key words, computer software, cost accounting, and mathematical techniques are terms which Team 6 had not used in its searches, and should be included in future efforts. In addition, the term die is found once as a key word and should be used in future searches in combination with the term mold.

Key Word: **Article No.**
(By Author's Last Name)

	1	20	22	23	26	29	30	31	37
Artificial Intelligence									
Budget Control							X		
Characteristics									
Coding System		X							X
Component Parts									
Computer Programs									
Computer Software									
Computers						X			
Cost Accounting		X					X		
Cost Estimating									X
Cycle Time									X
Design Cycle									
Die Cost									X
Economic Model		X							
Economics									
Group Technology		X							
Machinery Industry									
Mathematical Techniques		X							
Microprocessor									
Miscellaneous Cost									
Mold Construction Cost		X							
Mold Material Cost		X							

Key Word:

Article No.
(by Author's Last Name)

	1	20	22	23	26	29	30	31	37
Molding									
Plastics						X			
Plastics and Rubber Mold		X							
Plastics Films									
Plastics Machinery									
Plastics Plants						X			
Plastics Products				X					
Plastics Technology	X							X	
Polymers									
Process Cost									
Product Design							X		
Relative Cost Model									X
Rubber		X							
Thermoplastics				X	X				
Tooling Cost		X							

Key Word: **Article No.**

(by author's last name)

	39	52	67	73	82	84	85	97	110
Artificial Intelligence		X							
Budget Control									
Characteristics				X					
Coding System									
Component Parts				X					
Computer Programs	X								
Computer Software					X	X	X		
Computers	X							X	
Cost Accounting									
Cost Estimating									X
Cycle Time									
Design Cycle									X
Die Cost									
Economic Model									
Economics							X		
Group Technology									
Machinery Industry				X					
Mathematical Techniques		X							
Microprocessor								X	
Miscellaneous Cost									X
Mold Construction Cost									
Mold Material Cost									

Key Word:

Article No.

(by author's last name)

	39	52	67	73	82	84	85	97	110
Molding				X					
Plastics			X		X	X	X		
Plastics and Rubber Mold									
Plastics Films	X								
Plastics Machinery		X	X			X			
Plastics Plants									
Plastics Products	X				X		X		
Plastics Technology									
Polymers		X							
Process Cost									X
Product Design									
Relative Cost Model									
Rubber									
Thermoplastics									
Tooling Cost									

G. Key Author Analysis

A key author analysis is presented in figure A6-1 on pages A6 - 2,3. From it we see that the most frequently occurring authors in the literature search were:

	All Articles No. of Articles	18 On - Target No. of Articles
Poli, Corrado	22	2
Wilder, Robert	8	0
Dewhurst, Peter	3	0
Divgi, Jitendra	3	0
Kou, Sheng-Ming	2	2*
Rosato, D.V.	2	0
Scheuermann, H.	2	2
Akkad, Manoj	1	1
Evans, Colin	1	1
Fernandez, Ricardo	1	1
Foy, Francis R.	1	1
Hancock, F.J.	1	1
Johnson, John	1	1
Kammlade, John	1	1
Praveen, Khullar	1	1
Kim, S.G	1	1
Larson, H.R.	1	1
Pearce, Dennis	1	1
Santos, J.F.	1	1
Walsh, K.B.A.	1	1
Zenger, David	1	1

*Co-Authored with Poli

Corrado Poli has contributed heavily to the EMIM field and he is the most frequently occurring author in the literature search with 22 articles, two of which specifically mention EMIMs. Due to his prominence in the EMIM field, a search under his name was conducted. Robert Wilder is the second most frequently occurring author with 8 articles, though none mention EMIMs specifically. Kou and Scheuermann each appear twice as authors of articles specifically mentioning EMIMs.

Figure A6-1 - Key Author Analysis

Author:	No. of All Articles:	No. on Target:
Poli, Corrado	22	2
Wilder, Robert V.	8	0
Dewhurst, Peter	3	0
Divgi, Jitendra	3	0
Bernhardt, E.C.	2	0
Cinquegrana, Dave	2	0
Kirkland, Carl	2	0
Kuo, Sheng-Ming	2	1
Rosato, D.V.	2	0
Menges, Georg	2	0
Scheuermann, H.	2	2
Adams, J.W.	1	0
Akkad, Manoj. H.	1	1
Anonymous	1	0
Arehart, K.L.	1	0
Atkinson, Andrews	1	0
Axtell, Robert	1	0
Bailey, Rob	1	0
Bardocz, Laszlo	1	0
Beckert, B.A.	1	0
Beckstrom, Harold	1	0
Bertacchi, G.	1	0
Brooks, Rhonda L.	1	0
Brown, Joseph A.	1	0
Busch, J.V.	1	0
Corser, T.	1	0
Cutright, K.W.	1	0
Dym, Joseph	1	0
Ebeling, K.A.	1	0
Echan, Clayton	1	0
Escudero, J.	1	1
Evans, Collin W.	1	1
Ferguson, Dennis E.	1	1
Fernandez, Ricardo	1	0
Fine, C.H.	1	0
Foster, Phillip E.	1	1
Foy, Francis	1	0
Galvin, M.F.	1	0
Gosden, J.	1	1
Hancock, F.J.T.	1	0
Haynsworth, H.C.	1	0
Heng, Charlie A.S.	1	1
Johnson, John E.	1	1
Kammlade, John G.	1	1
Khullar, Praveen	1	0
Kim, S.G.	1	0
Knight, W.	1	0
Kreisher, Keith R.	1	0

Figure A6-1 - Key Author Analysis

Author:	No. of All Articles:	No of On Target:
Krouse, J.	1	0
Kuppurajan, D.	1	0
Lam, Chung Yau	1	0
Larson, H.R.	1	1
Lee, Soo-Li	1	1
Linsday, Karen	1	0
Lodge, Charles	1	0
Lyons, R.T.	1	0
Meredith, J.R.	1	0
Miller, Frederick W.	1	0
Mills, Robert	1	0
Mutsuddy, B.C.	1	0
Nelson, Leonard	1	0
Ngan Man-To, Louis	1	0
Nordquist, Watson N.	1	0
Ostwald, Port	1	0
Pearce, Dennis	1	1
Poggiali, B.	1	0
Potter, C.	1	0
Radnoti, Istvan	1	0
Rogers, Jack K.	1	0
Rondeau, Herbert F.	1	0
Rosa, David	1	0
Rothenberg, Richard G.	1	0
Ruffo, J.	1	1
Santos, J.F.	1	0
Schekulin, Karl	1	0
Shanmugasundaram, Shyam	1	0
Shluter, H.	1	0
Singhal K.	1	0
Smoluk, George R.	1	0
Sors, Laszlo	1	0
Sower, Victor E.	1	0
Stanisalo, J.	1	0
Suarez, John	1	0
Suh, N.P.	1	0
Sunderland, J.E.	1	0
Suri, Rajan	1	0
Terry, W. R.	1	0
Thayer, Gordon	1	0
Trantina, Gerald G.	1	0
Villegas, J.R.	1	0
Walsh, K.B.A.	1	1
Ward, Susan	1	0
Whalen, C.E.	1	0
White, R.A.	1	0
Ysseldyke, David A.	1	0
Young, Samuel L.	1	0
Zenger, David C.	1	1

H. Key Journal Analysis

Figure A7-1 lists the results of a key journal analysis performed on the articles identified in the literature search. The journal appearing most frequently was Modern Plastics. Of the 18 on-target articles, three each appeared in both Dissertations Abstracts International and the Proceedings of the 47th Annual Technical Conference of the Society of Plastics Engineers.

	All Articles No.	**18 on Target No.**
Modern Plastics	12	0
University of Massachusetts\Amherst	5	2
Dissertation Abstracts International	5	3
47th Annual Technical Conference of SPE	4	3
Plastics World	3	0
Plastverarbeiter	3	1

Key Journal Analysis - Figure A7-1

Journal	No. of all Articles	No. of On Target
11th Conference on Production Research	1	0
Technology, SME	1	0
1984 Fall Industrial Engineering Conference- Institute of Industrial Engineers	1	0
45th Annual Technical Conference and Exhibit of SPE	1	0
46th Annual Technical Conference of SPE	1	0
47th Annual Technical Conference of SPE	4	3
48th Annual Technical Conference, SPE	1	0
49th Annual Technical Conference Proceedings, SPE	1	0
7th International Conference on Assembly	1	0
Automation Proceedings, IFS ltd.	1	0

Journal:	No. of All Articles:	No. of on Target:
American Machinist	1	0
American Machinist\Metalworking Manufacturing	1	0
ASME	1	0
ASME: Advances in Design Automation	1	0
ASME: Computers in Engineering Proceedings	1	0
ASME: Manufacturing International Symposium on Product and Process Design Proceedings	1	0
AUTOFACT '89, SME	1	1
Business Week	1	0
Computer Aided Engineering	1	0
Computer Aided Engineering for Injection Molding	1	0
Computers in Industrial Engineering	1	0
Computers in Industry	1	0
Computers in Mechanical Engineering	1	0
Die Designing and Estimation (book)	1	0
Dissertation Abstracts International	5	3
European Rubber Journal	1	1
German Plastics	1	1
How to Make Injection Molds [book]	1	0
Interfaces	1	0
International Journal of Production Research	1	0
International Symposium on Design and Synthesis	1	0
Interview	1	0
Journal of Cellular Plastics	1	0

Journal:	No. of: All Articles:	No. on Target:
Key Engineering Materials	1	0
Machine Design	1	1
Manufacturing and Engineering Management	1	0
Manufacturing Engineering Transactions	2	0
Manufacturing Systems	1	0
Masters Abstracts	1	1
Material Engineering	1	1
Mechanical Engineering	2	0
Modern Plastics	2	0
N. American Metalwork Research Conference Proceedings	1	0
Carnegie Press	1	0
National SAMPE Symposium and Exhibition Proceedings	1	0
Physics Technology	1	0
Plasticon '81 Proceedings	1	1
Plastics and Polymers	1	0
Plastics and Rubber International	1	1
Plastics Design Forum	1	0
Plastics Engineering	2	1
Plastics Molds	1	0
Plastics World	3	0
Plastverarbeiter	3	2
Production and Inventory Management Journal	2	0
Quality Progress	1	0

Journal:	No. of All Articles:	No. On Target:
RETEC '87	1	0
RWTH Aachen	1	0
University of Massachusetts\Amherst	5	1
University of Rhode Island	1	0
Winter Annual Meeting of the American Society of Mechanical Engineers	2	0

H. Search Tree

Search Tree Key:

Pages A8-1,2 contain the logical combinations of key words used in the literature search. Each page is divided into sections that illustrate the key word combinations. Each section begins with an alpha-numeric code (for internal use) and a number in braces. The number in braces represents the number of articles found using the key word combination in that section. Beneath these two codes are a series of boxes shaded in grey. All words contained in a single grey box were joined in an "Or" conjunction to form a logical expression. The grey boxes were combined with other grey boxes by "And" conjunctions to form the final key word expression used in the search, with one exception. Word combination S57 on page A8-2 was slightly more complex. This expression featured two groupings of "And" conjunctions illustrated by boxes drawn around the two groupings. The boxes were joined by a "Not" conjunction, meaning that the search found references featuring key words fitting the logical expression in the first grouping that did not also fit the expression in the second grouping.

Each key word in the Search Tree is followed by a number indicating the number of references in the database which contain that key word. Many of the key words end with a question mark symbol (?), meaning that the search should include words with alternate endings. For example, the key word "mold?" represents mold, molds, molded, and molding.

The titles resulting from each search were analyzed to determine which articles were germane to EMIMs. The resultant articles form the core of the 110 article reference list.

Appendix Figure #1:

S25 [4]

Plastic? 114,979
or
Injection Mold? 7,894
or
Plastic? Product? 3,840
or
Plastic? Part? 1,622

& Cost? 147,517 & Estimat? 130,849 & Design? 460,175
&
Model 461,443

S35 [2]

Plastic? 114,979 & Injection Mold 7,894 & Cost(W)Model? 780

S37 [1]

Plastic? 114,979 & Injection Mold 7,894 & Economic? Model?

S45 [60]

Plastic? 114,979 & Injection Mold? 7,894 & Cost?

S47 [20]

Plastic? Product? 3,840
or
Plastic? Part? 1,162

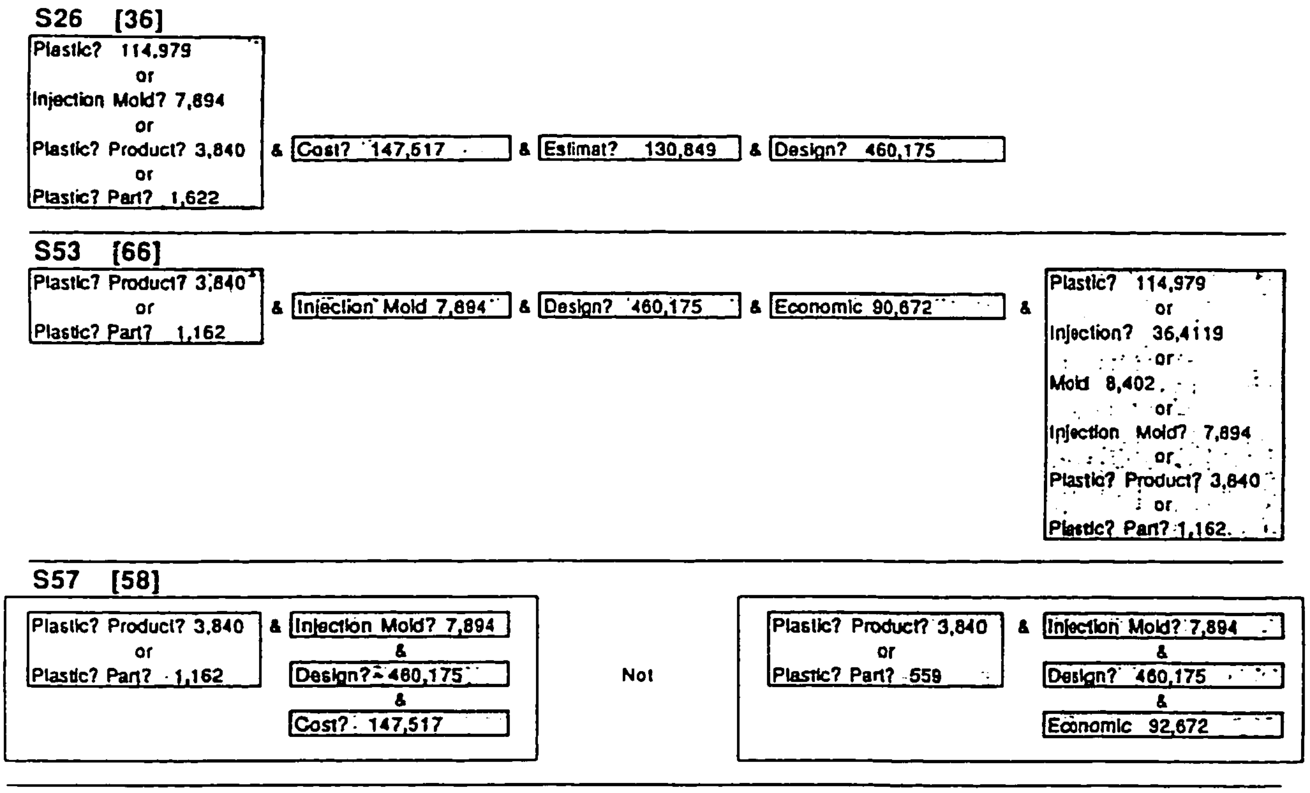
& Cost? 147,517 & Estimat? 130,849

S49 [4]

Plastic? Product? 3,840
or
Plastic? Part? 1,162

& Model? 461,443 & Injection Mold 7,894 & Cost? 147,517

Appendix Figure #2:



1993 Literature Search Summary

A Search Objective

The objective of this literature search was to update the existing literature search given in the E.M.I.M. report, September 30,1992. The search determined the published body of knowledge in the field of cost estimation for plastic injection molding parts. This included mold tool costs, materials cost, and part production costs.

B. Search Description

This search used different search trees than the ones used previously in the E.M.I.M. report of September 30, 1992. The search consisted of both on-line and off-line systems. The databases used included:

Databases from On-Line Systems

1. Academic Index
2. Dissertation Abstracts Online
3. Economic Literature Index
4. EI Compendex Plus
5. Industry Trends & Analysis
6. McGraw-Hill Publications On-Line
7. Ontap ABI/Inform

Databases from Off-Line Systems

1. ABI/Inform

C. System Descriptions

On-Line Systems - Dialog One search

The "Dialog Online Information Retrieval Service", from Dialog Information Services, Inc., contains over 380 databases in a broad scope of disciplines. The system uses a feature known as "one-search" that enables search of upto 20 files concurrently with one search strategy.

LOCATION:
Samuel C. Williams Library
Stevens Institute of Technology
Hoboken, New Jersey 07030

Off-Line Systems - Business Periodical Ondisc (BPO)

The "Business Periodical Ondisc" by UMI/Data Courier, combines the ABI/Inform database of article references and abstracts. This system allows the user to search for information in the database, display article references with abstracts, as well as display or print many of the actual articles.

LOCATION:
Samuel C. Williams Library
Stevens Institute of Technology
Hoboken, New Jersey 07030

D. Databases Descriptions

On-Line

1. ACADEMIC INDEX - File 88

Coverage:	1976 to the present
File Size:	931,496 records
Updates:	Monthly
Provider:	Information Access Company, Foster City, CA

Academic Index provides indexing of more than 400 scholarly and general interest publications. Coverage represents the most commonly held titles in over 120 college and university libraries. It also includes indexing and abstracts for articles, news reports, editorials on major issues, product evaluations, biographies, short stores, poetry, and reviews.

2. DISSERTATION ABSTRACTS ONLINE - File 35

Coverage: 1861 to present
File Size: 1,147,036 records
Updates: Monthly
Provider: University Microfilms International, Ann Arbor, MI

Dissertation Abstracts Online is a definitive subject, title, and author guide to virtually every American dissertation accepted at an accredited institution since 1861, when academic doctoral degrees were first granted in the United States. In addition, citations for thousands of Canadian dissertations, and an increasing number of papers accepted abroad, are included in the database. All subject areas are covered.

3. ECONOMIC LITERATURE INDEX - File 139

Coverage: 1969 to the present
File Size: 282,216 records
Updates: Quarterly
Provider: The American Economic Association, Pittsburgh, PA

Economic Literature Index is an index of journal articles and book reviews from 260 economic journals and from approximately 200 monographs per year. The descriptive abstracts are approximately 100 words in length and are written by the author or editor of the journal article; all in English. The database corresponds to the index section of the quarterly *Journal of Economic Literature* and to the annual *Index of Economic Articles.*

4. EI COMPENDEX PLUS - File 8

Coverage: 1970 to the present
File Size: 2,822,199 records
Updates: Monthly
Provider: Engineering Information Inc., New York, NY

The Compendex Plus database provides abstracted information from the world's significant literature of engineering and technology. Subjects covered include: civil, energy, environmental, geological and biological engineering; electrical, electronics, control engineering; chemical, mining, metals, fuel engineering; mechanical, automotive, nuclear, aerospace engineering; computers, robotics, and industrial robots. In addition, this database includes records of significant published proceedings of engineering and technical conferences.

5. INDUSTRY TRENDS & ANALYSIS - File 192

Coverage:	January 1977 to present
File Size:	2,300 records
Updates:	Bimonthly
Provider:	Arthur D. Little Decision Resources, Burlington, MA

The Industry Trends & Analysis database includes industry forecasts, technology assessments, product and market overviews, public opinion surveys, and management commentaries. Industries and technologies covered in the file are: the chemical industry, including specialty chemicals; the health care industry, pharmaceuticals, medical equipment and devices, diagnostic products, health care delivery services; bio-technology; advanced materials; food processing; environmental issues; the information processing and telecommunications industries, including office automation, computers, equipment manufactures, and services.

6. MCGRAW-HILL PUBLICATION ONLINE - File 624

Coverage:	1985 to the present
File Size:	33,173
Updates:	Weekly
Provider:	McGraw-Hill, Inc., New York, NY

McGraw-Hill Publications Online provides the complete text for many major McGraw-Hill publications. This database covers general business as well as specific industries, including aerospace, chemical processing, electronics, and construction.

7. ONTAP ABI/INFORM - File 215

Coverage:	Selected record from 1987, 1988, 1989, and 1990
File Size:	23,284 records
Updates:	Closed file
Provider:	UMI/Data Courier and Dialog Information Services, Inc.

Ontap ABI/Inform provides a database containing references and abstracts of information an all phases of management and administration. It includes selected records from 1987, 1988, 1989 , and 1990 of ABI/Inform (File 15).

Off-Line

1. ABI/INFORM

Coverage: December 1986 - November 1992
File Size: 515,242 records
Provider: UMI/Data Courier, Louisville, KY

The ABI/Inform database contains references and abstracts from more than 800 business and management periodicals with the capacity to view or print the complete article from many of the periodicals. ABI/Inform is a source of information on companies, products, business conditions, trends, corporate strategies and management techniques.

E. Literature Search Trees

On-Line Search

AUTHOR:

Search	Description	Count
S1	Poli, C. or Poli, Corrado	31
S2	Kuo, Sheng-Ming	1
S3	Boothroyd, Geoffrey	13
S4	Dewhurst, P. or Dewhurst, P.K. or Dewhurst, Peter	30
S5	Zenger, D. or Zenger, David Carl	2
S6	Menges, George	59

ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS:

Search	Description	Count
S1	Artificial Intelligence	19270
S2	Expert Systems	13143
S3	S1 or S2	23473
S4	Plastics or Thermoplastics or Injection Molding	84157
S5	Mold? or Mould? or Diemold? or Tool?	146806
S6	S3 and S4	77
S7	S3 and S5	3375
S8	S15 and Plastics	40

ENGINEERING ECONOMICS:

Search	Description	Count
S1	Engineering()Economy	119
S2	Engineering()Economics	369
S3	S1 or S2	480
S4	Time()Value()Money	1
S5	Time Value	2
S6	Capital Investment? or Capital Outlay?	791
S7	Resource Allocation or Financial Analysis or Project Finance	967
S8	S3 or S5 or S6 or S7	2232
S9	Plastics or Themoplasics or Injection Molding	84157
S10	Mold? or Mould? or Diemold? or Tool?	146806
S11	S8 and (S9 and S10)	109

TOTAL NUMBER OF ARTICLES ON-LINE =	362

Off-Line Search

AUTHOR:

Search	Description	Count
S1	Poli	5
S2	Boothroyd or Dewhrst	13
S3	Kuo and Sheng-Ming or S.H. or Sheng Ming	2
S4	Menges	0
S5	Zenger	18

ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS:

Search	Description	Count
S1	Artificial Intelligence	985
S2	Expert Systems	1404
S3	S1 or S2	1941
S4	Plastic? or thermoplastics or injection molding	2042
S5	mold? or mould? or diemolding or tool?	12106
S6	S3 and S4	8
S7	S3 and S5	477
S8	S7 and plastics	4
S9	S6 or S8	8

ENGINEERING ECONOMICS:

Search	Description	Count
S1	Engineering Economy	71
S2	Time Value of Money	0
S3	Capital Investment or Capital Outlay? or Resource Allocation or Financial Analysis or Project Financing	3220
S4	Analyis or Determine? or Decision?	33032
S5	S1 or S2	71
S6	S3 and S4	620
S7	S5 or S6	685
S8	Plastic? or thermoplastics or injection molding	2042
S9	mold? or mould? or die or diemolding or tool?	12106
S10	S7 and S8	1
S11	S7 and S9	57
S12	S10 and S11	58

TOTAL NUMBER OF ARTICLES OFF-LINE =	104

F. Summary Of Results

F.1. Key Author Analysis

The following table lists all the authors found in both the off-line and on-line literature searchesby the most frequent citations and by alphabetical order. The authors with the most signifigant target articles for the search were Boothroyd, G and Dewhurst, P. They co-authored 21 articles.

Key author with most frequent citations

Boothroyd, G.	21
Dewhurst, P.	21
Poli, C.	3
Dixon, J.	2
Kim, S.	2
Paulson, C.	2
Simmons, M.	2
Suh, N.	2
Vasilash, G.	2
Welter, T.	2

Key Authors by Alpha Last Name:

Abe, A.	1
Arinze, O.	1
Auffenberg, G.	1
Bata, G.	1
Bernhardt, G.	1
Bertacchi, G.	1
Billatos, S.	1
Boothroyd, G.	21
Carter, W.	1
Caulkin, S.	1
Cavanaugh, P.	1
Chase, M.	1
Chiplin, B.	1
Dastidar, P.	1
Dewhurst, P.	21
Dixon, J.	2
Dvorak, P.	1
Fallone, P.	1
Fradette, L.	1
Gable, J.	1
Giaccotto, C.	1
Gwinett, E.	1
Ho, C.	1
Hu, L.	1
Ishiguro, M.	1
Kaplan, J.	1
Kim, S.	2
Knight, W.	1
Lennartz, C.	1
Mahajan, P.	1
Maedo, T.	1
Markus, G.	1
Matthissen, H	1
Menges, G.	1
Motherway, J.	1
Morishita, K.	1
Mustafa, M.	1
Nagai, A.	1

Naknno, G.	1
Noaker, P.	1
O'Brien, C.	1
O'Guin, M.	1
Parker, M.	1
Paulson, C.	2
Paulson, D.	1
Persson, I.	1
Poli, C.	3
Rogers, J.	1
Salloum, G.	1
Schiemann, P	1
Shim, J.	1
Simmons, M.	2
Smith, S.	1
Suh, N.	2
Sunderland, J	1
Tseng, A.	1
Vaghul, M.	1
Vasilash, G.	2
VerDuin, W.	1
Wacht, R.	1
Welter, T.	2
Zenger, D.	1
Zinsmeister, G.	1
Total references	113
Total authors	63

F.2 Key Journal Analysis

The following tables list all the sources of articles obtained through out both the off-line and on-line literature searches by the most frequent citations and by alphabetical order. The three most occuring sources were the *Annual Technical Conference Exhibit of Society of Plastics Engineers, Machine Design*, and the *Society of Mechanical Engineers Technical Papers.* Each one yeilded five articles.

Key journal with most frequent citations

Annual Technical Conference Exhibit of Society of Plastics Engineers	5
Machine Design	5
Society of Mechanical Engineers Technical Paper	5
Assembly Engineering	3
CIRP Annals	3
Mechanical Engineering	3
Computers and Industrial Engineering	2
Flexible Automation Proceedings	2
Industry Week	2
Production	2

Key journal by alpha name of journal

Advances in Design Automation	1
Annual Technical Conference Exhibit of Society of Plastics Engineers	5
Assembly Automation	1
Assembly Engineering	3
Automation	1
Business	1
CIRP Annals	3
Computers and Industrial Engineering	2
Design Engineering Technical Conference	1
Engineering Costs and Production Economics	1
Flexible Automation Proceedings	2
Industry Week	2
International Computers in Engineering Conference and Exhibition	1
International Journal of Materials Production Technology	1
International Journal of Production Economics	1
ISA Transactions	1
Journal of Accountancy	1
Journal of Operations Research Society	1
Kunstoffe-German Plastics	1
Machine Design	5
Management Today	1
Managerial Finance	1
Manufacturing Engineering Transactions	1
Manufacturing Systems	1
Mechanical Engineering	3
Modern Plastics	1
Printed Circuit Design	1
Processing of Polymers and Polymeric Composites	1
Production	2
Production and Inventory Management Review and APICS News	1
Records Management Quarterly	1
Robotics and Computer-Intergrated Manufacturing	1
Robotics World	1
Society of Automotive Engineering Proceedings	1
Society of Mechanical Engineers Technical Paper	5
Tooling and Production	1
Winter Annual Meeting of American Society of Mechanical Engineers	1
11th Conference on Production Research and Technology	1

F.3. Results Of Literature Search

A total of 466 articles were identified in the literature search. 104 articles were found off-line while 362 articles were found on-line. All the abstracts for the 466 articles were reviewed. Some articles were duplicates from last year's search and some articles were not relevant. 60 articles were judged to be relevant and new. These 60 articles are included in this section. Reference lists in chronological and alphabetical order by author's last name are provided in Section C. An annotated bibliography is provided in Section D.

A. Basic Statistics

This section explains the methodology used in this research. Statistics is the science of collecting, organizing and interpreting numerical data. The purpose of using statistics is to make inferences on the data collected. Its focus is on problem-solving. The practice of statistics also requires judgment. It is easy to list the mathematical assumptions that justify the use of a particular procedure, but not always easy to decide when that procedure can be used in practice.

B. Central Limit Theorem

When estimating the mean of a population, a probability is usually attached to the measure of the error of the estimate. In other words, when using the mean of a random sample to estimate the mean of a population, it should be asserted that the error in the estimation is sufficiently small. Central limit theorem is the fundamental theorem of statistics that enables stronger probability statements in such situations. It states that:

If n (the sample size) is large, the theoretical sampling distribution of the mean can be approximated closely with a normal distribution.

This theorem justifies the use of the normal curve. It applies to infinite populations, and also to populations where n, though large, constitute but a small portion of the population.

C. Correlation Matrix Analysis[1]

Investigating the relationships between two or more variables involves correlation and regression analysis. When the variables are large in number, it is convenient to represent their mutual relationships in the form of a correlation matrix.

The questions asked are as follows:

1. Does a statistical relation appear to exist between the random variables involved?
2. How strong is the apparent degree of the statistical relation, in the sense of the possible predictive ability the relation affords?
3. Can a simple rule be formulated for predicting one variable from the other variables, and if so, how good is this rule?

The first two questions can be answered with the help of analysis of correlation and the third question can be answered with the help of regression.

---

[1] Hays, "Statistics", 4th Edition, Holt, Reinhart and Winston, 1988.

The sample correlation coefficient is defined as:

$$\gamma_{xy} = \frac{\sum_{i=1}^{n} (x_i - m_x)(y_i - m_y)}{n s_x s_y}$$

Where the n pairs of values (X_i, Y_i) represent a sample of size n from the bivariate population and m_x, m_y, s_x and s_y represent the sample means and sample standard deviations of the two variables X and Y.

D. Variable Plots[2]

These help to interpret the correlation by means of scatter diagrams which are graphs showing, in two-dimensional space, the pairs of values (x_i, y_i). The diagrams are valuable in that they provide some idea about the form of the functional relationship between two variables x and y, if such a functional relationship in fact exists. Figures below show typical scatter diagrams for linear as well as nonlinear functional relationships.

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[2] Freedman, Pisaui, Purves, "Statistics", W. W. Norton & Co., 1980.

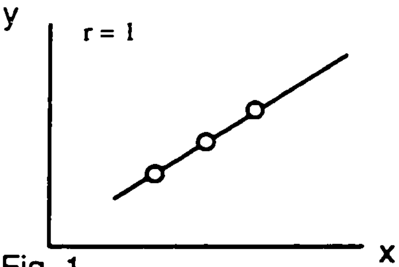

Fig. 1
A scatter diagram showing a perfect positive linear relationship

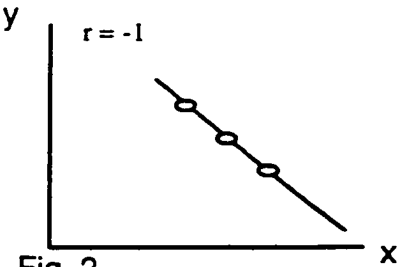

Fig. 2
A scatter diagram showing a perfect negative linear relationship

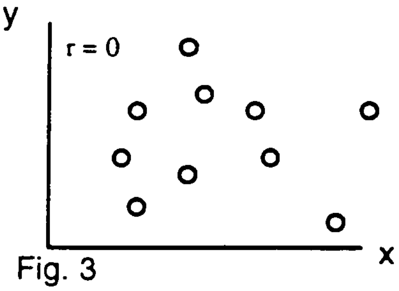

Fig. 3
A scatter diagram showing no linear relationship

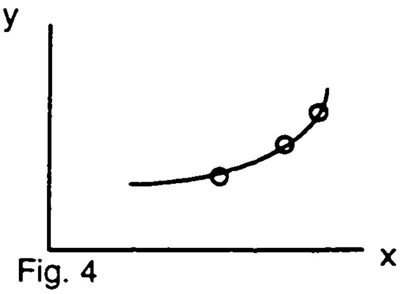

Fig. 4
A scatter diagram showing a nonlinear relationship

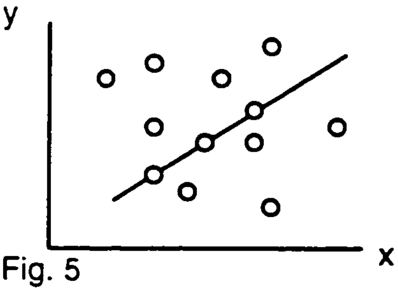

Fig. 5
A scatter diagram showing a weak positive linear relationship

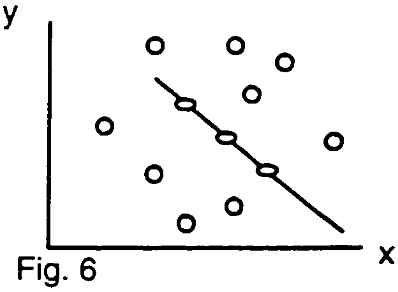

Fig. 6
A scatter diagram showing a weak negative linear relationship

E. Measures of Central Tendency and Dispersion

E.1 Mean

Mean of a random variable x indicates the central tendency of the probability distribution of the random variable. This is also the expected value of the random variable, usually represented as $E(X) = \mu$. The mean is often used as a parameter for the probability distribution. The property of the mean is the best summarized by the statement that the expectation of the deviation about the mean is zero in any distribution. Thus, $E(X - \mu) = 0$.

If n observations are denoted by $X_1, X_2, \ldots X_n$, their mean is

$$\overline{X} = \frac{1}{n}(X_1 + X_2 + \ldots + X_n) = \frac{1}{n}\sum_{i=1}^{n} X_i$$

E.2 Median

Median is the value of a random variable x that lies midway between its smallest possible value and its largest possible value. For a continuous distribution, the median is a point at which the total area under the curve of Probability Distribution Function (PDF) is divided equally into two segments, each of which has an area equal to 1/2. In other words, the probability that x is less than the median is 1/2 and the probability that x is greater than the median is also 1/2. Thus if $P(x \leq a) \geq .5$ and $P(x \geq a) \geq .5$, then a is called a median of the distribution of x.

E.3 Mode

Mode is the value of the random variable x at which the Probability Mass Function (PMF) or the or the Probability Distribution Function (PDF) of x reaches its highest point. The determination of the mode for a given random variable is performed using the standard methods of calculus for finding the maximum value of a function. Sometimes, the probability distribution of a random variable may exhibit more than one relative maximum points. In such a case, the number of maximum points is called the modality of that random variable.

E.4 Variance

A measure of central tendency, such as mean or median or mode summarizes only one aspect of a probability distribution and is not sufficient to characterize the distribution. Probability distributions exhibit spread or dispersion, which is the tendency for observations to depart from the mean value. A deviation from the mean, $(x - \mu)$, expresses how "off" the mean is from a particular value. For any distribution, the variance V(x) or σ^2 is given by the expectation of the squared deviation from the mean. Thus,

$$V(x) = \sigma^2 = E(x - \mu)^2$$

E.5 Standard Deviation

Although the variance is an adequate way of describing the degree of variability in distribution, it is a quantity in squared units of measurement. This inconvenience can be avoided by using the positive square root of the variance as the index of variability. The square root of the variance for a distribution is called the standard deviation and is an index of variability in the original measurement units. Thus:

$$\delta = \sqrt{E(X - \mu)^2}$$

F. t and F statistics

F.1. t-Distribution[3]

Traditionally, statistical inference has been divided into problems of estimation, in which various unknown parameters of populations are estimated,

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[3] Box, Hunter and Hunter, "Statistics for Experimenters", John Wiley & Sons, 1978.

and tests of hypotheses, in which specific assertions about populations or their parameters are either accepted or rejected. The tests usually refer to the estimation of means. An estimate is a value that is intended to match some characteristic (parameter) of a population. The difference between that which is intended to match and that which matches is the error involved. The probability of the maximum error provides the confidence limits for the estimate.

In the case where the sample size is large enough, the sampling distribution of the mean can be treated as if it were a normal distribution. However, in the case of small samples, the analysis can be based on the statistic

$$t = \frac{\bar{y} - \mu}{s/\sqrt{n}}$$

where $\bar{y}$ is the sample mean and s, the sample standard deviation. The sampling distribution of this statistic is the student t-distribution which has a shape similar to the normal distribution and is symmetrical about the zero mean.

F.2 t-Tests[4]

Let the quantity $\bar{y}$ be the average of the particular sample of observations that happens to be available. Without further assumption there is little more that can be said about it. If, however, the observations can be regarded as a random sample from some population with mean μ and variance σ^2, the following is known:

- $\bar{y}$ has for its mean value the population mean μ.
- $\bar{y}$ varies about μ with standard deviation $\delta/\sqrt{n}$

Thus as we imagine taking a larger sample, $\bar{y}$ tends to lie closer and closer to μ. Hence it is reasonable to regard y as an estimate of μ. Similarly, the sample variance s^2 has a mean value of σ^2 and varies about that value with a standard deviation proportional to $1/\sqrt{n}$. Hence under the statistical assumption of random sampling we can regard s^2 as an estimate of σ^2.

Assuming the random sample to be drawn from a normal distribution, the quantity $(\bar{y} - \mu)/(s - \sqrt{n})$ is distributed with n - 1 degrees of freedom in the t-distribution. Thus the t-distribution provides us a way for estimation of the mean and variance of a population, given that the mean and variance of a random sample are known.

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[4] Ibid.

The t-test is often used for testing statistical hypotheses. The hypothesis to be tested is denoted by the symbol H_0. Such a hypothesis is commonly referred to as the "null hypothesis", meaning that this is the hypothesis that is assumed to be used in the test. The other hypothesis which is assumed to be true when the null hypothesis is false, is referred to as the "alternative hypothesis" and denoted by the symbol H_1. Both the null and the alternative hypothesis are stated before any statistical test of significance is performed.

F.3. F-Distribution[5]

Suppose two random samples x_1 and x_2 are drawn from a normal population. Let N_1 be the number of observations in the first sample and N_2 the number of observations in the second. Also, let s_1^2 and s_2^2 be the variances of the two samples. Then the statistic F given by the formula $F = s_1^2/s_2^2$ has a sampling distribution called the F-distribution.

There are two sample variances involved and two sets of degrees of freedom, namely, $(N_1 - 1)$ in the numerator and $(N_2 - 1)$ in the denominator. Each pair of degrees of freedom determines an F distribution which is usually represented as $F(N_1 - 1, N_2 - 1)$.

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[5] Dixon and Massey, "Introduction to Statistical Analysis", 3rd Edition, McGraw-Hill, 1969.

F.4 F-test

The F distribution can be used to test the hypothesis that the variances $=_1^2$ and $=_2^2$ of the two normally distributed populations are equal. It is not necessary to assume that the two populations have equal means. To test this hypothesis our procedure is to take a random sample from each population and compute the ratio of the sample variances, $F = s_1^2/s_2^2$, rejecting the hypothesis if the observed value is unusually large or unusually small.

F.5. Goodness of Fit

The term goodness of fit refers to the comparison of observed sample distribution with some theoretical frequency distribution. For this comparison, x^2 distribution is used.

Suppose there are k categories and that a random sample of N observations is taken such that each observation must fall in one and only one category. The observed frequency in each category is then counted and denoted by $f_1, f_2, \ldots, f_k$ where $\Sigma f_i = N$. We are interested in situations in which there is some theoretical frequency $F_1, F_2, \ldots F_k$ for each category, where $'F_i = N$. The question is whether the observations agree or disagree with the values $F_1, F_2, \ldots,$ F_k; that is, the hypothesis that states the values of the theoretical frequencies needs to be tested.

The statistic is

$$\chi^2 = \sum_{i=1}^{k} \frac{(f_i - F_i)^2}{F_i}$$

with (k - 1) degrees of freedom

G. Regression Analysis[6]

While the correlation problem considers the joint variation of two measurements, the regression problem considers the frequency distributions of one variable when another is held fixed at each of several levels. Regression analysis[7] thus refers to the techniques for the derivation of an equation by which one of the variables, the dependent variable, may be estimated from the other variables which are the independent variables. Simple regression analysis deals with only one dependent and one independent variable, while in multiple regression analysis, there are two or more independent variables but still only one dependent variable.

The variation is plotted in the form of a scatter diagram and is called the regression curve. If the regression curve is a straight line for the range of x values under consideration, we say that there is a linear regression.

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[6] Dixon and Massey, Jr., "Introduction to Statistical Analysis", 3rd Ed., McGraw-HIll, 1969.
[7] Freund and Williams, "Elementary Business Statistics : The Modern Approach", Prentice-Hall, 1982.

G.1. Curve Fitting

In any research project, whenever possible, a relationship in terms of mathematical equations between the known quantities and the quantities that are to be predicted is searched for. The observed data is to be used to derive a mathematical equation that can be used to predict the value of one variable from a given value of another. The procedure used for this is curve fitting. It consists of three steps:

(i) Deciding what kind of "predicting" equation is to be used,

(ii) Finding the particular equation that appears to be the most appropriate,

(iii) Setting certain questions about the goodness of fit. The choice of the curve depends on both the theoretical considerations as well as direct inspection of the data.

G.2. Linear Regression

The simplest and most widely used equation is the linear equation in two unknowns, which is of the form $y = a + bx$. The numerical constants a and b are estimated from the sample data. Linear equations are useful and important not only because many relationships are actually of this form, but also because they provide close approximations to relationships which would otherwise be difficult to describe in mathematical terms.

The criterion used for defining a "best" fit is the method of least squares. It requires that the line that is supposed to fit to the observed data be such that the sum of the squares of the vertical deviations of the points from the line is a minimum. Let $(x_1,y_1), (x_2,y_2), \ldots, (x_n,y_n)$ be the n data points. The equation of the line is written as a + bx, where the symbol $\hat{y}$ is used to distinguish between the observed values of y and the corresponding values $\hat{y}$ on the line. Then the least squares criterion requires that we minimize the sum of the squares of the differences between the y's and $\hat{y}$'s. This is done by solving the so called "normal equations", which are of the form:

$$\sum y = na + b\left(\sum \mu\right)$$
$$\sum xy = a\left(\sum \mu\right) + b\left(\sum \mu^2\right)$$

The solutions of the normal equations are of the form:

$$a = \frac{\left(\sum y\right)\left(\sum x^2\right) - \left(\sum x\right)\left(\sum xy\right)}{m\left(\sum x\right) - \left(\sum x\right)^2}$$

$$b = \frac{m\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{m\left(\sum x^2\right) - \left(\sum x\right)^2}$$

G.3. Regression Analysis

The least-squares line is interpreted as the regression line and the predictions made from it are treated as averages, or expected values. However, several questions remain unanswered, such as:

(i) How good are the values we found for the constants a and b in the equation $\hat{y}$ = a + bx?

(ii) How can the limits and an associated degree of confidence which can measure the goodness of a prediction in the same way that a confidence interval measures the goodness of an estimate of the mean of a population be obtained?

To answer such questions the regression analysis is carried out. The values of a and b obtained are only estimates of the true values of these constants. Letting the true values be α and β, gives the true regression line $\mu = \alpha + \beta x$. Customarily, α and β are called the regression coefficients and a and b are called the estimated regression coefficients.

In linear regression analysis the x's are assumed to be constants, not values of random variables, and for each value of x the variable to be predicted is assumed to have a certain distribution whose mean is $\alpha + \beta x$. In normal regression analysis, it is further assumed, that these distributions are all normal distributions, having the same standard deviation σ.

Under these assumptions, inferences about the regression coefficients α and β may be based on the statistics:

$$t = \frac{a - \alpha}{s\sqrt{\frac{1}{n} + \frac{n\hat{x}^2}{n\left(\sum x^2\right) - \left(\sum \mu\right)^2}}}$$

and

$$t = \frac{b - \beta}{s}\sqrt{\frac{n\left(\sum x^2\right) - \left(\sum x\right)^2}{n}}$$

whose sampling distributions are t-distributions with n - 2 degrees of freedom. Here α and β are the regression coefficients to be estimated or tested, and a and b are their estimates calculated from a given set of data by the method of least squares. Values of n, $\bar{x}$, Σx, Σx^2 come from the original paired data, and s is an estimate of σ, the common standard deviation of the normal distributions, given by

$$s = \sqrt{\frac{\sum (y - \hat{y})^2}{n-2}}$$

Once again, y is an observed value of y and $\hat{y}$ is the corresponding value on the least-squares line. s is often called the standard error of estimate and can be calculated using the formula

$$s = \sqrt{\frac{\sum y^2 - a\left(\sum y\right) - b\left(\sum xy\right)}{n-2}}$$

The confidence intervals for the regression coefficients α and β, corresponding to the interval $-t_{\alpha/2} < t < t_{\alpha/2}$ are:

$$a \pm t_{\alpha/2} \cdot s\sqrt{\frac{1}{n} + \frac{n\hat{x}^2}{n\left(\sum x^2\right) - \left(\sum x\right)^2}}$$

and

$$b \pm \frac{t_{\alpha/2}}{\sqrt{\frac{n\left(\sum x^2\right) - \left(\sum x\right)^2}{n}}}$$

G.4. Multiple Regression[8]

It is sometimes desirable to describe the joint relationship of a single Y variable to several X variables. If the Y variable is well described by the other variables we often want to know the extent of this dependence and the actual regression equation.

For a single x we estimate a and b to obtain the equation $y = a + b(x - \overline{X})$. For multiple x variables, $x_1, x_2, \ldots x_k$, we need to compute a set of coefficients b_i in the expression:

$$y = b_0 + b_1x_1 + b_2x_2 + \ldots + b_kx_k$$

The coefficients are determined to provide the minimum sum of squares of differences between the observed y's and this linear combination of the x values.

Generally, if we let the observations on the first individual be represented by

$$y_1, x_{11}, x_{21}, x_{31}, \ldots, x_{k1}$$

and those on the second individual by

$$y_2, x_{12}, x_{22}, x_{32}, \ldots, x_{k2}$$

and so on to the nth or last individual,

$$y_n, x_{1n}, x_{2n}, x_{3n}, \ldots, x_{kn}$$

then the required solution for $b_0, b_1, \ldots, b_n$ is obtained by solving for these coefficients in the following set of equations:

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[8] Dixon & Massey, "Introduction to Statistical Analysis", 3rd Ed., McGraw-Hill, 1969.

$$nb_0 + b_1\Sigma x_{1i} + b_2\Sigma_{2i} + \ldots + b_k\Sigma_{ki} = \Sigma_i$$

$$b_0\Sigma^2{}_{1i} + b_1\Sigma_{2i} + b_2\Sigma_{1i}x_{2i} + \ldots + b_k\Sigma_{1i}x_{ki} = \Sigma_{1i}y_i$$

$$b_0\Sigma_{2i} + b_1\Sigma_{2i}x_{1i} + b_2\Sigma_{2i}{}^2 + \ldots + b_k\Sigma_{2i}x_{ki} = \Sigma_{2i}y_i$$

$$\ldots$$

$$b_0\Sigma_{ki} + b_1\Sigma_{ki}x_{1i} + b_2\Sigma_{ki}x_{2i} + \ldots + b_k\Sigma_{ki}{}^2 = \Sigma_{ki}y_i$$

The computations are best performed on a computer and standard software packages are available.

H. Principal Components[9]

A new class of techniques is of immense use in picking apart the dependence structure between variables when a priori patterns of causality are not available. These methods fall under the general heading of "factor analysis". By using these attempts are made to find and separate those hidden factors which have generated the dependence or variation in the responses. This means that the observable, or manifest, variates are represented as functions of a smaller number of latent factor variates. The mathematical form of these functions must be such as which will generate the covariances or correlations among the responses. If few in number, a more parsimonious description of the dependence structure can be obtained. This analysis of the dependence structure amounts to the statistical estimation of the coefficients of the functions.

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[9] Morrison,Donald, "Multivariate Statistical Methods", 3rd Edition, McGraw-Hilll, 1990.

Consider a set of random variables $x_1, \ldots, x_p$ having a certain multivariate distribution with mean vector μ and covariance matrix ε. The rank of ε is $r \leq p$, and the q largest characteristic roots

$$\lambda_1 > \ldots . > \lambda q$$

of ε are all distinct.

From this population a sample of N independent observation vectors is drawn. The observations can be written as the N x p matrix

$$X = \begin{bmatrix} x_{11} \cdots\cdots x_{1p} \\ \hline x_{N1} \cdots\cdots x_{Np} \end{bmatrix}$$

The estimate of ε will be the sample covariance matrix S. The information we shall need for our principal component analysis will be contained in S.

The first principal component of the observations X is that linear compound

$$Y_1 = a_{11}x_1 + \ldots + a_{p1}x_p$$

of the responses whose sample variance

$$s^2_{Y_1} = \sum_{i=1}^{p} \sum_{j=i}^{p} a_{i1} a_{j1} s_{ij} = \overline{a}_1' S a_1$$

is greatest for all coefficient vectors normalized so that

$$a_1' a_1 = 1$$

But what is the utility of this artificial variate constructed from the original responses? In the extreme case of X of rank one the first principal component would explain all the variation in the multivariate system. In the more usual case of the data matrix of full rank the importance and usefulness of the component would be measured by the proportion of the total variance attributable to it.

The second principal component is that linear compound

$$Y_2 = a_{12}x_1 + \ldots + a_{p2}x_p$$

whose coefficients have been chosen, subject to the constraints

$$\bar{a}_2'\bar{a}_2 = 1, \bar{a}_1'\bar{a}_2 = 0,$$

so that the variance of Y_2 is a maximum. The first constraint is merely a scaling to assure the uniqueness of the coefficients, while the second requires that $\bar{a}_1$ and $\bar{a}_2$ be orthogonal. The immediate consequence of orthogonality is that the variances of the successive components sum to the total variance of the responses.

The same procedure is repeated for finding the other principal components. This analysis is essentially equivalent to a factorization of S into the product of a matrix L and its transpose. The factorization is unique up to the coefficient signs, since the component coefficients have been chosen to partition the total variance orthogonally into successively smaller portions are distinct, only one set of coefficient vectors will accomplish this purpose.

The principal-component-technique is essentially that of summarizing most of the variation in a multivariate system in fewer variables. Unless the system is of less than full rank, some variance will always be unexplained if fewer than p components are taken to describe the system. In practice one usually knows what minimum number of components with large and distinct variances should be extracted. Beyond that number components might be computed with some arbitrarily large proportion of the variances has been explained.

Frequently, it is better to summarize the complex in terms of the first components with large and markedly distinct variances and include as highly specific and unique variates those responses which are generally independent in the system. Beyond these, tests of hypotheses and confidence intervals can be used to determine whether the remaining component variances are identical.

H.1. Eigenvalues and Eigenvectors

A matrix and a vector may be adapted to each other in such a way that the matrix-vector multiplication has the same effect as multiplying the vector by some scalar, so that

$$\overline{A}\,\overline{x} = \alpha\overline{x}$$

This equation actually represents a homogeneous system and has one solution $\overline{x} = 0$. This however, does not convey any information on the matrix $\overline{A}$. In order to obtain information on the matrix $\overline{A}$ other solutions are needed. Non vanishing solutions exist only for selected values of α. These values can be determined from the characteristic equation of the matrix $\overline{A}$ which is,

$$\det(\overline{A} - \alpha\overline{I}) = 0$$

The solutions of this equation are called the "eigenvalues" of matrix $\overline{A}$.

If an eigenvalue $\alpha_1 \ldots \alpha_n$ is substituted in the above equation, non vanishing solutions are obtained. These solutions are vectors, denoted by $\overline{x}_1 \ldots \overline{x}_n$ and are called eigenvectors of the matrix $\overline{A}$.

In practice, for convenience, matrices are often transformed into the diagonal form. By diagonalization, the specification of the matrix is rendered more concise. The number of non vanishing elements in a diagonal matrix is n, as distinct from the usual n^2. Moreover, the eigenvalues of a matrix are common to a whole set of matrices which are mutually related by colinearity transformations.

I. Time Series[10]

It is generally assumed that the sample upon which the estimates and tests are based is a random sample from the population of interest. In problems of prediction, however, "time-series data", i.e., the observation of the values of

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[10] Winkler and Mays, "Statistics", 2nd Edition, Holt, Reinhart and Winston, 1975.

certain random variables at successive points in time is needed. To obtain a series of observations on variables such as these, the observations must be made at different times. Whatever the interval between observations, the resulting set of data forms a time-series.

If dealing with time-series data, the sample may not be a random sample. In particular, the error terms may not be statistically independent; instead, they may be correlated with each other. This is a problem of autocorrelation. Statistical procedures are available for testing for the presence of autocorrelation.

An important point with regard to time-series data is the problem of extrapolation over time. If the dependent variable is observed over time, this dependent variable may be wanted to be predict for some future time period. But the regression equation is based on data from past periods, so essentially the prediction is beyond the range of the past data, using the justification that the trend observed in the past will continue in the future.

There are various ways of forecasting the future values of variables. The intrinsic method predicts the future values of variables from their past values. Time-series analysis is the important statistical technique used to implement the intrinsic method. The statistical data are observed and recorded at regular intervals of time. Often the observations show a seemingly haphazard movement of data through time. Nevertheless, if some simplifying assumptions are made it becomes possible to identify, explain and measure the fluctuations that appear in time-series.

Specifically, there are four basic types of variation which, when superimposed, account for the observed changes over a period of time and give the series its erratic appearance. These are:

- secular trend
- seasonal variation
- cyclical variation
- irregular variation

Often, there is a multiplicative relationship present between these four components.

I.1. Moving Averages[11]

A secular trend is often considered to be an indication of the general sweep of the development of a time-series. However, the following possibilities may exist regarding the trend:

- it may be uncertain whether the trend is linear or whether it might be better described by some other kind of curve,
- It may be unsure whether it is a trend or part of a cycle

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[11] Freund and Williams, " Elementary Business Statistics: The Modern Approach", 4th Ediiton, Prentice-Hall, 1982.

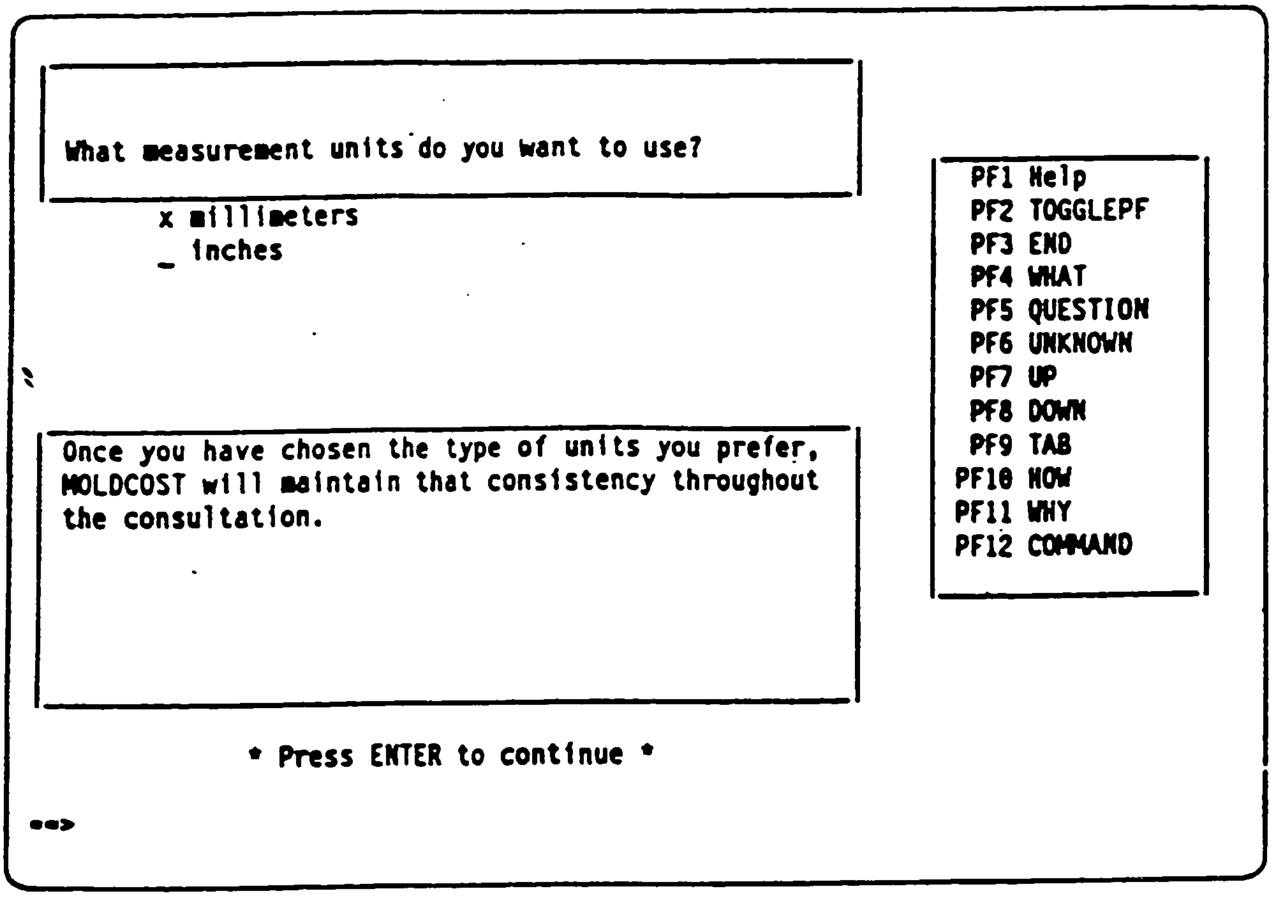
- Obtaining a mathematical equation may not be of interest.

In any of these cases, the overall behavior of a time-series may be described quite well by means of an artificial series called a moving average. A moving average is constructed by replacing each value in a series by the mean of itself and some of the values directly preceding and directly following it.

I.2. Exponential Smoothing

Another technique similar to moving average is exponential smoothing, which is used to smooth certain unwanted fluctuations out of a time-series, thus describing their underlying nature. The smoothed value at time t is a weighted average of the observed value at time t, and all the other past (historical) values in the series. The weight assigned to each observed value in the series decreases exponentially.

Measurement Units

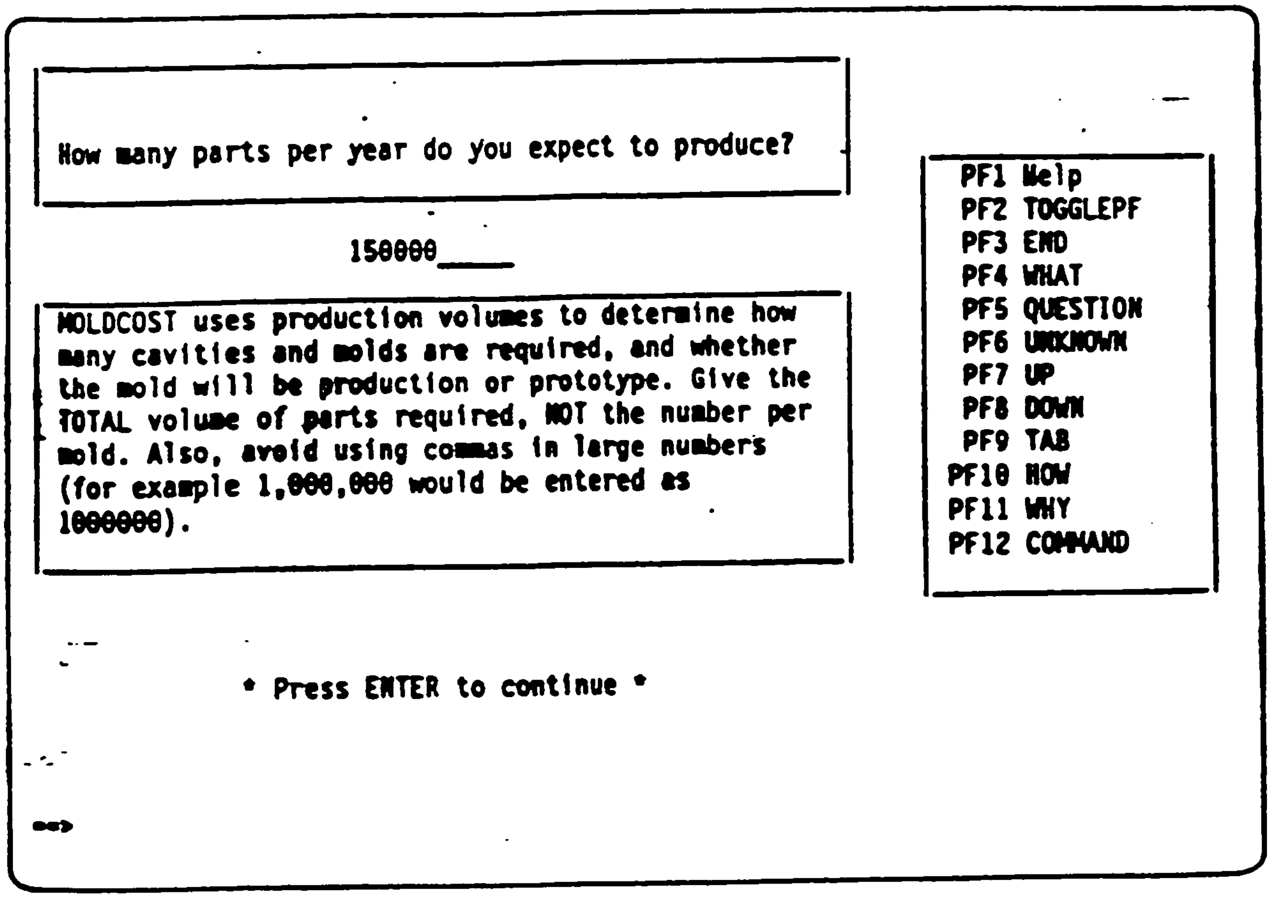


```
What measurement units do you want to use?
      x millimeters
      _ inches

Once you have chosen the type of units you prefer,
MOLDCOST will maintain that consistency throughout
the consultation.

              * Press ENTER to continue *

==>
```

MOLDCOST will be asking for some dimensions and tolerances. It can handle answers in either inches or millimeters, but the units must be specified up front. You can't switch from one to the other in the middle of a consultation.

Figure 1.

Production Volume

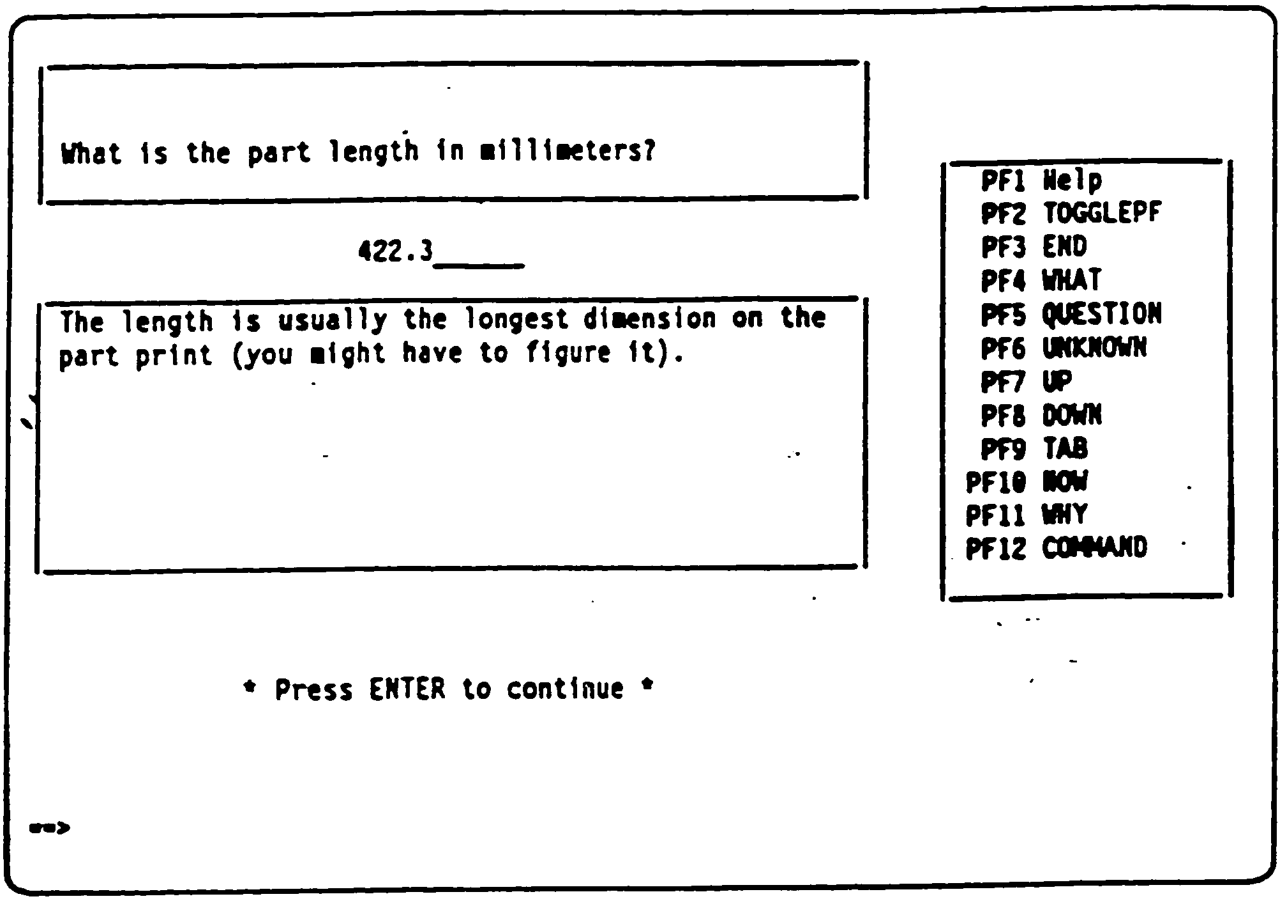


```
How many parts per year do you expect to produce?

              150000_____

MOLDCOST uses production volumes to determine how      PF1 Help
many cavities and molds are required, and whether      PF2 TOGGLEPF
the mold will be production or prototype. Give the     PF3 END
TOTAL volume of parts required, NOT the number per     PF4 WHAT
mold. Also, avoid using commas in large numbers        PF5 QUESTION
(for example 1,000,000 would be entered as             PF6 UNKNOWN
1000000).                                              PF7 UP
                                                       PF8 DOWN
                                                       PF9 TAB
                                                       PF10 HOW
                                                       PF11 WHY
                                                       PF12 COMMAND

         * Press ENTER to continue *

==>
```

The yearly production volume is used to help optimize the number of cavities and molds. It is also the deciding factor in whether the mold will be a prototype (aluminum) or a production tool (steel). The dividing line for the decision is 1000 pieces per year. As mentioned earlier, you will be able to change the mold material type later. (See *Changing Assumptions.*)

Figure 2

Part Length

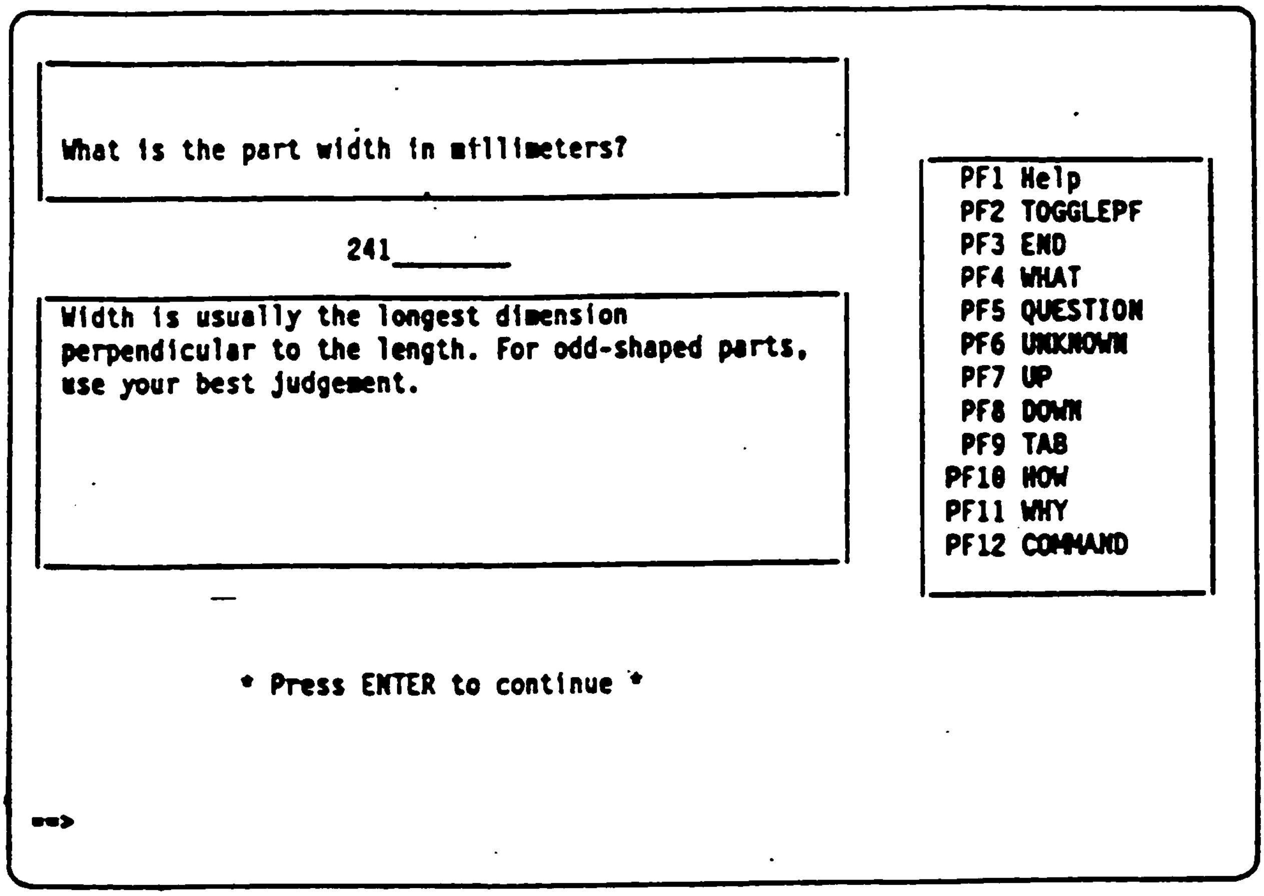


```
What is the part length in millimeters?

              422.3_____

The length is usually the longest dimension on the
part print (you might have to figure it).

                                                      PF1 Help
                                                      PF2 TOGGLEPF
                                                      PF3 END
                                                      PF4 WHAT
                                                      PF5 QUESTION
                                                      PF6 UNKNOWN
                                                      PF7 UP
                                                      PF8 DOWN
                                                      PF9 TAB
                                                     PF10 HOW
                                                     PF11 WHY
                                                     PF12 COMMAND

          * Press ENTER to continue *

==>
```

Part length is usually the longest dimension on the part. This dimension might not be stated explicitly on the drawing; it may be the sum of several listed dimensions. Part length directly influences the base equation.

Figure 3

Part Width



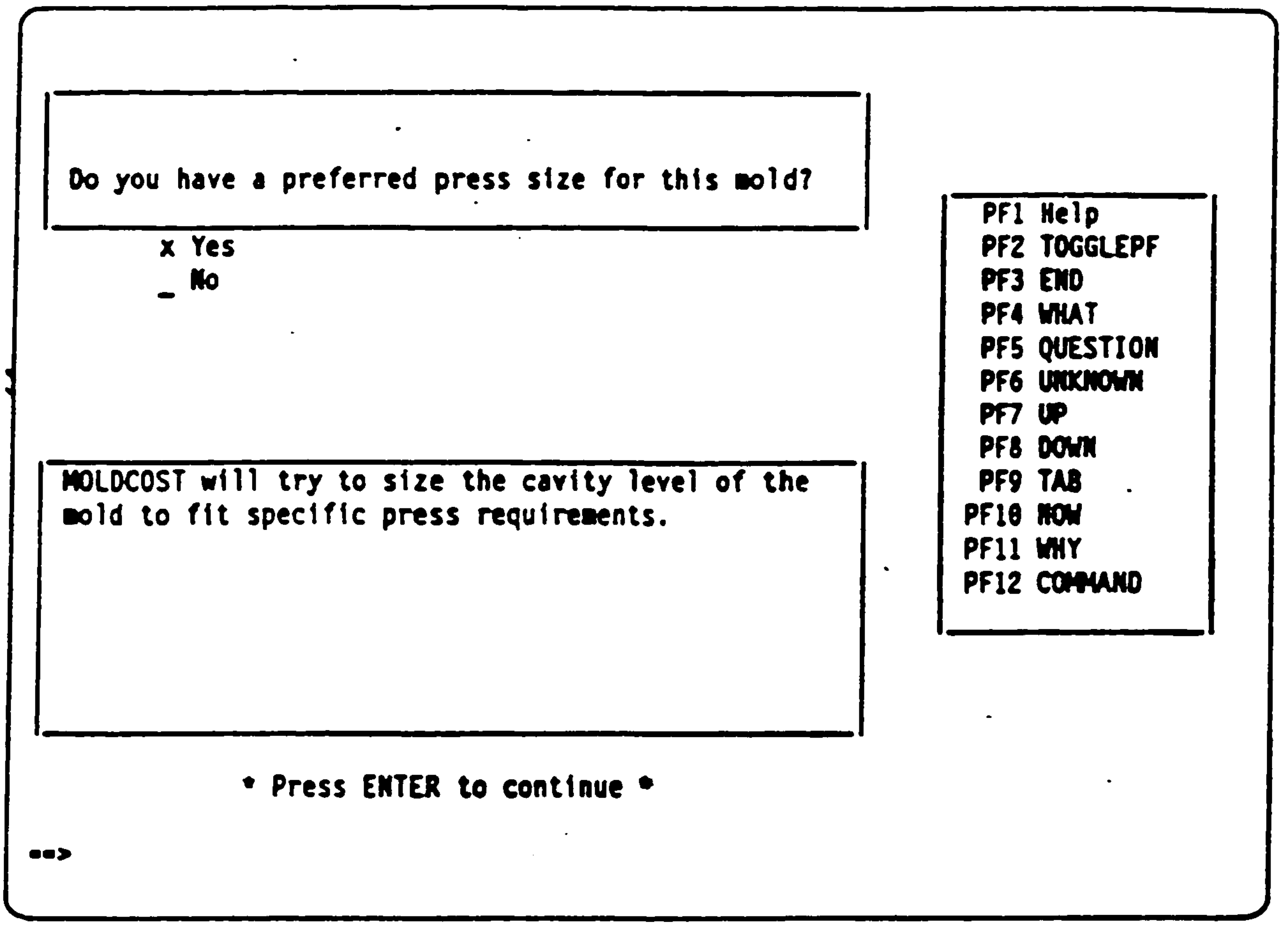
```
What is the part width in millimeters?

                  241______

Width is usually the longest dimension
perpendicular to the length. For odd-shaped parts,
use your best judgement.

                 * Press ENTER to continue *

==>
```

```
 PF1 Help
 PF2 TOGGLEPF
 PF3 END
 PF4 WHAT
 PF5 QUESTION
 PF6 UNKNOWN
 PF7 UP
 PF8 DOWN
 PF9 TAB
PF10 HOW
PF11 WHY
PF12 COMMAND
```

Part width is usually the longest direction perpendicular to the length. In the case of circular or spherical shapes, part width is equivalent to part length. Although width does not directly affect the base cost, it is used to help determine part size, tonnage, and cavity level. It may be hard to define these dimensions for oddly shaped parts. When all else fails, use your best judgment.

Figure 4

Press Size Preference

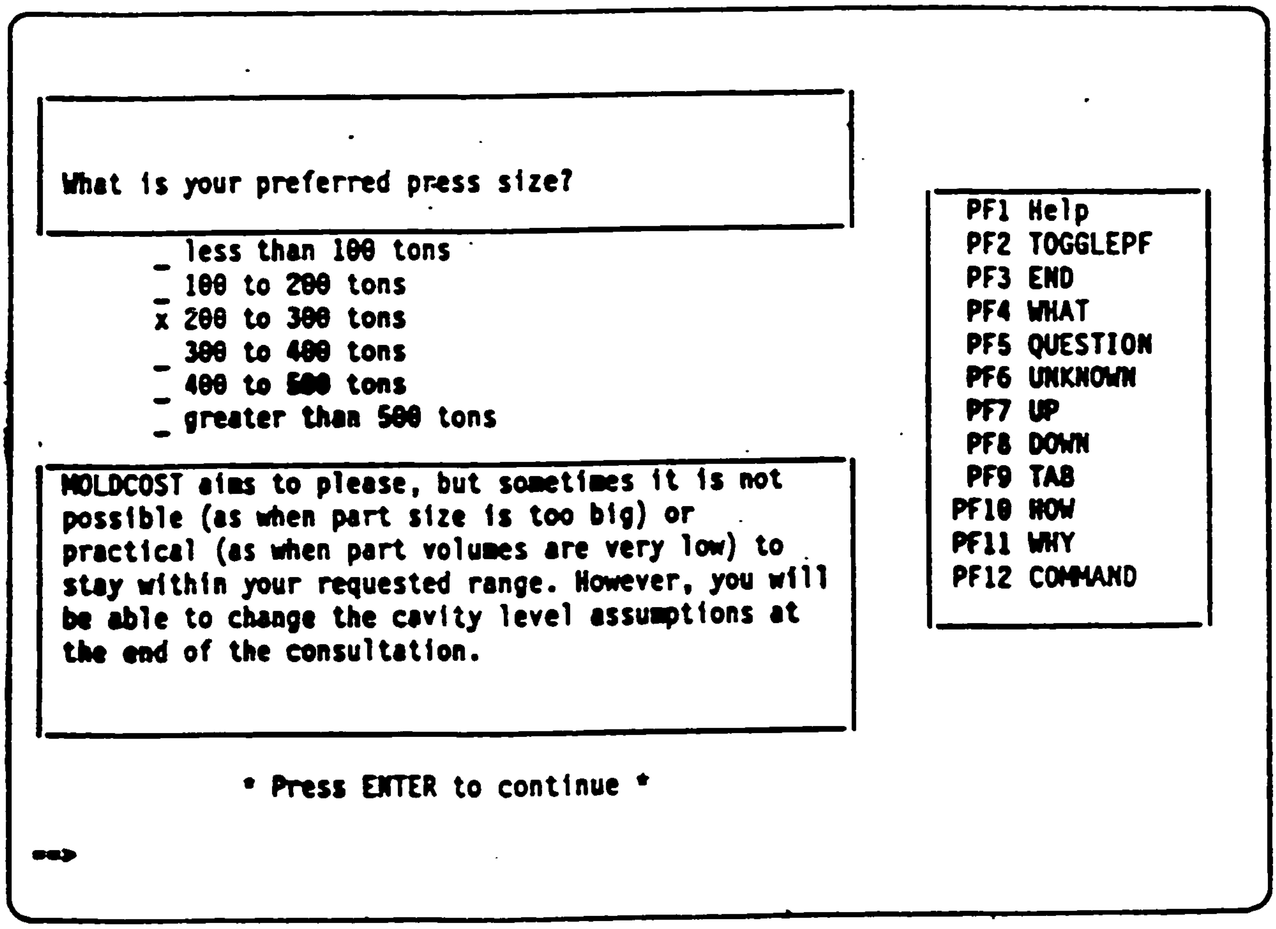


```
Do you have a preferred press size for this mold?

      x Yes
      _ No

MOLDCOST will try to size the cavity level of the
mold to fit specific press requirements.

                * Press ENTER to continue *

==>
```

You may have a preferred press size for your mold, either because the molding will be done at your own site or you have a particular vendor in mind. If "yes" is selected, you will later be prompted to specify that size (in terms of clamp tonnage). MOLDCOST will then try to size the cavity level of the mold to accommodate your request. The system will override your request if the part size is too big. If "no" is selected, MOLDCOST will use its best judgment based on part size and production volumes.

Figure 5

Preferred Press Size

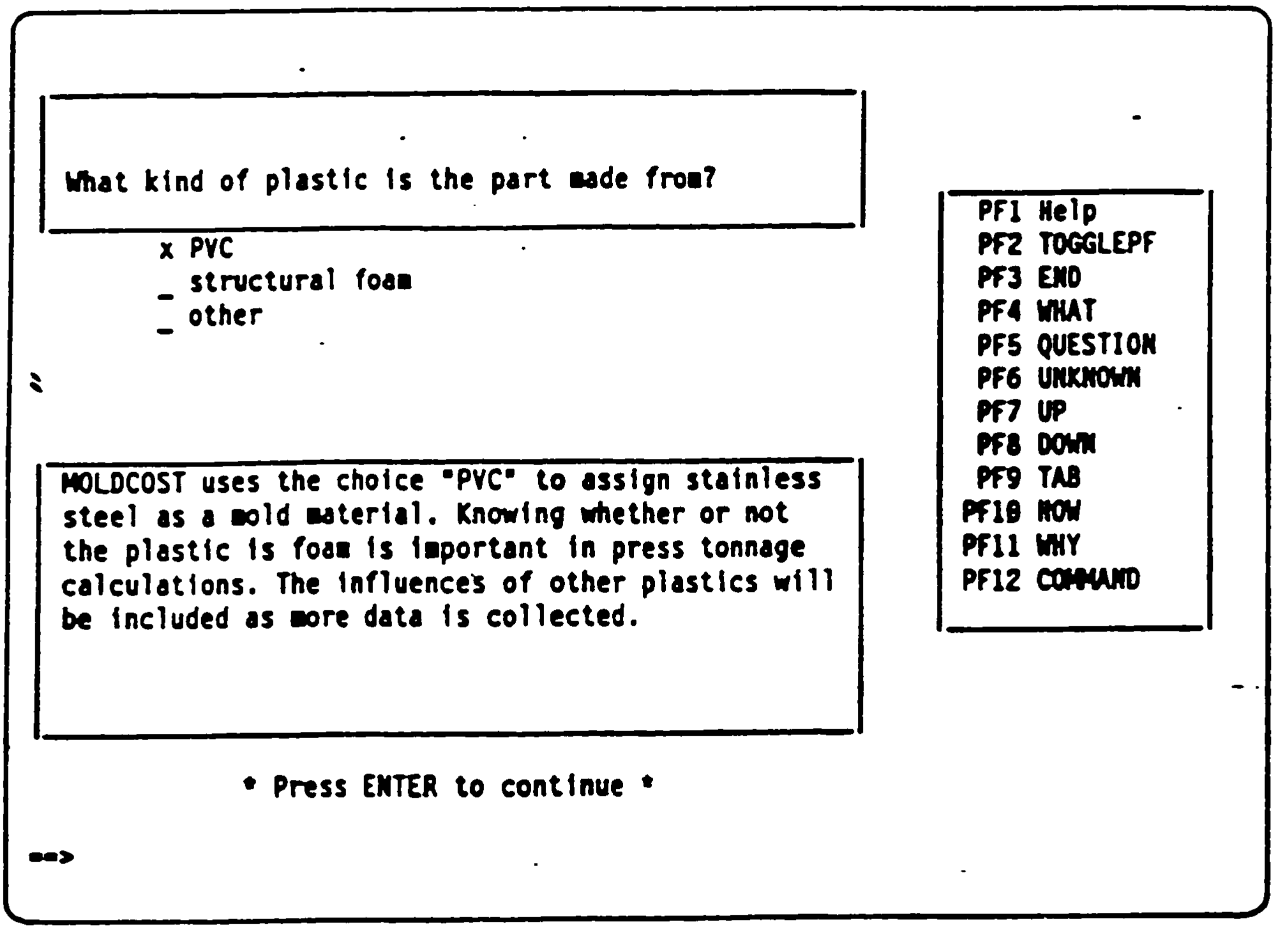


```
What is your preferred press size?

      _ less than 100 tons                         PF1  Help
      _ 100 to 200 tons                            PF2  TOGGLEPF
      x 200 to 300 tons                            PF3  END
      _ 300 to 400 tons                            PF4  WHAT
      _ 400 to 500 tons                            PF5  QUESTION
      _ greater than 500 tons                      PF6  UNKNOWN
                                                   PF7  UP
MOLDCOST aims to please, but sometimes it is not   PF8  DOWN
possible (as when part size is too big) or         PF9  TAB
practical (as when part volumes are very low) to   PF10 HOW
stay within your requested range. However, you will PF11 WHY
be able to change the cavity level assumptions at  PF12 COMMAND
the end of the consultation.

            * Press ENTER to continue *

==>
```

If the part can be molded under your selected tonnage, that tonnage will be treated as a maximum tonnage allowable per mold. This means that MOLDCOST will allow any number of cavities needed for your specified production volumes up to the number constrained by the press tonnage. (You could actually get a lower tonnage than you asked for - MOLDCOST assumes that no one wants to build a 64 cavity mold to run 1000 parts per year, even though it may be physically possible.) If you disagree with the assumed cavity level, you will be able to override it at the end of the consultation (see **Changing Assumptions**).

Figure 6

Plastic



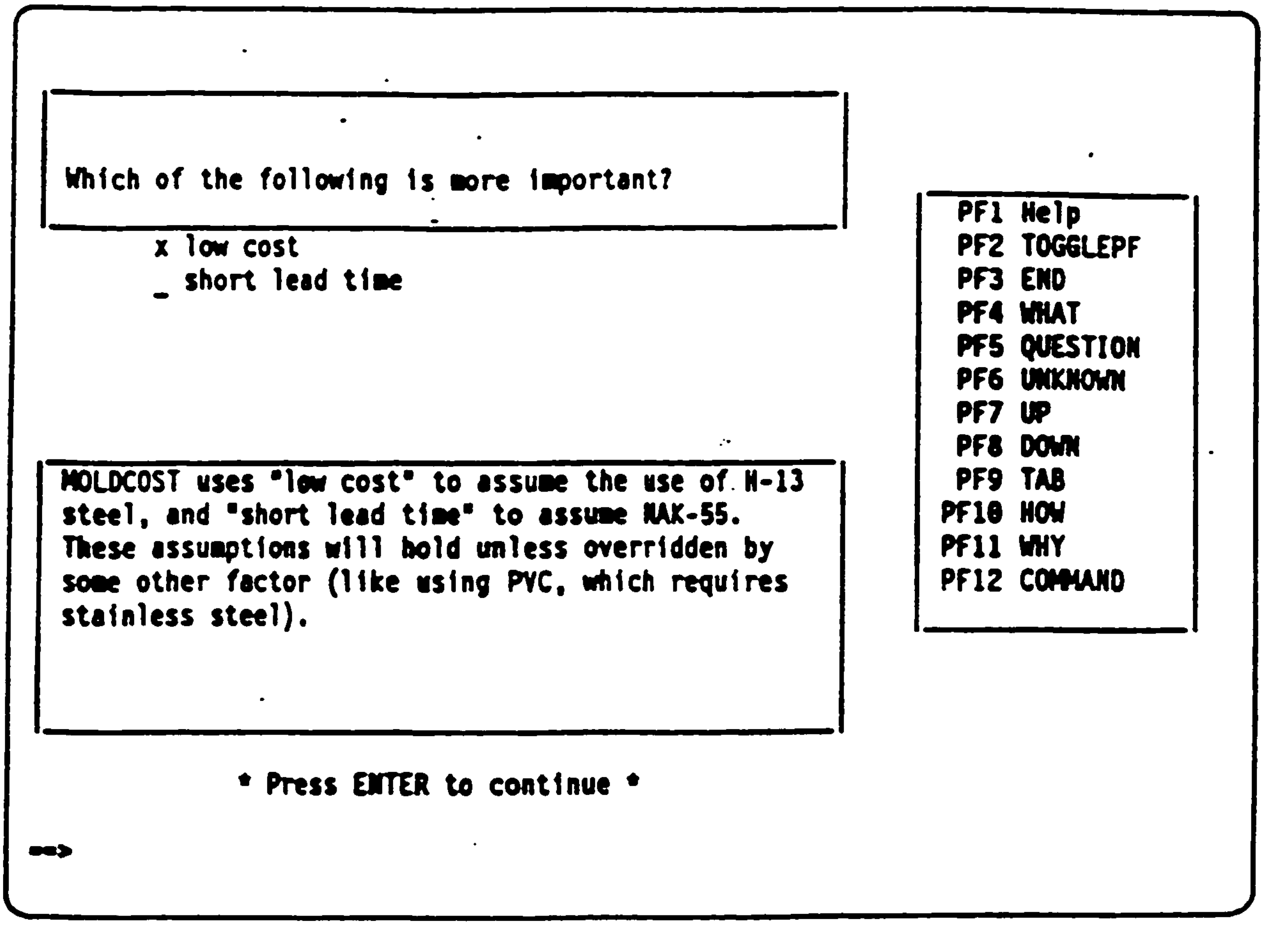
```
What kind of plastic is the part made from?

        x PVC
        _ structural foam
        _ other

MOLDCOST uses the choice "PVC" to assign stainless
steel as a mold material. Knowing whether or not
the plastic is foam is important in press tonnage
calculations. The influences of other plastics will
be included as more data is collected.

              * Press ENTER to continue *

==>
```

```
 PF1 Help
 PF2 TOGGLEPF
 PF3 END
 PF4 WHAT
 PF5 QUESTION
 PF6 UNKNOWN
 PF7 UP
 PF8 DOWN
 PF9 TAB
PF10 HOW
PF11 WHY
PF12 COMMAND
```

Based on the survey results, only two types of plastic influenced mold cost. Stainless steel molds are required for use with PVC to prevent corrosion. Structural foam decreases the tonnage requirement per cavity, which may affect cavity level. Choosing "other" has no affect on cost.

Figure 7

Low Cost vs. Short Lead Time



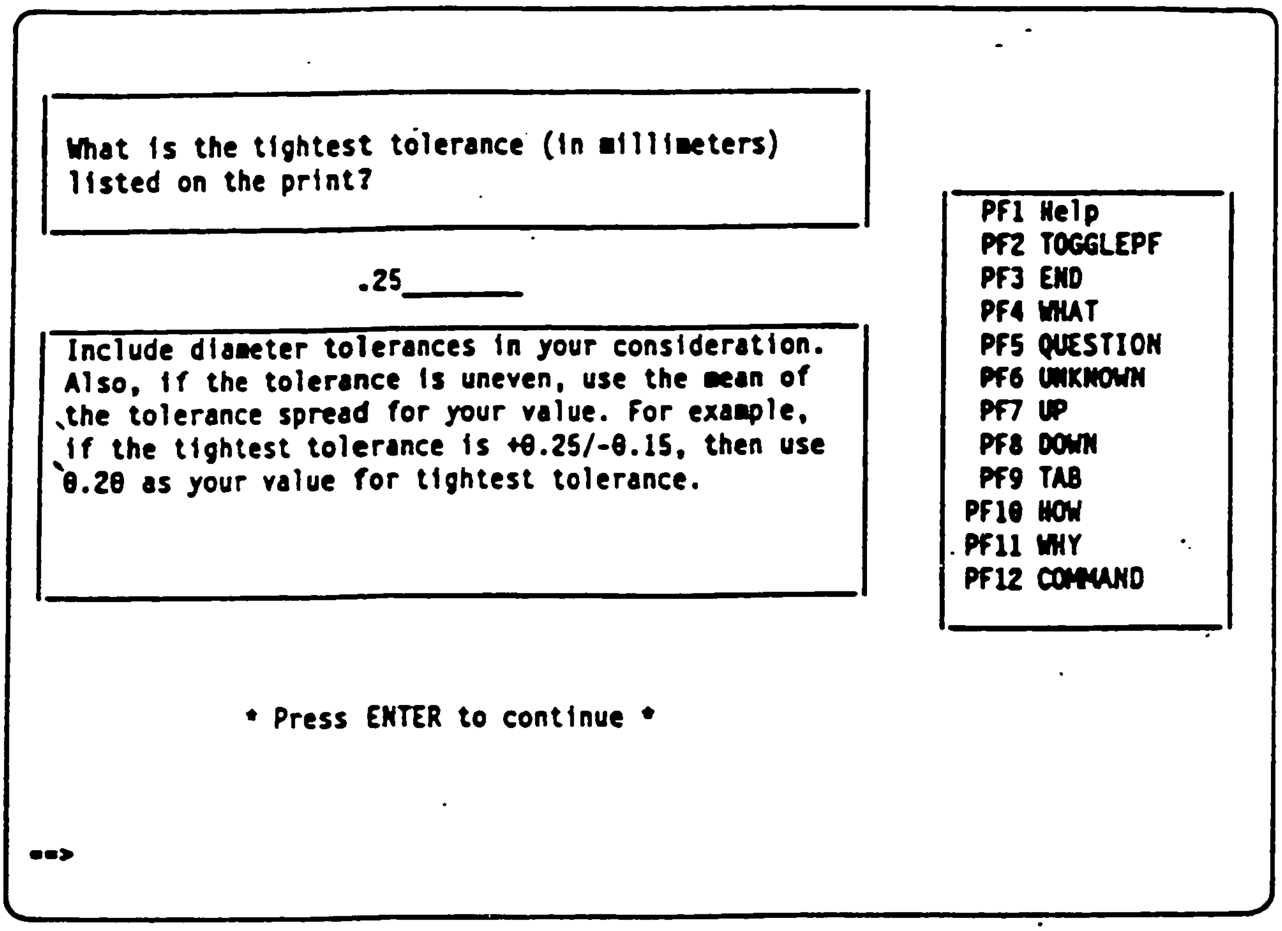
```
Which of the following is more important?

      x low cost
      _ short lead time

                                                  PF1  Help
                                                  PF2  TOGGLEPF
                                                  PF3  END
                                                  PF4  WHAT
                                                  PF5  QUESTION
                                                  PF6  UNKNOWN
                                                  PF7  UP
                                                  PF8  DOWN
                                                  PF9  TAB
                                                  PF10 HOW
                                                  PF11 WHY
                                                  PF12 COMMAND

MOLDCOST uses "low cost" to assume the use of H-13
steel, and "short lead time" to assume NAK-55.
These assumptions will hold unless overridden by
some other factor (like using PVC, which requires
stainless steel).

            * Press ENTER to continue *

==>
```

This question is asked in order to determine the type of steel. "Low cost" assumes H-13 steel and "Short lead time" assumes NAK-55, which is more expensive. These assumptions will hold throughout the consultation unless altered by some other factor (use of PVC, need for a prototype, etc.). You will have the opportunity to change MOLDCOST'S assumption at the end of the consultation (see **Changing Assumptions**).

Figure 8

Answering the Questions

Tightest Tolerance

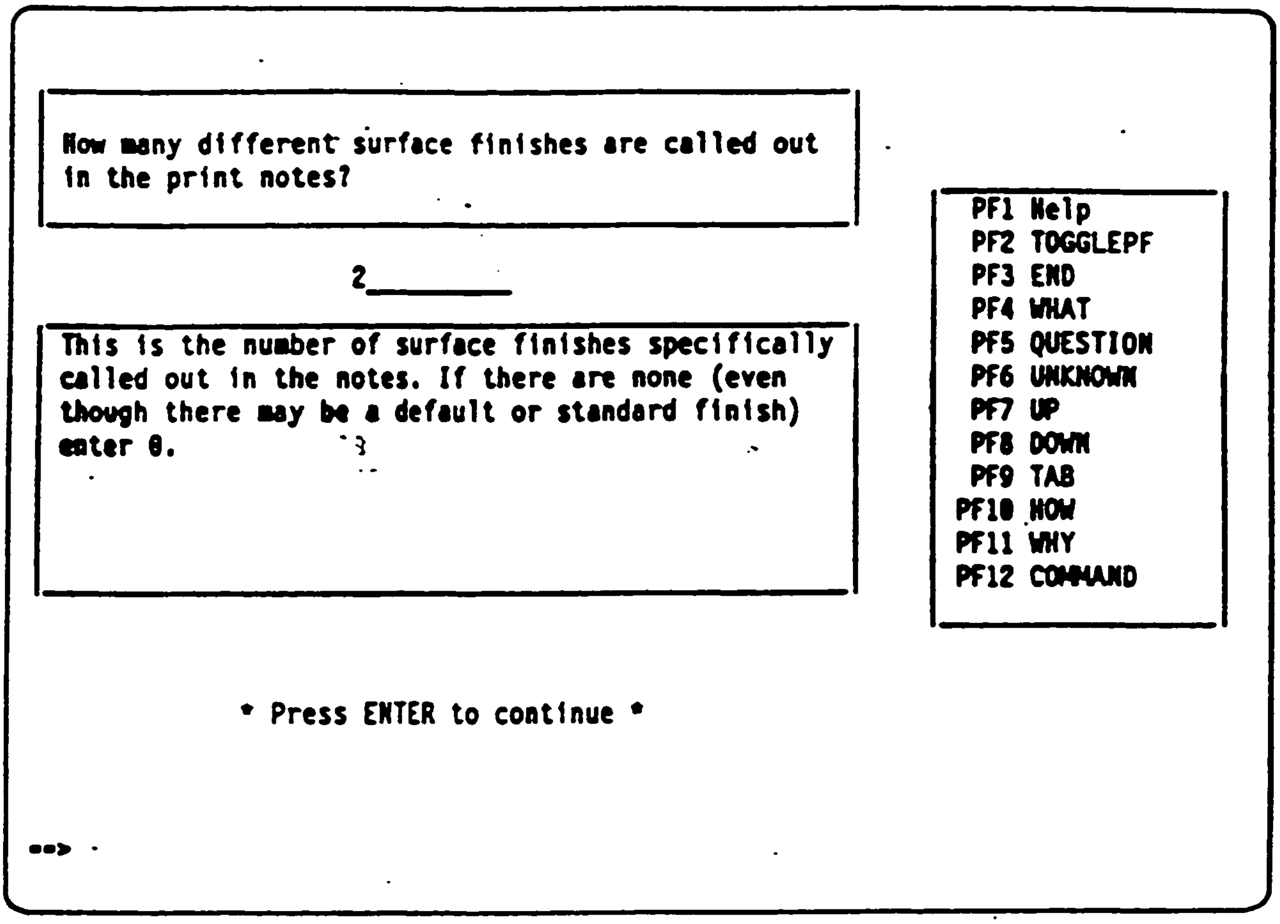


```
What is the tightest tolerance (in millimeters)
listed on the print?

            .25_______

Include diameter tolerances in your consideration.
Also, if the tolerance is uneven, use the mean of
the tolerance spread for your value. For example,
if the tightest tolerance is +0.25/-0.15, then use
0.20 as your value for tightest tolerance.

                                                     PF1 Help
                                                     PF2 TOGGLEPF
                                                     PF3 END
                                                     PF4 WHAT
                                                     PF5 QUESTION
                                                     PF6 UNKNOWN
                                                     PF7 UP
                                                     PF8 DOWN
                                                     PF9 TAB
                                                     PF10 HOW
                                                     PF11 WHY
                                                     PF12 COMMAND

          * Press ENTER to continue *

==>
```

Look over your part drawing to see which dimension has the tightest tolerance. By "tightest" we mean the smallest as an absolute value, not the smallest in proportion to the size of the dimension. If a tolerance is uneven, use the mean so that the tolerance is balanced. For example, if the tolerance is +0.25/-0.15, use 0.20 as the value.

Figure 9

Surface Finish

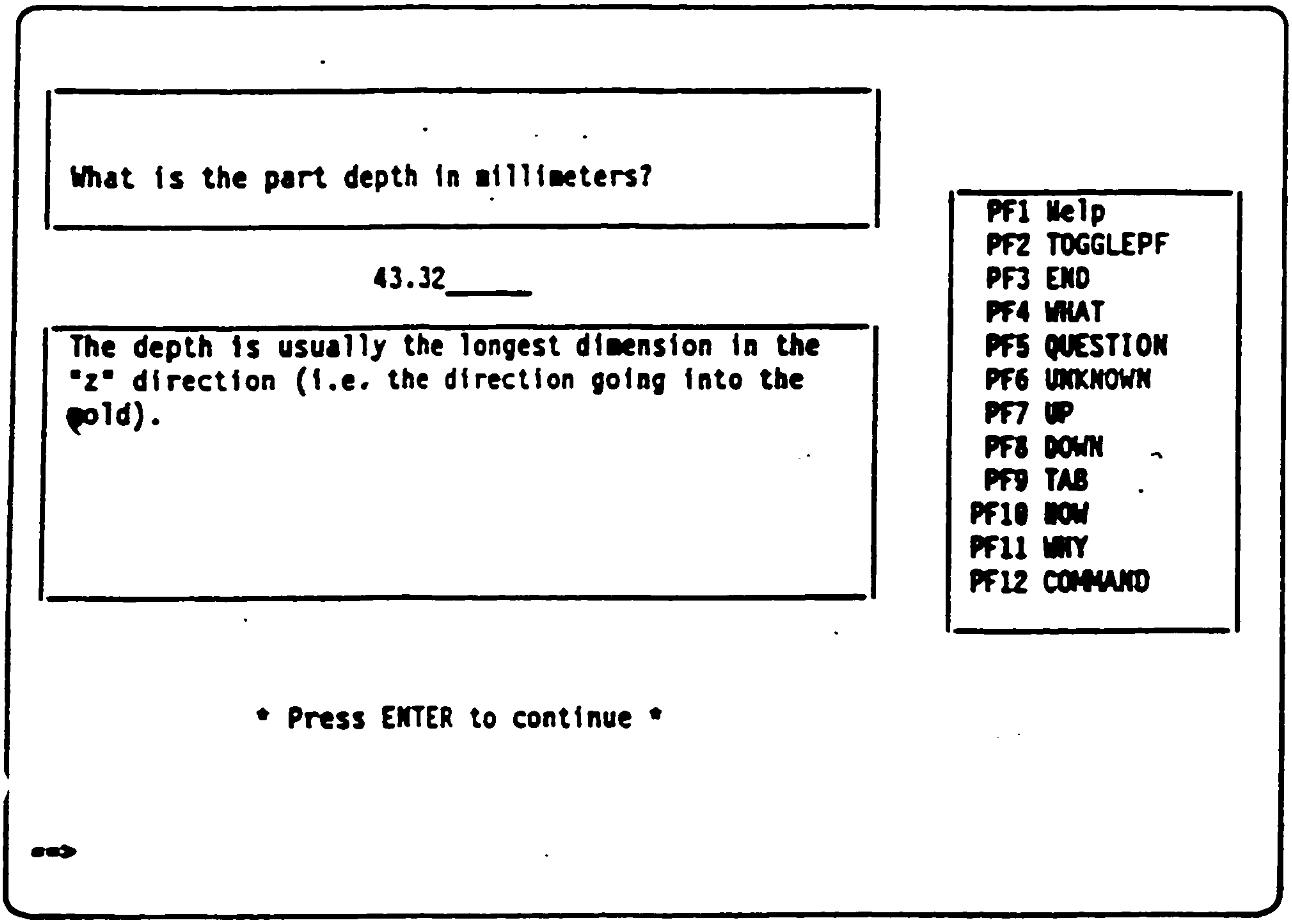


```
How many different surface finishes are called out
in the print notes?

                    2________

This is the number of surface finishes specifically
called out in the notes. If there are none (even
though there may be a default or standard finish)
enter 0.

                                        PF1 Help
                                        PF2 TOGGLEPF
                                        PF3 END
                                        PF4 WHAT
                                        PF5 QUESTION
                                        PF6 UNKNOWN
                                        PF7 UP
                                        PF8 DOWN
                                        PF9 TAB
                                       PF10 HOW
                                       PF11 WHY
                                       PF12 COMMAND

         * Press ENTER to continue *

==>
```

While there are many different kinds of surface finishes available, our survey data has shown that cost is affected more by how many than by what kind. It has been taken into account that there will be some standard or unspecified finish on the part. If this is all there is, enter 0. Count only each unique surface finish called out in the print notes when calculating your value.

Figure 10

Part Depth

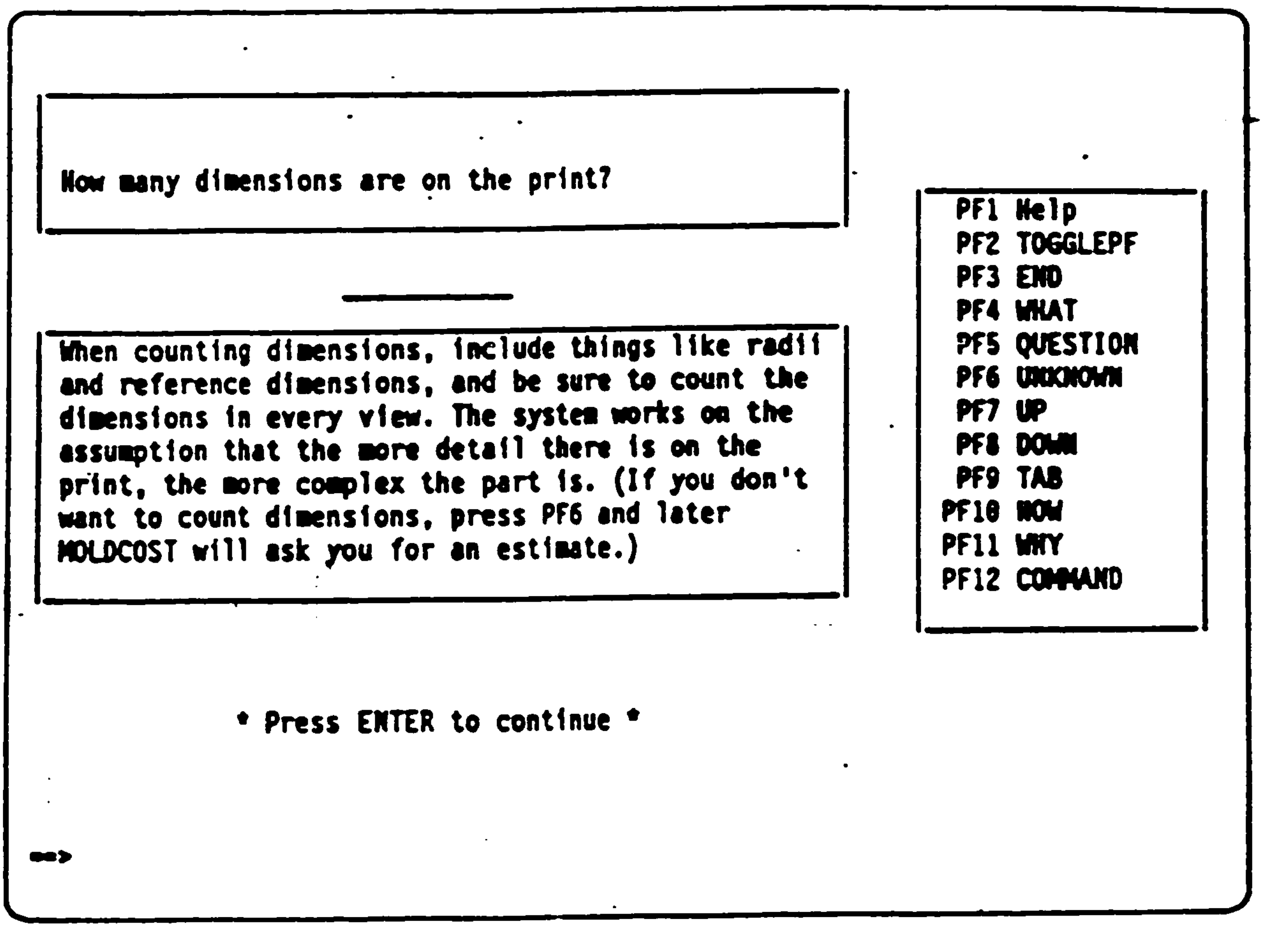


```
What is the part depth in millimeters?

                    43.32_____

The depth is usually the longest dimension in the
"z" direction (i.e. the direction going into the
mold).

        * Press ENTER to continue *

==>
```

The depth is usually the longest dimension perpendicular to the length and width. Try to define depth as being the dimension in the direction moving into the mold. In some cases, this may cause it to be longer than the width. If you can't determine the orientation in the mold, just use your best judgement.

Figure 11

Number of Dimensions



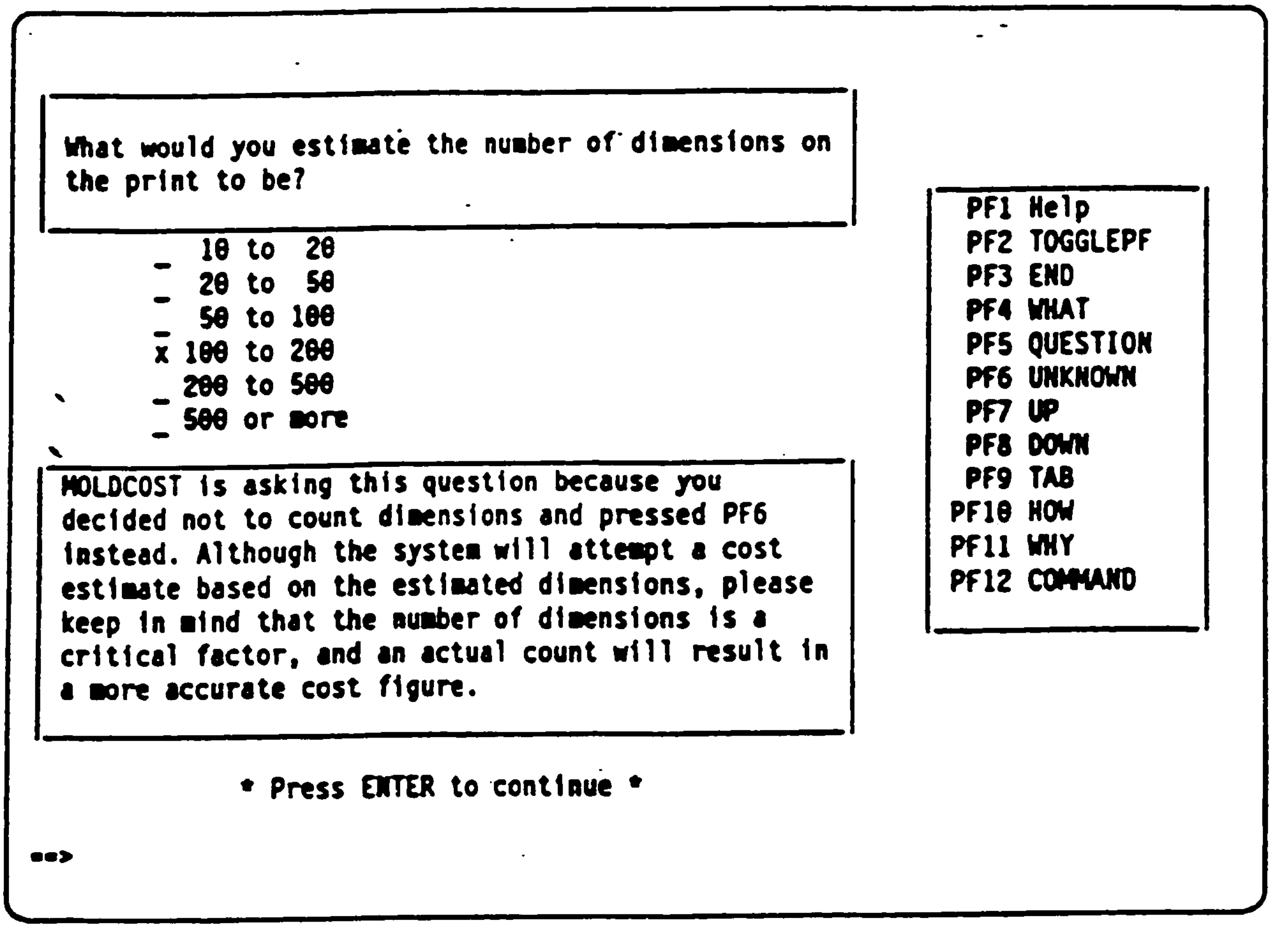
```
How many dimensions are on the print?

When counting dimensions, include things like radii
and reference dimensions, and be sure to count the
dimensions in every view. The system works on the
assumption that the more detail there is on the
print, the more complex the part is. (If you don't
want to count dimensions, press PF6 and later
MOLDCOST will ask you for an estimate.)

                * Press ENTER to continue *

==>
```

We found a very high correlation between the number of dimensions on a part drawing and the mold cost. This number is used as a relatively simple and objective index of part complexity. When counting, include all reference dimensions, even though they might be duplicated throughout the drawing(s). The theory behind this is that the more times a dimension is shown, the more explanation must be required. Therefore, the part must be more complex.

Presently, the assumption is that repetitions like 0.253 (10X) should be counted as one half the number of times the dimension occurs on the part. In the example above, this dimension would be counted five times. This allows for the fact that repeating a dimension ten times indicates more complexity than a single dimension, but not as much as ten different dimensions. You may want to create your own counting scheme.

Figure 12

Estimated Number of Dimensions

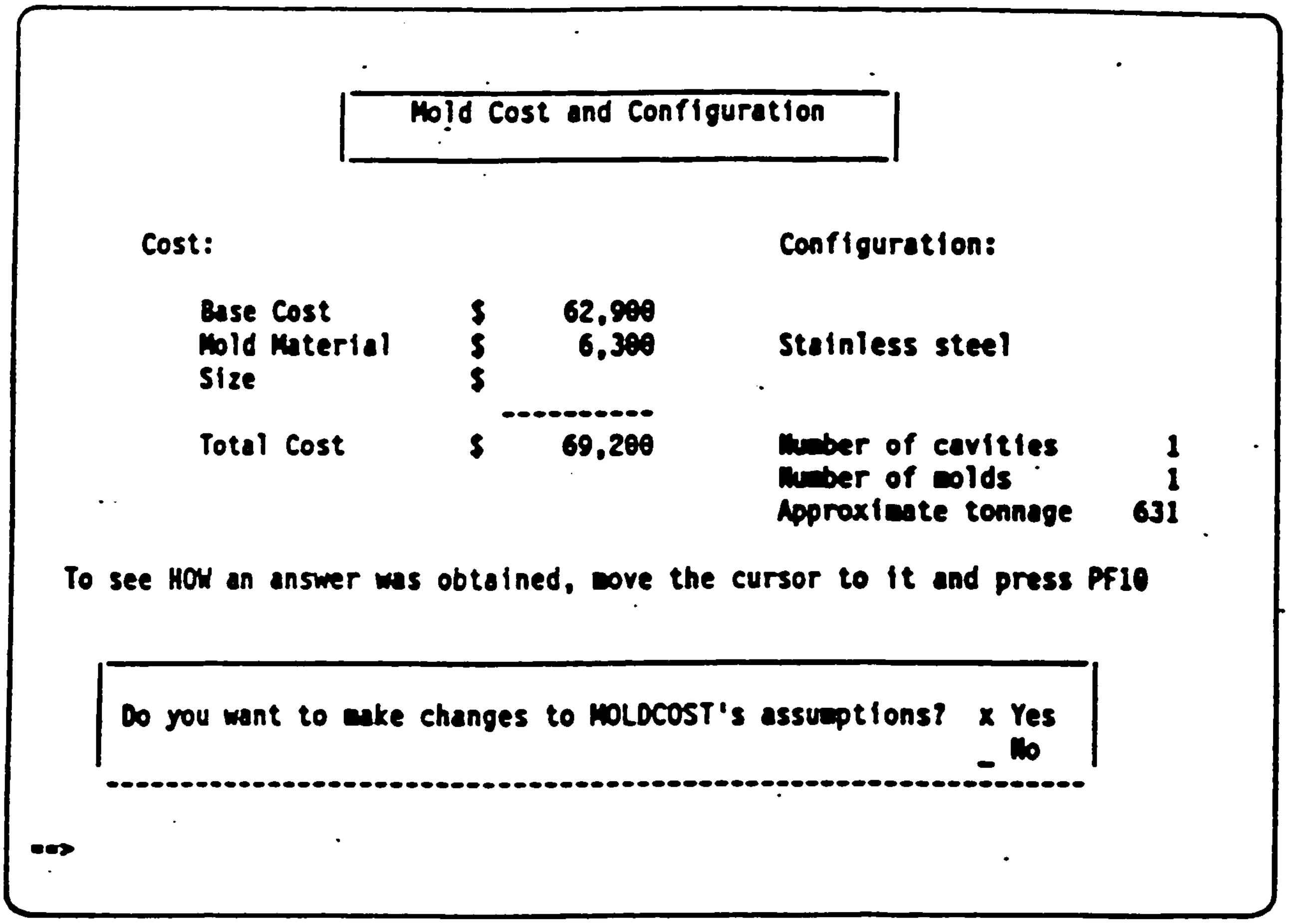


```
What would you estimate the number of dimensions on
the print to be?

     _  10 to  20
     _  20 to  50
     _  50 to 100
     x 100 to 200
     _ 200 to 500
     _ 500 or more

MOLDCOST is asking this question because you
decided not to count dimensions and pressed PF6
instead. Although the system will attempt a cost
estimate based on the estimated dimensions, please
keep in mind that the number of dimensions is a
critical factor, and an actual count will result in
a more accurate cost figure.

                                   PF1 Help
                                   PF2 TOGGLEPF
                                   PF3 END
                                   PF4 WHAT
                                   PF5 QUESTION
                                   PF6 UNKNOWN
                                   PF7 UP
                                   PF8 DOWN
                                   PF9 TAB
                                  PF10 HOW
                                  PF11 WHY
                                  PF12 COMMAND

              * Press ENTER to continue *

==>
```

Sometimes, you may be faced with a part drawing containing several pages and hundreds of dimensions. In such a case, you may not want to count every dimension. By pressing PF6 on the previous screen, you tell the system that you don't know the answer. You will then be prompted to estimate the number from a set of ranges. Although knowing the actual number of dimensions will provide a more accurate answer, guessing when faced with hundreds of dimensions is not as bad as it seems. The function is logarithmic, which means that errors in your guess at high values will not affect the cost as errors in your guess at low values. This makes more sense when you observe that adding a single dimension to a part with five dimensions increases the complexity of it much more than adding one to a part with five hundred.

Figure 13

Interpreting the Answer Screen



```
                    Mold Cost and Configuration

     Cost:                                   Configuration:

         Base Cost          $      62,900
         Mold Material      $       6,300    Stainless steel
         Size               $
                               ----------
         Total Cost         $      69,200    Number of cavities        1
                                             Number of molds           1
                                             Approximate tonnage     631

To see HOW an answer was obtained, move the cursor to it and press PF10

   Do you want to make changes to MOLDCOST's assumptions?  x Yes
                                                           _ No
  ---------------------------------------------------------------

==>
```

If you have answered all the questions successfully, you should get a screen showing a cost breakdown and assumed mold configuration. They are defined as follows:

Base Cost:	The cost derived from the base equation. It is calculated solely on the basis of the six factors outlined in the introduction.
Mold Material:	The cost impact of the material indicated in the "Configuration" section, as compared to H-13 steel.
Size:	The cost impact of extremely small part size. It is assumed that cost decreases with decreasing part size, but eventually a point is reached where cost rises because of the detailed work required. This factor compensates for the general assumption by increasing cost for parts under 2 millimeters in length.
Number of Cavities:	The number of cavities is calculated by three independent methods: 1. Restrictions imposed by the size of the part 2. The number which will support the yearly production volume

Figure 14 Interpreting the Answer Screen

Changing Assumptions

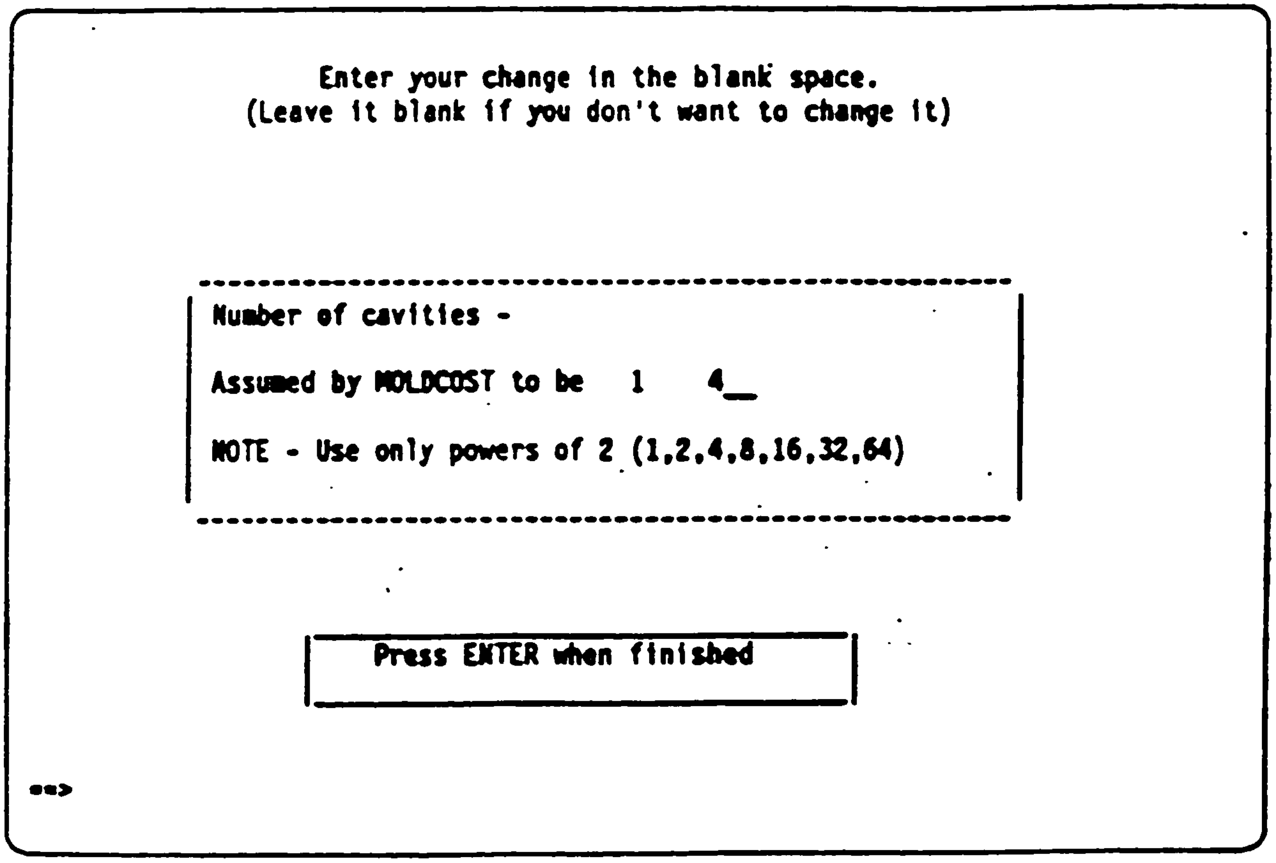
Figure 15

At the bottom of the answer screen is a box containing the question

Do you want to make changes to MOLDCOST's assumptions?

If you answer "no", you get one last look at the output screen and then return to the ESCE logo to exit or run another consultation. If you choose "yes", you will have the ability to change the number of cavities and/or the mold material. Since the number of molds and press tonnage are derived from the number of cavities and since the other factors displayed on the answer screen are the direct result of your answers to MOLDCOST's questions, number of cavities and mold material are the only properties that can be changed in this way.

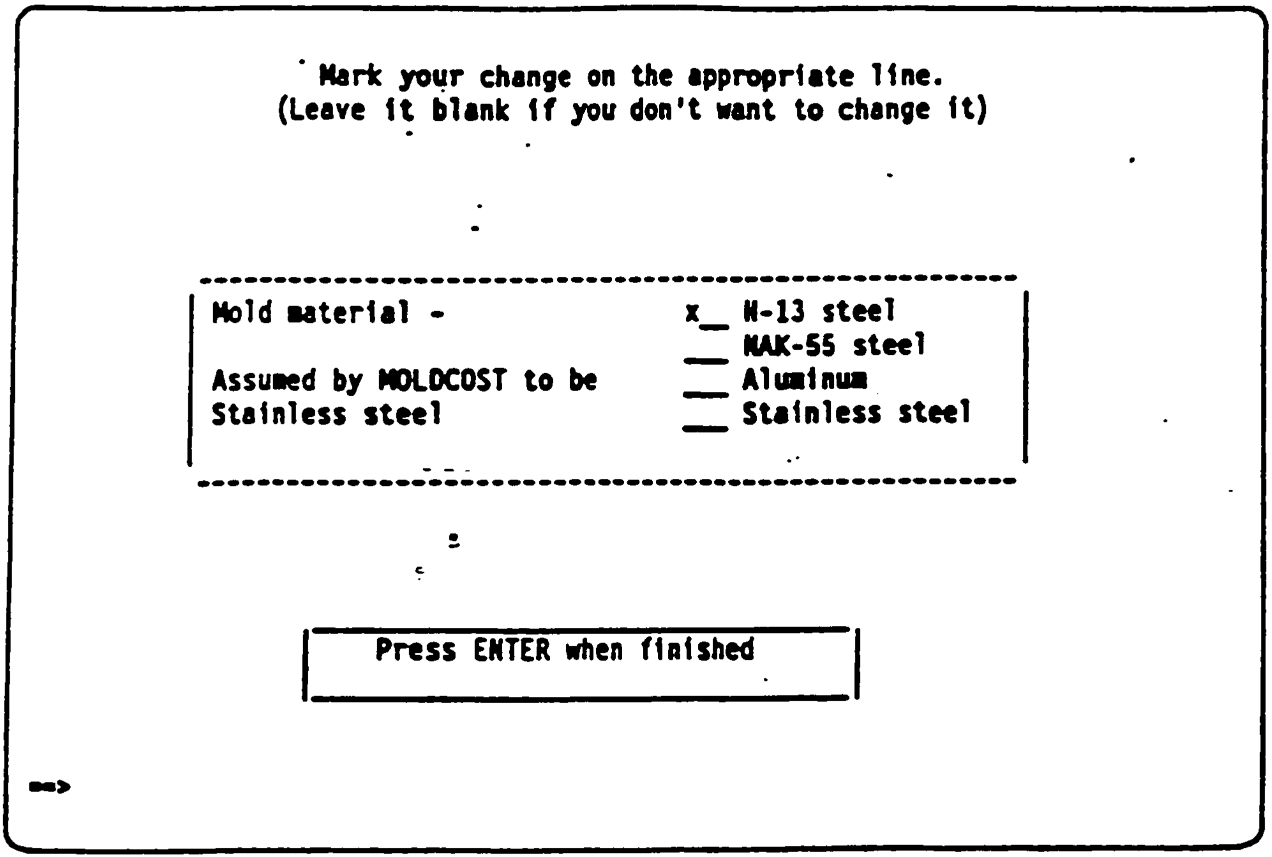
Number of Cavities



```
Enter your change in the blank space.
(Leave it blank if you don't want to change it)

Number of cavities -

Assumed by MOLDCOST to be  1    4_

NOTE - Use only powers of 2 (1,2,4,8,16,32,64)

Press ENTER when finished

==>
```

In the first screen, MOLDCOST shows you the present cavity level and offers the chance to change it. Enter a number or simply press ENTER if you don't want it changed. Keep in mind that there is an upper limit of 64 cavities, and the number must be a power of 2 (i.e. 1, 2, 4, 8, 16, 32, or 64). There is no checking for reasonableness, so if you want a 64 cavity cover mold, you'll get it (even if it costs $1 million and requires a 15,000 ton press!).

Mold Material



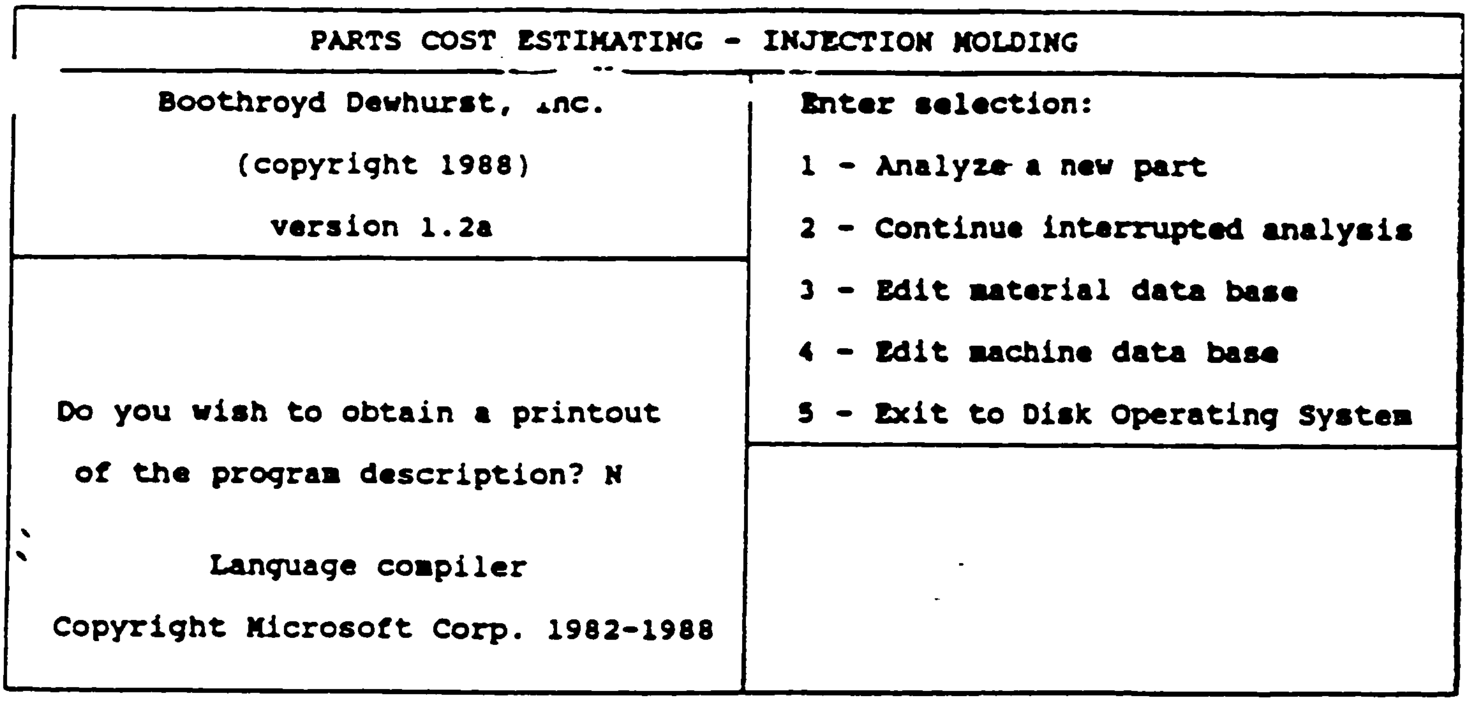
```
Mark your change on the appropriate line.
(Leave it blank if you don't want to change it)

---------------------------------------------------------------
| Mold material -                    x__ H-13 steel           |
|                                    ___ NAK-55 steel         |
| Assumed by MOLDCOST to be          ___ Aluminum             |
| Stainless steel                    ___ Stainless steel      |
|                                                             |
---------------------------------------------------------------

              | Press ENTER when finished |

==>
```

In the second screen, MOLDCOST shows you the presently selected material and offers the changes available. Just mark the one you want with an "X". Again, there is no checking for reasonableness (that was done the first time through the estimate).

When you are finished, you will return to the answer screen. The system will now display the recalculated costs based on your changes. To return to the ESCE logo screen for a fresh start, press **ENTER**.

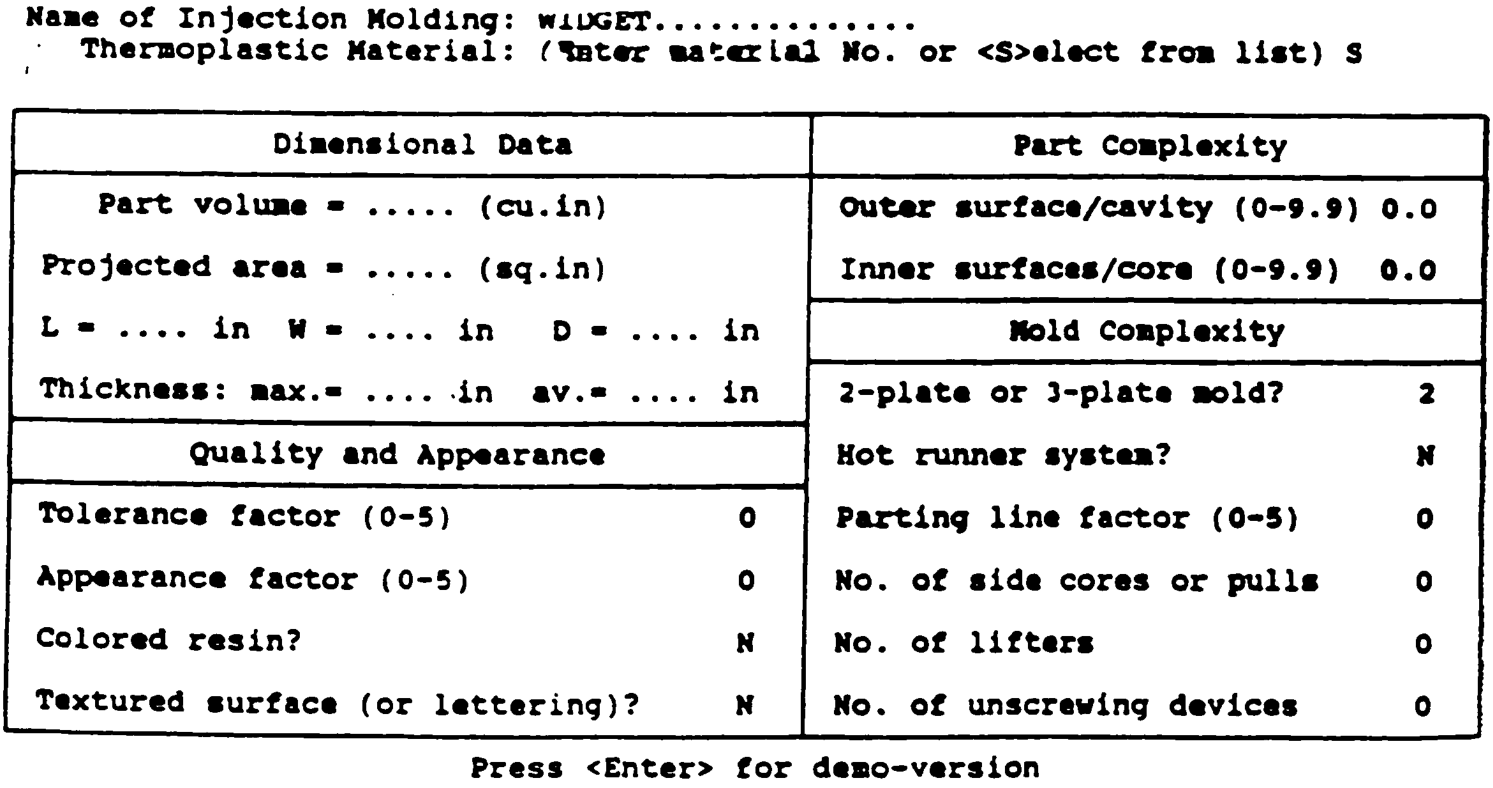
Figure 16

BDI Figure 1



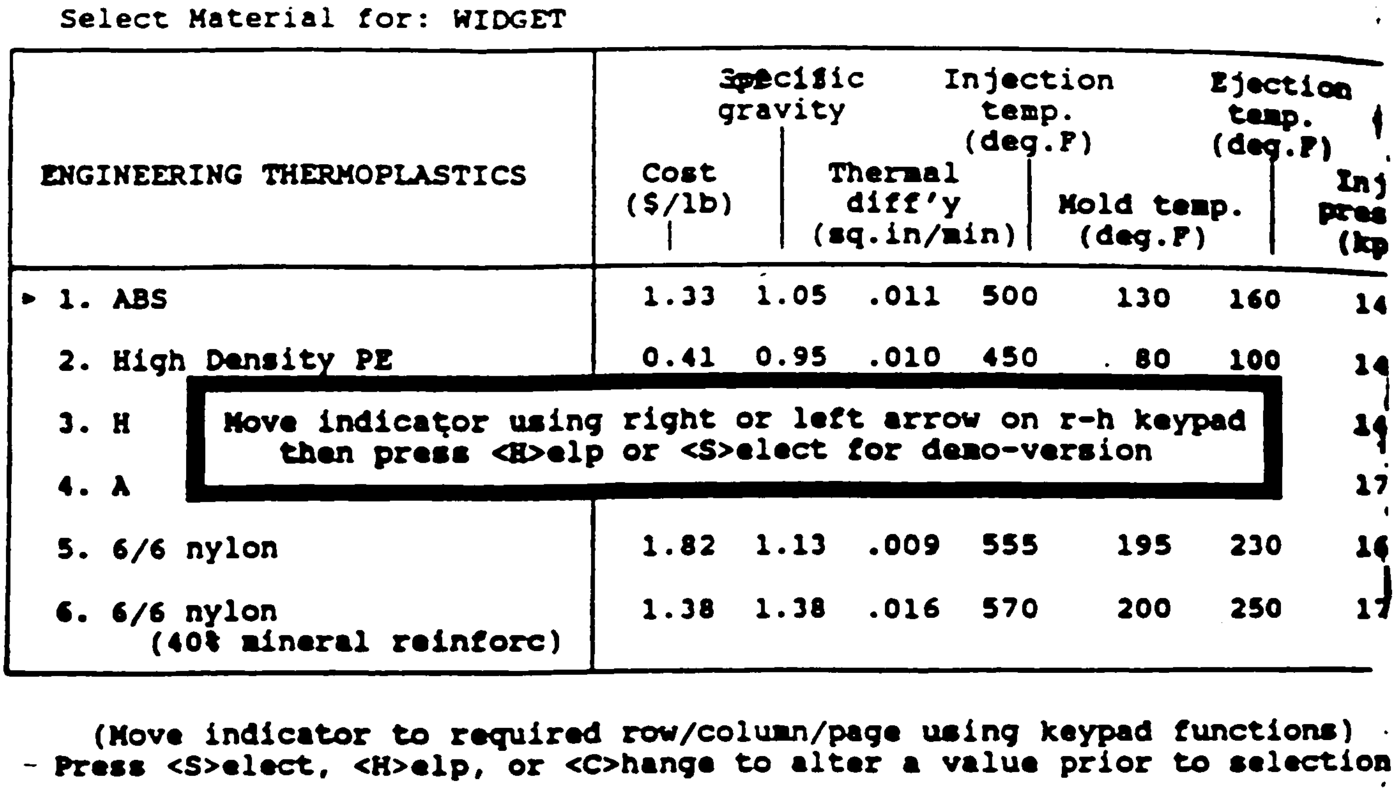
```
PARTS COST ESTIMATING - INJECTION MOLDING

Boothroyd Dewhurst, Inc.          Enter selection:

(copyright 1988)                  1 - Analyze a new part

version 1.2a                      2 - Continue interrupted analysis

                                  3 - Edit material data base

                                  4 - Edit machine data base

Do you wish to obtain a printout  5 - Exit to Disk Operating System

of the program description? N

Language compiler

Copyright Microsoft Corp. 1982-1988
```

BDI Figure 2



```
Name of Injection Molding: WIDGET..............
  Thermoplastic Material: (Enter material No. or <S>elect from list) S

            Dimensional Data                          Part Complexity
   Part volume = ..... (cu.in)              Outer surface/cavity (0-9.9) 0.0
 Projected area = ..... (sq.in)             Inner surfaces/core (0-9.9)  0.0
 L = .... in   W = .... in    D = .... in               Mold Complexity
 Thickness: max.= .... in   av.= .... in    2-plate or 3-plate mold?       2
         Quality and Appearance             Hot runner system?             N
 Tolerance factor (0-5)               0     Parting line factor (0-5)      0
 Appearance factor (0-5)              0     No. of side cores or pulls     0
 Colored resin?                       N     No. of lifters                 0
 Textured surface (or lettering)?     N     No. of unscrewing devices      0
                     Press <Enter> for demo-version
```

BDI Figure 3



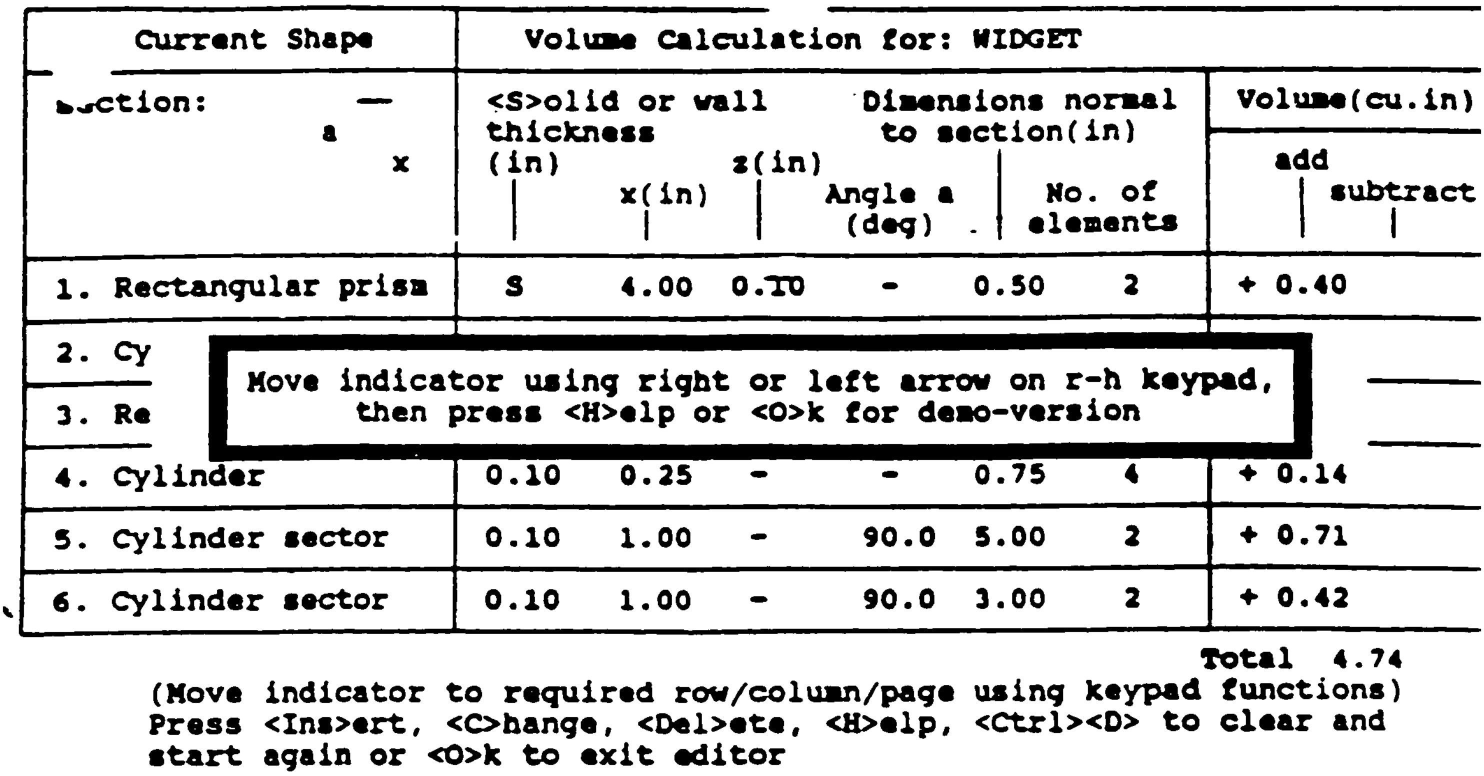
Select Material for: WIDGET

ENGINEERING THERMOPLASTICS	Cost ($/lb)	Specific gravity	Thermal diff'y (sq.in/min)	Injection temp. (deg.F)	Mold temp. (deg.F)	Ejection temp. (deg.F)	Inj pres (kp
▸ 1. ABS	1.33	1.05	.011	500	130	160	14
2. High Density PE	0.41	0.95	.010	450	80	100	14
3. H							14
4. A							17
5. 6/6 nylon	1.82	1.13	.009	555	195	230	16
6. 6/6 nylon (40% mineral reinforc)	1.38	1.38	.016	570	200	250	17

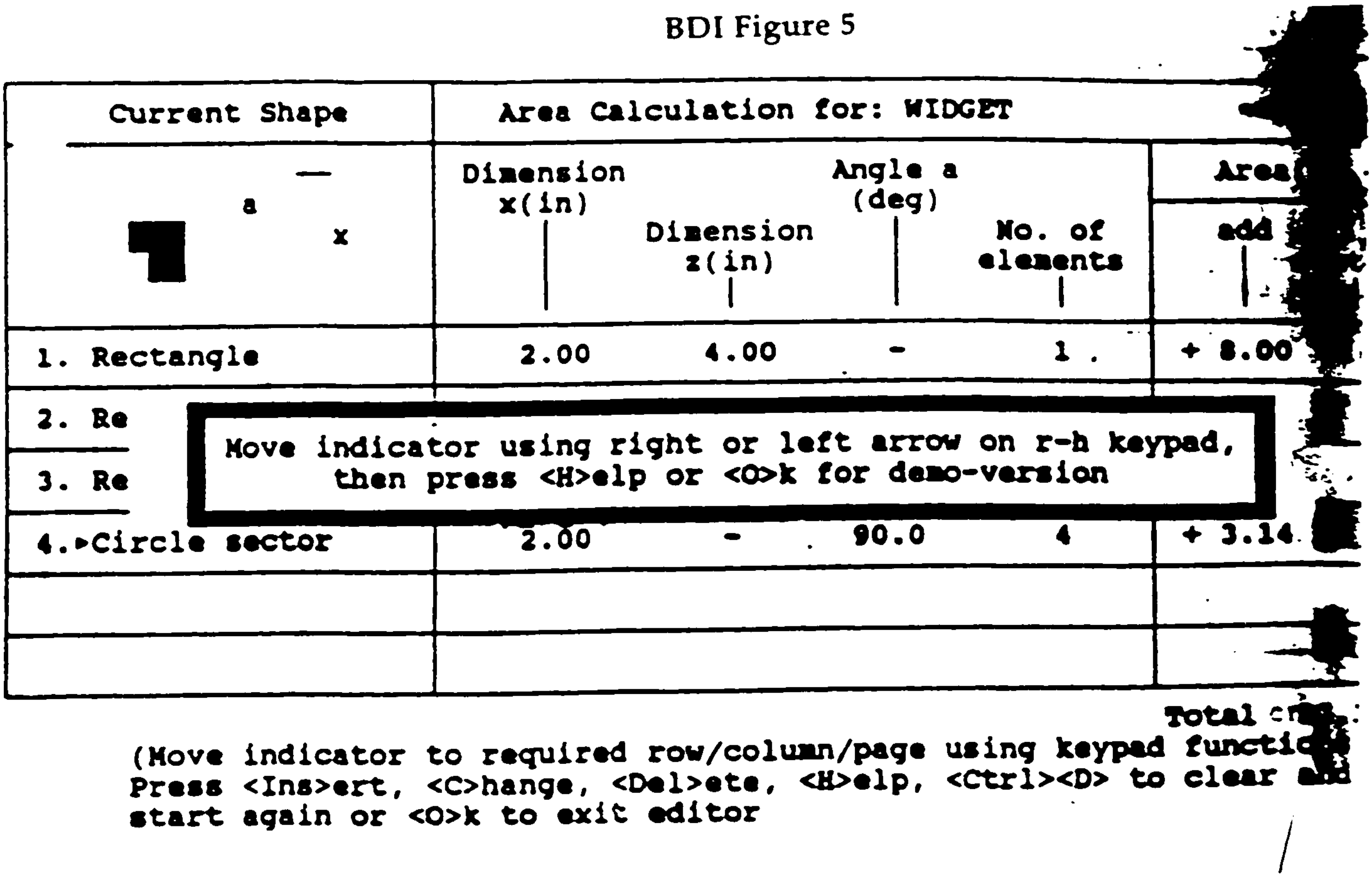
Move indicator using right or left arrow on r-h keypad
then press <H>elp or <S>elect for demo-version

(Move indicator to required row/column/page using keypad functions)
Press <S>elect, <H>elp, or <C>hange to alter a value prior to selection

BDI Figure 4



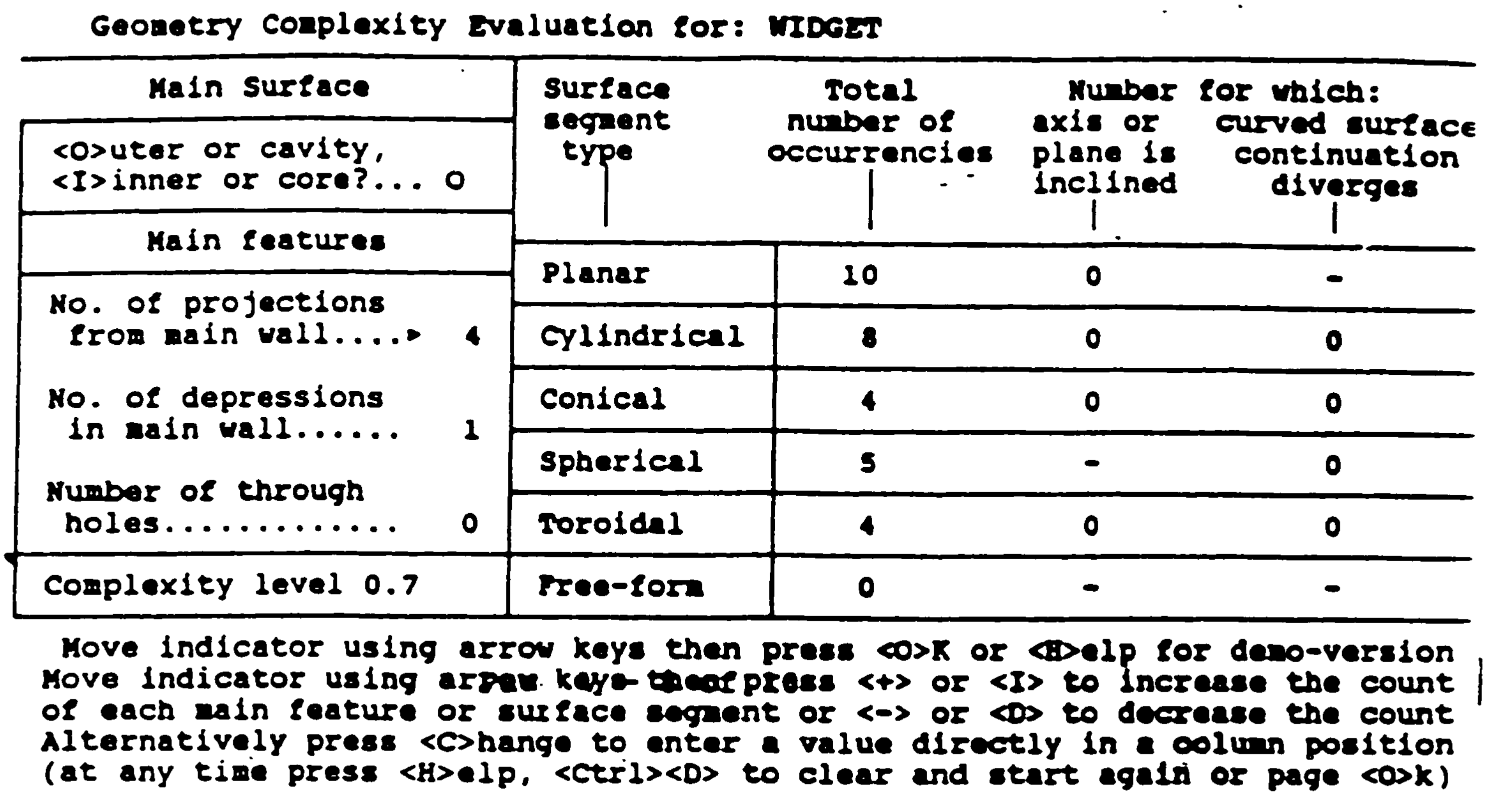
```
Current Shape           | Volume Calculation for: WIDGET
------------------------+-----------------------------------------------------+----------------
Section:          —     | <S>olid or wall     Dimensions normal               | Volume(cu.in)
              a         | thickness            to section(in)                 |
                  x     | (in)           z(in)              |                 | add
                        |  |       x(in)   |   Angle a       |   No. of        |  |  subtract
                        |  |         |     |   (deg)         |   elements      |  |     |
------------------------+-----------------------------------------------------+----------------
1. Rectangular prism    |  S      4.00   0.10    -       0.50     2          | + 0.40
------------------------+-----------------------------------------------------+----------------
2. Cy
     Move indicator using right or left arrow on r-h keypad,
        then press <H>elp or <O>k for demo-version
3. Re
------------------------+-----------------------------------------------------+----------------
4. Cylinder             | 0.10    0.25    -       -       0.75     4          | + 0.14
------------------------+-----------------------------------------------------+----------------
5. Cylinder sector      | 0.10    1.00    -      90.0     5.00     2          | + 0.71
------------------------+-----------------------------------------------------+----------------
6. Cylinder sector      | 0.10    1.00    -      90.0     3.00     2          | + 0.42
------------------------+-----------------------------------------------------+----------------
                                                                   Total   4.74
(Move indicator to required row/column/page using keypad functions)
Press <Ins>ert, <C>hange, <Del>ete, <H>elp, <Ctrl><D> to clear and
start again or <O>k to exit editor
```



BDI Figure 5

```
Current Shape            Area Calculation for: WIDGET
                         Dimension           Angle a              Area
            a            x(in)               (deg)                add
                    x              Dimension           No. of
                                   z(in)               elements
1. Rectangle              2.00      4.00      -          1 .      + 8.00
2. Re   Move indicator using right or left arrow on r-h keypad,
3. Re       then press <H>elp or <O>k for demo-version
4.▸Circle sector          2.00      -        90.0        4        + 3.14

                                                               Total c
(Move indicator to required row/column/page using keypad functio
Press <Ins>ert, <C>hange, <Del>ete, <H>elp, <Ctrl><D> to clear and
start again or <O>k to exit editor
```

BDI Figure 6



Geometry Complexity Evaluation for: WIDGET

Main Surface

<O>uter or cavity,
<I>inner or core?... O

Main features

No. of projections from main wall....▸ 4

No. of depressions in main wall...... 1

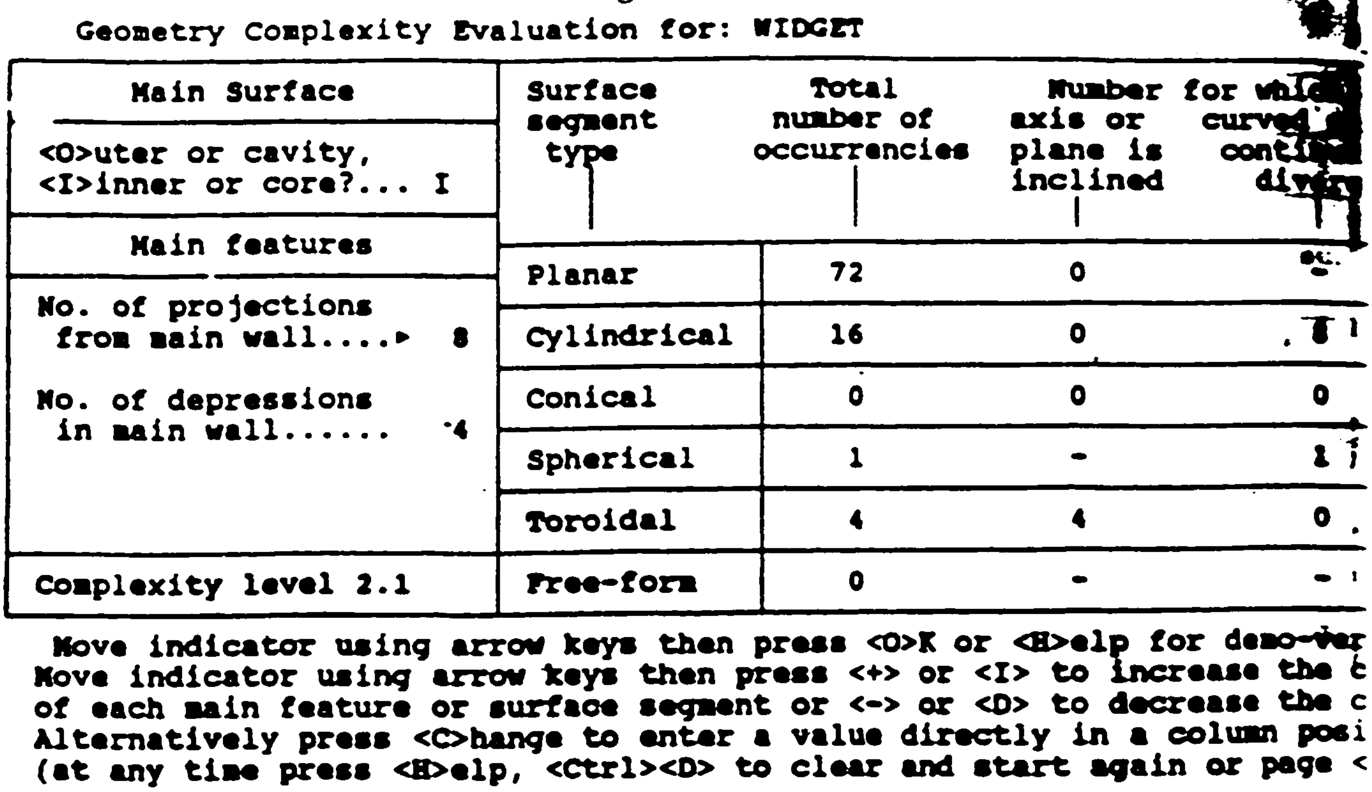
Number of through holes............. 0

Complexity level 0.7

Surface segment type	Total number of occurrencies	Number for which: axis or plane is inclined	curved surface continuation diverges
Planar	10	0	-
Cylindrical	8	0	0
Conical	4	0	0
Spherical	5	-	0
Toroidal	4	0	0
Free-form	0	-	-

Move indicator using arrow keys then press <O>K or <H>elp for demo-version
Move indicator using arrow keys then press <+> or <I> to increase the count
of each main feature or surface segment or <-> or <D> to decrease the count
Alternatively press <C>hange to enter a value directly in a column position
(at any time press <H>elp, <Ctrl><D> to clear and start again or page <O>k)

BDI Figure 7



Geometry Complexity Evaluation for: WIDGET

Main Surface

<O>uter or cavity,
<I>inner or core?... I

Main features

No. of projections from main wall....▸ 8

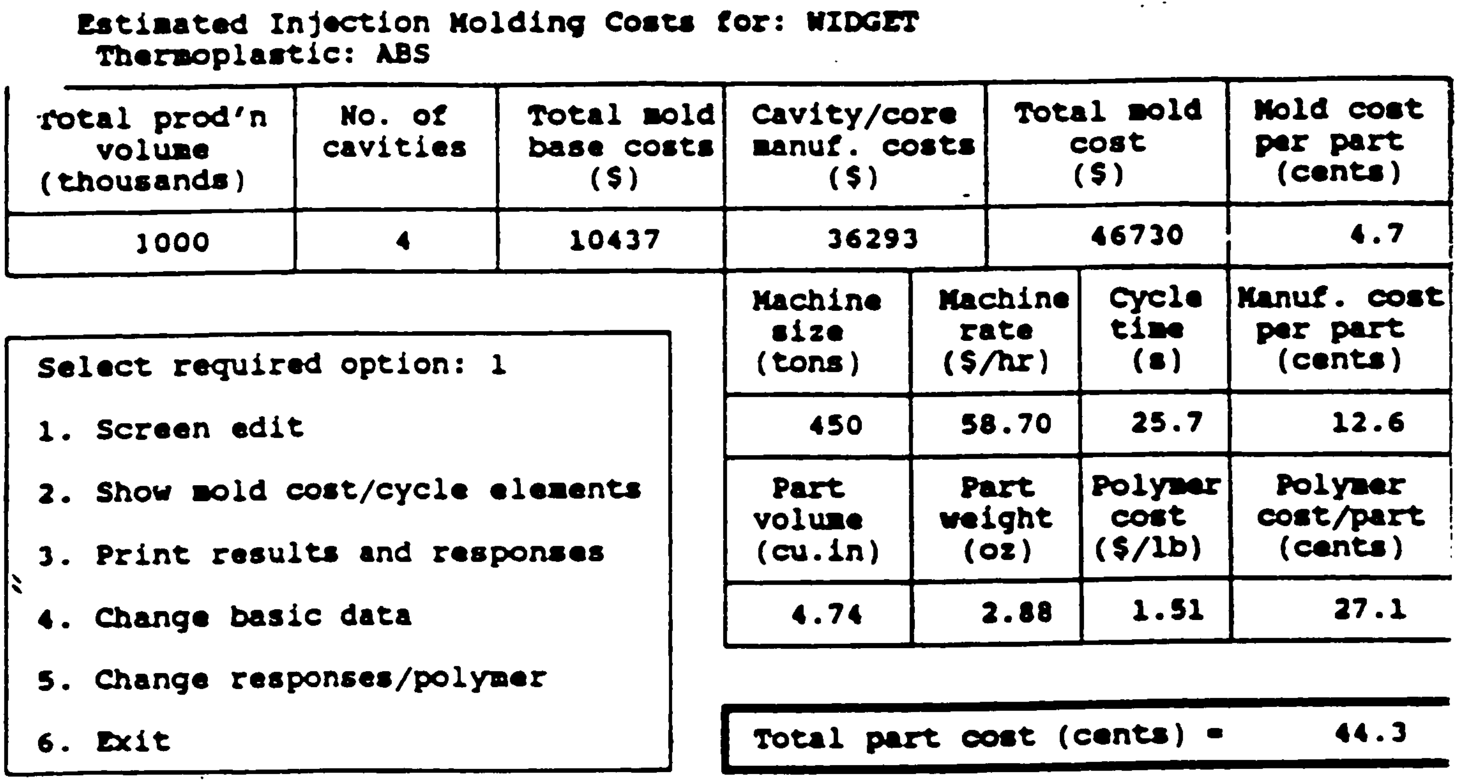
No. of depressions in main wall...... 4

Complexity level 2.1

Surface segment type	Total number of occurrencies	Number for wh axis or plane is inclined	curv conti div
Planar	72	0	-
Cylindrical	16	0	8
Conical	0	0	0
Spherical	1	-	1
Toroidal	4	4	0
Free-form	0	-	-

Move indicator using arrow keys then press <O>K or <H>elp for demo-ver
Move indicator using arrow keys then press <+> or <I> to increase the t
of each main feature or surface segment or <-> or <D> to decrease the c
Alternatively press <C>hange to enter a value directly in a column posi
(at any time press <H>elp, <Ctrl><D> to clear and start again or page <

BDI Figure 8



Estimated Injection Molding Costs for: WIDGET
Thermoplastic: ABS

Total prod'n volume (thousands)	No. of cavities	Total mold base costs ($)	Cavity/core manuf. costs ($)	Total mold cost ($)	Mold cost per part (cents)
1000	4	10437	36293	46730	4.7

Machine size (tons)	Machine rate ($/hr)	Cycle time (s)	Manuf. cost per part (cents)
450	58.70	25.7	12.6

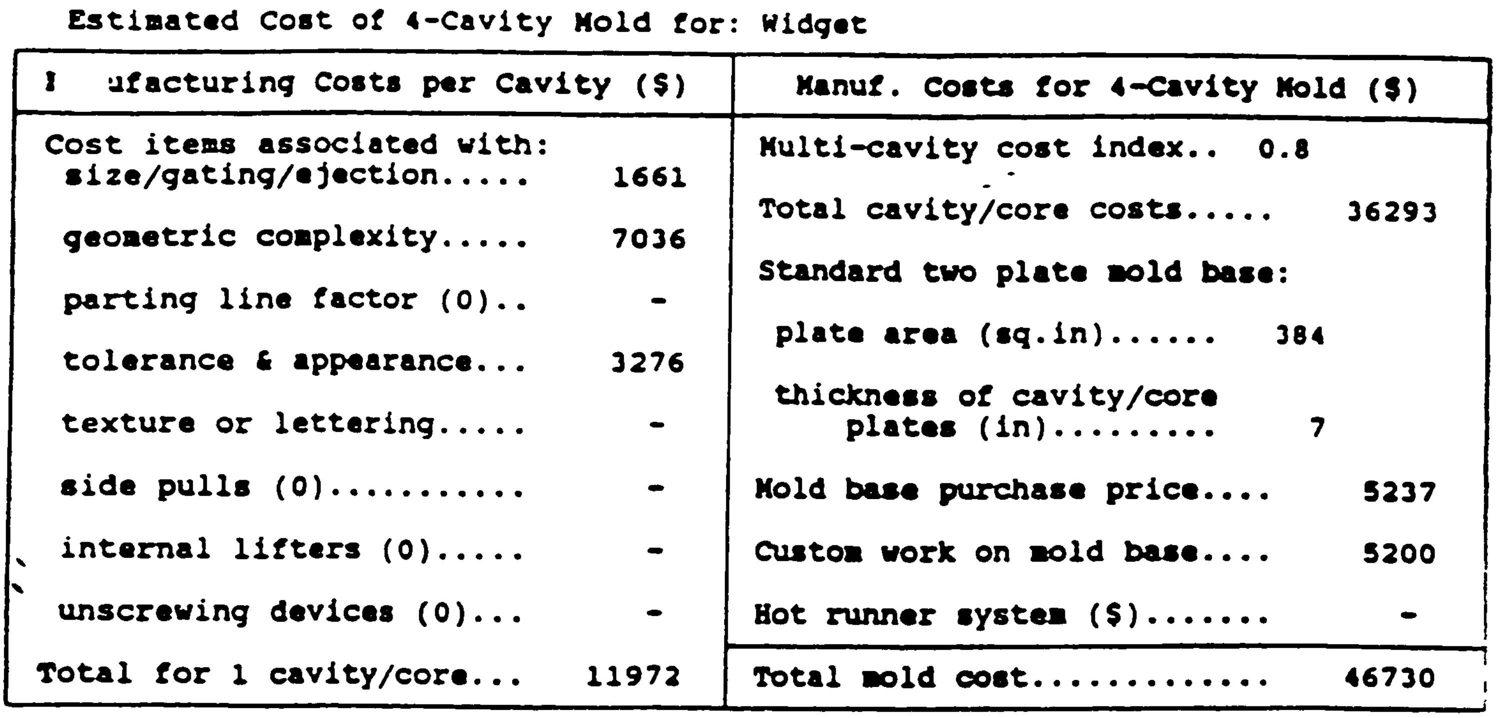
Part volume (cu.in)	Part weight (oz)	Polymer cost ($/lb)	Polymer cost/part (cents)
4.74	2.88	1.51	27.1

Select required option: 1

1. Screen edit
2. Show mold cost/cycle elements
3. Print results and responses
4. Change basic data
5. Change responses/polymer
6. Exit

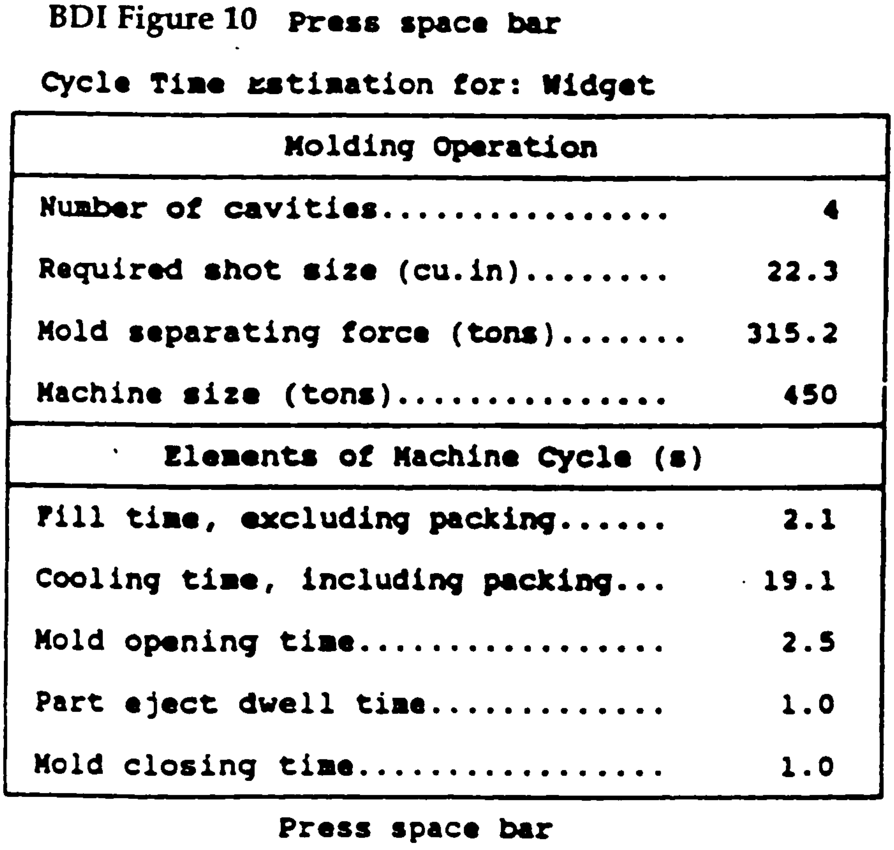
Total part cost (cents) = 44.3

BDI Figure 9



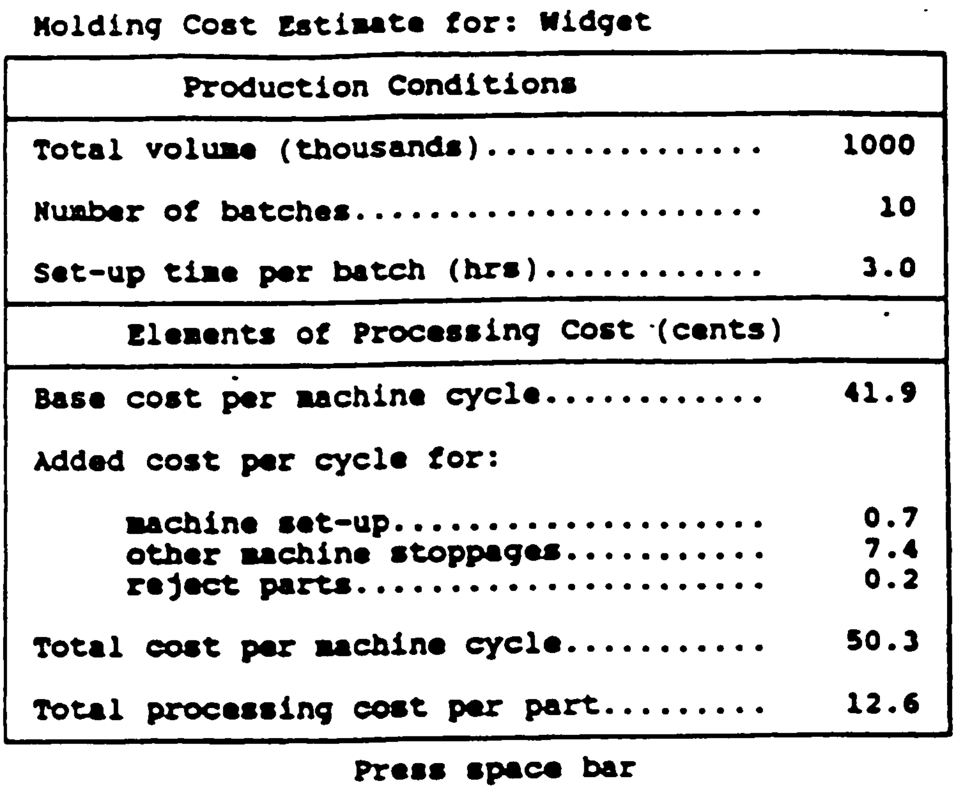
```
Estimated Cost of 4-Cavity Mold for: Widget

 Manufacturing Costs per Cavity ($)   Manuf. Costs for 4-Cavity Mold ($)

 Cost items associated with:          Multi-cavity cost index..  0.8
  size/gating/ejection.....    1661
                                      Total cavity/core costs.....    36293
  geometric complexity.....    7036
                                      Standard two plate mold base:
  parting line factor (0)..      -
                                       plate area (sq.in)......   384
  tolerance & appearance...    3276
                                       thickness of cavity/core
  texture or lettering.....      -         plates (in).........     7

  side pulls (0)...........      -    Mold base purchase price....     5237

  internal lifters (0).....      -    Custom work on mold base....     5200

  unscrewing devices (0)...      -    Hot runner system ($).......        -

 Total for 1 cavity/core...   11972   Total mold cost.............    46730
```

BDI Figure 10



```
Press space bar

Cycle Time Estimation for: Widget

                 Molding Operation

 Number of cavities................          4

 Required shot size (cu.in)........       22.3

 Mold separating force (tons).......     315.2

 Machine size (tons)...............        450

           Elements of Machine Cycle (s)

 Fill time, excluding packing......        2.1

 Cooling time, including packing...       19.1

 Mold opening time.................        2.5

 Part eject dwell time.............        1.0

 Mold closing time.................        1.0

                 Press space bar
```

BDI Figure 11



```
Molding Cost Estimate for: Widget
┌──────────────────────────────────────────────────┐
│          Production Conditions                   │
├──────────────────────────────────────────────────┤
│ Total volume (thousands)..............    1000   │
│                                                  │
│ Number of batches.....................      10   │
│                                                  │
│ Set-up time per batch (hrs)...........     3.0   │
├──────────────────────────────────────────────────┤
│      Elements of Processing Cost (cents)         │
├──────────────────────────────────────────────────┤
│ Base cost per machine cycle...........    41.9   │
│                                                  │
│ Added cost per cycle for:                        │
│                                                  │
│      machine set-up...................     0.7   │
│      other machine stoppages..........     7.4   │
│      reject parts.....................     0.2   │
│                                                  │
│ Total cost per machine cycle..........    50.3   │
│                                                  │
│ Total processing cost per part........    12.6   │
└──────────────────────────────────────────────────┘
                 Press space bar
```

The data and analyses in this appendix are arranged in the following order:

- Shop A
  - Data
  - Histogram
  - Graphs
- Shop B
  - Data
  - Histogram
  - Graphs
- Shop C
  - Data
  - Histogram
  - Graphs
- Q-Q plots for data sets

SHOP A DATA ARRANGED IN ASCENDING JOB ORDER

[illegible]	Hours	[illegible]	Error	[illegible]
1082	155.31	281.50	-44.83	36.72
1088	416.58	418.25	-0.40	33.31
1089	935.29	1057.25	-11.54	17.39
1090	222.07	230.25	-3.55	38.00
1092	181.96	327.75	-44.48	35.57
1093	788.80	754.75	4.51	24.93
1095	123.71	149.25	-17.11	40.02
1097	2811.40	2610.75	7.69	-21.33
1099	53.64	48.50	10.61	42.53
1109	785.53	1193.50	-34.18	13.99
1113	684.76	855.25	-19.94	22.42
1116	111.29	120.00	-7.26	40.75
1131	804.02	775.25	3.71	24.41
1132	978.29	671.75	45.63	26.99
1134	605.73	645.25	-6.12	27.66
1143	443.19	347.75	27.45	35.07
1152	4173.96	1740.00	139.88	0.37
1153	381.84	254.00	50.33	37.41
1154	247.42	295.00	-16.13	36.38
1164	229.20	130.50	75.63	40.48
1165	442.64	426.75	3.72	33.10
1166	661.82	776.50	-14.77	24.38
1176	1410.89	886.25	59.20	21.65
1183	419.09	392.75	6.71	33.95
1185	268.96	238.50	12.77	37.79
1186	339.27	331.00	2.50	35.49
1187	609.00	426.75	42.04	33.[illegible]
1193	198.16	121.75	62.76	40.70
1198	373.42	351.00	6.39	34.99
1199	378.27	514.25	-26.44	30.92
1201	386.56	349.75	10.52	35.22
1210	357.51	353.25	1.21	34.[illegible]
1213	250.69	246.50	1.70	37.59
1215	128.07	77.25	65.78	41.81
1216	96.84	71.50	35.45	41.96
1217	598.62	786.50	-23.89	24.17
1219	559.02	273.50	104.40	36.92
1220	1970.71	1975.00	-0.22	-5.49
1221	14.13	14.00	0.95	43.39
1224	32.91	47.25	-30.35	42.56
1225	239.96	139.25	72.32	40.27
1226	241.60	265.25	-8.92	37.13
1228	512.07	327.00	56.60	35.59
1239	682.67	621.25	9.74	28.13
1240	34.76	30.25	14.97	42.98
1245	698.11	477.75	46.12	31.83
1246	336.29	176.00	91.07	39.35
1251	1223.44	674.25	81.45	26.93
1252	682.53	508.50	34.22	31.06
1253	341.73	54.50	527.03	42.[illegible]
1254	[illegible]	[illegible]	[illegible]	[illegible]

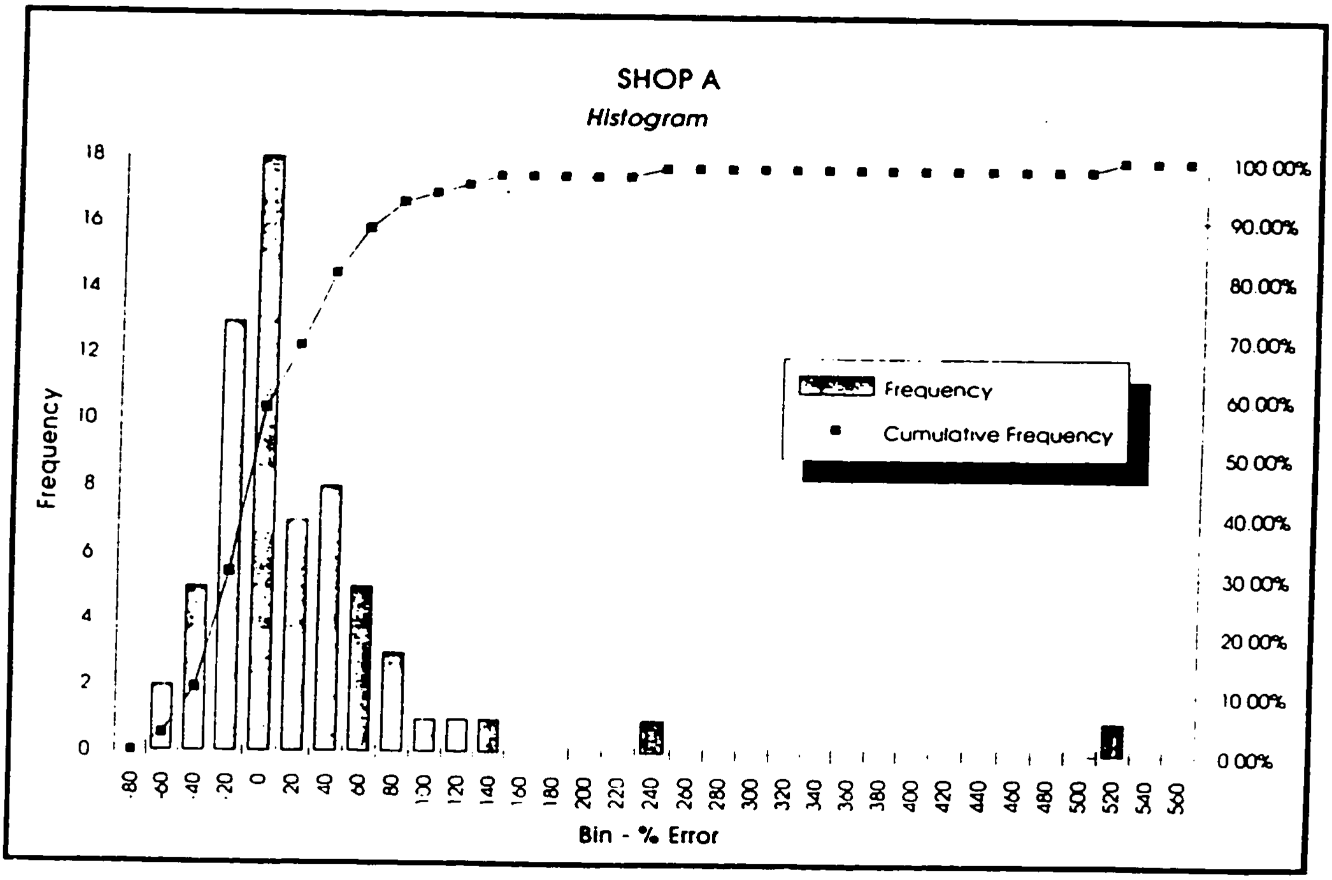
[illegible]	Hours	Hours	Error	[illegible]
1256	889.49	659.50	34.87	27.30
1257	47.22	64.25	-26.50	42.14
1258	83.11	23.75	249.94	43.15
1261	120.13	92.25	30.23	41.44
1265	354.40	197.75	79.22	38.81
1268	163.51	64.50	153.51	42.13
1270	585.71	501.00	16.91	31.25
1275	411.36	399.50	2.97	33.78
1283	295.11	231.25	27.62	37.97
1285	761.42	521.25	46.08	30.75
1292	538.82	526.25	2.39	30.62
1300	124.58	126.00	-1.13	40.60
1303	466.60	255.50	82.62	37.37
1313	146.20	154.50	-5.37	39.89
1314	62.40	43.50	[illegible]	[illegible]

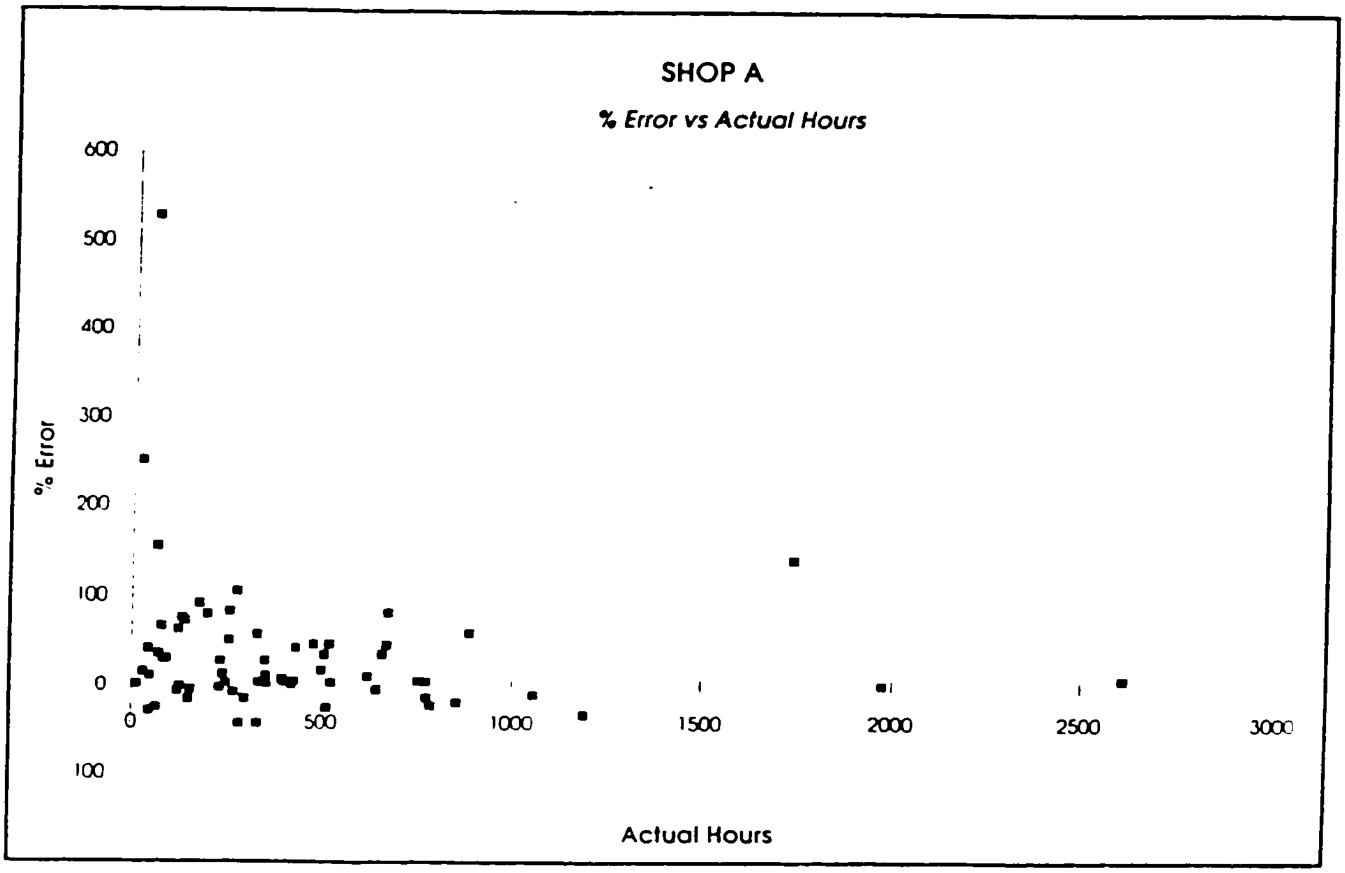
Basic Statistics

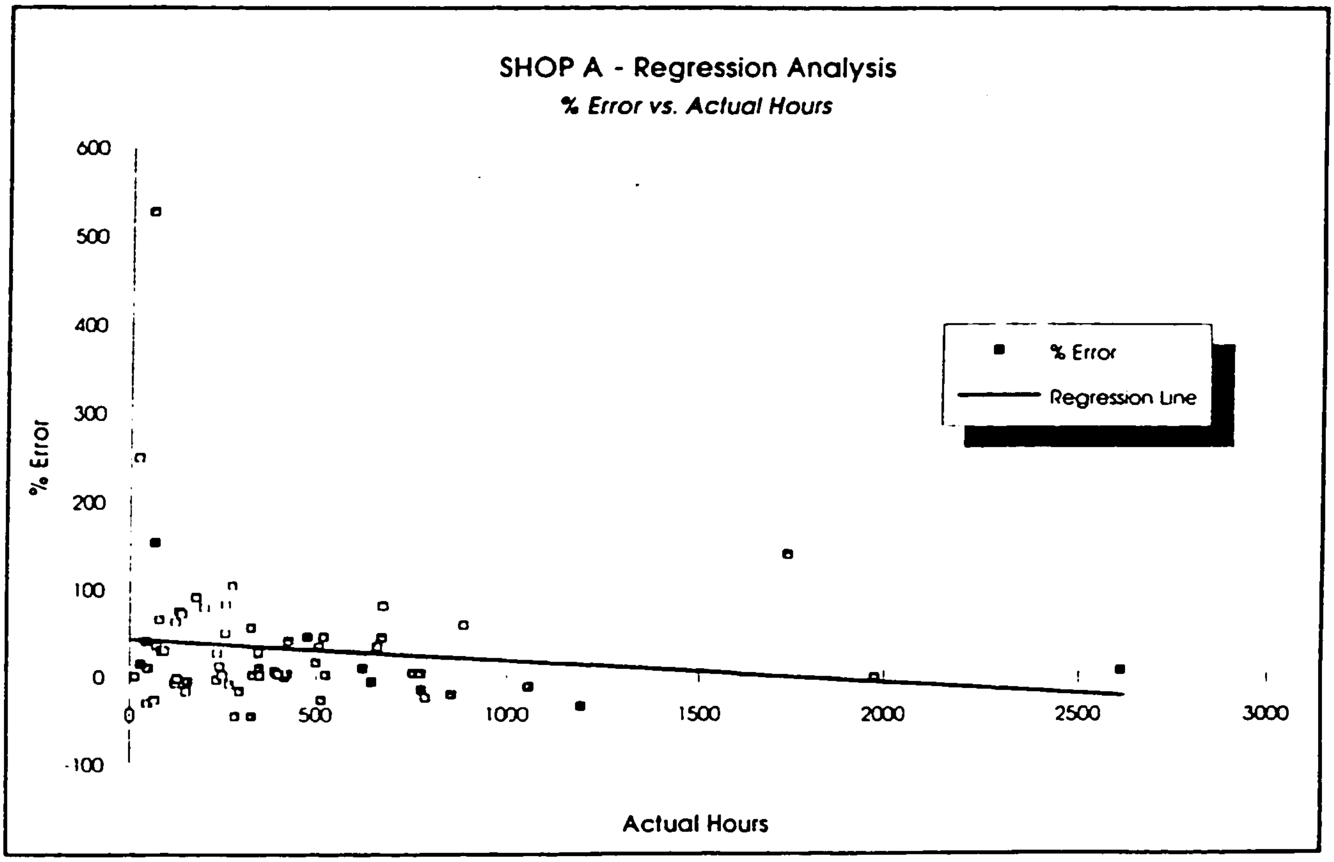
Number of Jobs	66
Mean of % Error	32.67%
Median of % Error	10.13%
Variance of % Error	6262.31%
Standard Deviation of % Error	79.13%

Regression Statistics (% Error vs. Actual Hours)

Multiple R	0.1457
R Square	0.0212
Adjusted R Square	[illegible]
Standard Error	[illegible]


SHOP A
Histogram
Frequency
18
16
14
12
10
8
6
4
2
0
Frequency
Cumulative Frequency
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
-80
-60
-40
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
Bin - % Error


SHOP A
% Error vs Actual Hours
600
500
400
300
200
100
0
100
% Error
0
500
1000
1500
2000
2500
3000
Actual Hours


SHOP A - Regression Analysis
% Error vs. Actual Hours
% Error
600
500
400
300
200
100
0
-100
0
500
1000
1500
2000
2500
3000
Actual Hours
% Error
Regression Line

SHOP B DATA

[illegible]	[illegible]	[illegible]	[illegible]
125.00	92.00	35.87	-1.36
80.00	104.00	-23.08	-4.21
75.00	57.00	31.58	6.94
10.00	7.00	42.86	18.81
50.00	99.00	-49.49	-3.02
95.00	79.00	20.25	1.72
68.00	103.00	-33.98	-3.97
68.00	82.00	-17.07	1.01
75.00	99.00	-24.24	-3.02
75.00	38.00	97.37	11.45
14.00	18.00	-22.22	16.20
22.00	22.00	0.00	15.25
22.00	31.00	-29.03	13.11
5.00	3.50	42.86	19.64
90.00	147.00	-38.78	-14.41
20.00	24.00	-16.67	14.77
135.00	165.00	-18.18	-18.68
80.00	80.00	0.00	1.48
231.00	339.00	-31.86	-59.97
132.00	165.00	-20.00	-18.68
20.00	42.00	-52.38	10.50
42.00	117.00	-64.10	-7.29
95.00	102.00	-6.86	-3.74
54.00	56.00	-3.57	7.18
10.00	8.00	25.00	18.57
60.00	50.00	20.00	8.60
32.00	26.00	23.08	14.30
52.00	34.00	52.94	12.40
21.00	25.00	-16.00	14.54
29.00	16.00	81.25	16.67
95.00	127.00	-25.20	-9.67
15.00	16.00	-6.25	16.67
55.00	21.00	161.90	15.48
43.00	58.00	-25.86	6.71
114.00	163.00	-30.06	-18.21
77.00	113.00	-31.86	-6.35
50.00	71.00	-29.58	3.62
65.00	105.00	-38.10	-4.45
36.00	37.00	-2.70	11.69
24.00	47.00	-48.94	9.32
45.00	11.00	309.09	17.86
200.00	112.00	78.57	-6.11
128.00	110.00	16.36	-5.63
30.00	30.00	0.00	13.35
58.00	63.00	-7.94	5.52
220.00	206.00	6.80	-28.41
64.00	55.00	16.36	7.42
56.00	121.00	-53.72	-8.24
37.00	94.00	-60.64	-1.84
100.00	164.00	-39.02	-18.45
8.00	21.00	-61.90	15.48

[illegible]	[illegible]	[illegible]	[illegible]
180.00	175.00	2.86	-21.06
105.00	177.00	-40.68	-21.53
33.00	39.00	-15.38	11.21
41.00	37.00	10.81	11.69
41.00	26.00	57.69	14.30
55.00	77.00	-28.57	2.20
155.00	365.00	-57.53	-66.14
72.00	51.00	41.18	8.37
140.00	167.00	-16.17	-19.16
360.00	269.00	33.83	-43.36
62.00	90.00	-31.11	-0.89
16.00	19.00	-15.79	15.96
45.00	58.00	-22.41	6.71
135.00	230.00	-41.30	-34.11
118.00	160.00	-26.25	-17.50
23.00	48.00	-52.08	9.08
57.00	95.00	-40.00	-2.07
24.00	22.00	9.09	15.25
55.00	138.00	-60.14	-12.28
91.00	76.00	19.74	2.43
41.00	40.00	2.50	10.98
58.00	48.00	20.83	9.08
57.00	41.00	39.02	10.74
80.00	131.00	-38.93	-10.62
70.00	116.00	-39.66	-7.06
55.00	74.00	-25.68	2.91
74.00	127.00	-41.73	-9.67
28.00	25.00	12.00	14.54
25.00	25.00	0.00	14.54
24.00	23.00	4.35	15.01
172.00	90.00	91.11	-0.89
40.00	38.00	5.26	11.45
256.00	264.00	-3.03	-42.15
159.00	111.00	43.24	-5.87
38.00	34.00	11.76	12.41
45.00	34.00	32.35	12.41
36.00	103.00	-65.05	-3.97
36.00	43.00	-16.28	10.26
43.00	23.00	86.96	15.01
45.00	37.00	21.62	11.64
102.00	81.00	25.93	1.25
60.00	85.00	-29.41	0.30
210.00	267.00	-21.35	-42.54
50.00	38.00	31.58	11.43
180.00	321.00	-43.93	-55.71
42.00	45.00	-6.67	9.79
35.00	33.00	6.06	12.64
30.00	21.00	42.86	15.48
102.00	130.00	-21.54	-10.38
116.00	193.00	-39.90	-25.33
250.00	378.00	-33.86	-52.62

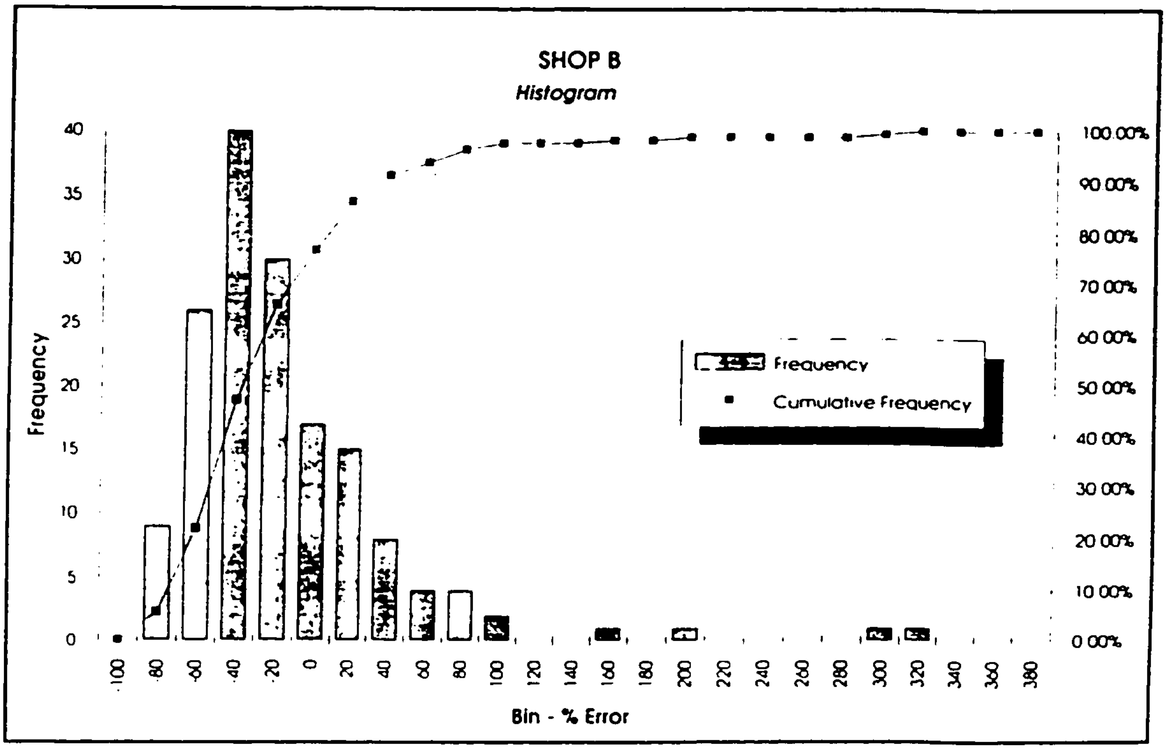
SHOP B DATA

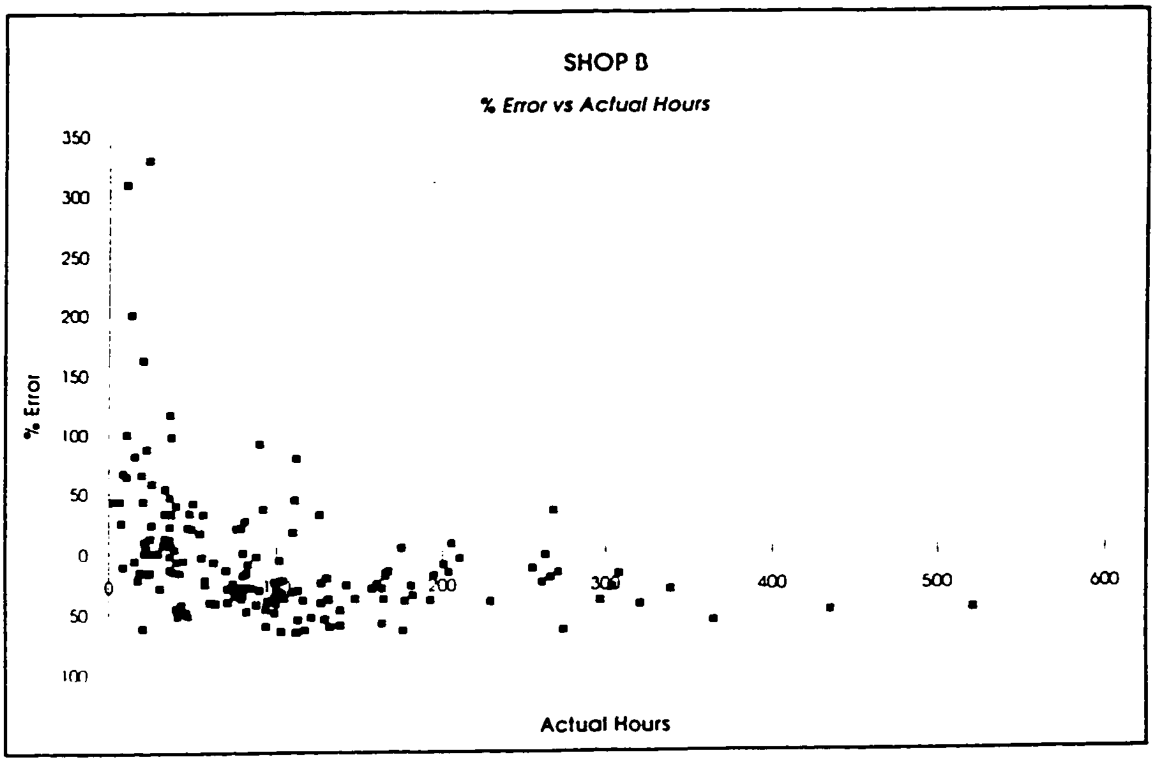
[illegible]	[illegible]	[illegible]	[illegible]
220.00	436.00	-49.54	-82.99
270.00	521.00	-48.18	-103.16
36.00	61.00	-40.98	5.99
157.00	195.00	-19.49	-25.80
25.00	44.00	-43.18	10.03
62.00	99.00	-37.37	-3.02
58.00	100.00	-42.00	-3.26
38.00	41.00	-7.32	10.74
50.00	113.00	-55.75	-6.35
70.00	100.00	-30.00	-3.26
65.00	80.00	-18.75	1.48
170.00	204.00	-16.67	-27.94
195.00	262.00	-25.57	-41.70
8.00	9.00	-11.11	18.33
130.00	181.00	-28.18	-22.48
110.00	157.00	-29.94	-16.79
220.00	256.00	-14.06	-40.28
75.00	83.00	-9.64	0.77
103.00	24.00	329.17	14.77
22.00	41.00	-46.34	10.74
67.00	163.00	-58.90	-18.21
51.00	132.00	-61.36	-10.85
48.00	75.00	-36.00	2.67
53.00	75.00	-29.33	2.67
58.00	129.00	-55.04	-10.14
98.00	275.00	-64.36	-44.79
54.00	37.00	45.95	11.69
42.00	71.00	-40.85	3.62
85.00	88.00	-3.41	-0.41
165.00	126.00	30.95	-9.43
52.00	80.00	-35.00	1.48
22.00	11.00	100.00	17.86
72.00	138.00	-47.83	-12.28
62.00	176.00	-64.77	-21.29
42.00	82.00	-48.78	1.01
65.00	49.00	32.65	8.84
58.00	81.00	-28.40	1.25
60.00	70.00	-14.29	3.86
74.00	110.00	-32.73	-5.63
37.00	64.00	-42.19	5.28
32.00	37.00	-13.51	11.69
80.00	37.00	116.22	11.69
103.00	142.00	-27.46	-13.23
117.00	182.00	-35.71	-22.72
225.00	272.00	-17.28	-44.07
15.00	9.00	66.67	18.33
49.00	79.00	-37.97	1.72
33.00	20.00	65.00	15.72
18.00	11.00	63.64	17.86
50.00	88.00	-43.18	-0.41

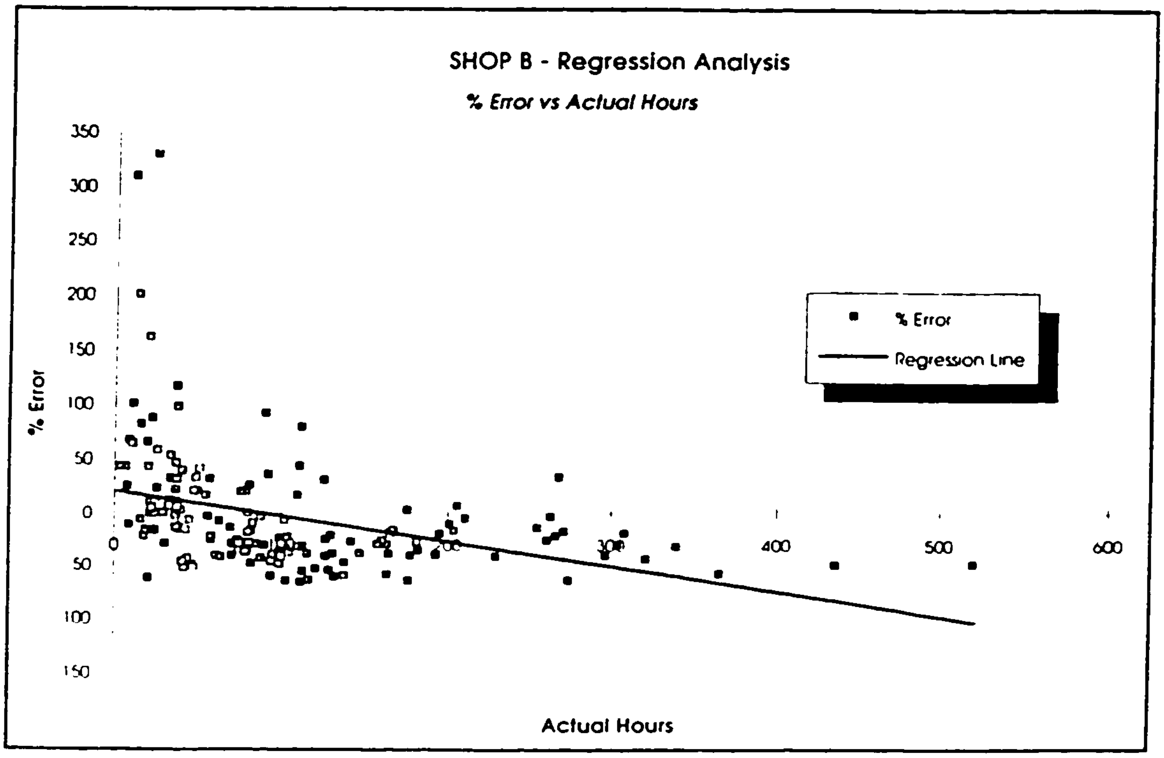
[illegible]	[illegible]	[illegible]	[illegible]
50.00	94.00	-46.81	-1.84
42.00	14.00	200.00	17.15
180.00	201.00	-10.45	-27.23
176.00	297.00	-40.74	-50.01
200.00	211.00	-5.21	-29.60
213.00	304.00	-29.93	-51.67
38.00	112.00	-66.07	-6.11

Basic Statistics	
Number of Jobs	159
Mean of % Error	-4.29%%
Median of % Error	-18.18%
Variance of % Error	3254.04%
Standard Deviation of % Error	57.04%

Regression Statistics (% Error vs. Actual Hours)	
Multiple R	0.3721
R Square	0.1384
Adjusted R Square	0.1329
Standard Error	53.063


SHOP B
Histogram
Frequency
40
35
30
25
20
15
10
5
0
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Frequency
Cumulative Frequency
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
Bin - % Error


SHOP B
% Error vs Actual Hours
% Error
350
300
250
200
150
100
50
0
50
100
0
200
300
400
500
600
Actual Hours


SHOP B - Regression Analysis
% Error vs Actual Hours
350
300
250
200
150
100
50
0
50
100
150
% Error
0
100
200
300
400
500
600
Actual Hours
% Error
Regression Line

SHOP C Data in Chronological Order

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mar-85	22407.00	21900.00	-2.26	0.83
Jun-85	40476.00	4990.00	-87.67	8.91
Oct-85	40238.00	44990.00	11.81	-11.25
Dec-85	10921.00	6755.00	-38.15	8.62
Feb-86	5750.00	5319.00	-7.50	12.11
Jul-86	7373.00	5435.00	-26.29	11.01
Oct-86	3186.00	2890.00	-9.29	13.84
Dec-86	4913.00	5950.00	21.11	12.68
May-87	18272.00	17785.00	-2.67	3.63
Oct-87	49915.00	51800.00	3.78	-17.80
Oct-87	4410.00	4415.00	0.11	13.02
Oct-87	6609.00	8950.00	35.42	11.53
Jan-88	7749.00	6800.00	-12.25	10.75
Apr-88	9335.00	6835.00	-26.78	9.68
Aug-88	16757.00	15725.00	-6.16	4.65
Sep-88	25980.00	26900.00	3.54	-1.59
Nov-88	12338.00	20780.00	68.42	7.65
Dec-88	17837.00	22800.00	27.82	3.92
Dec-88	6751.00	8350.00	23.69	11.43
Dec-88	15893.00	10495.00	-34.03	5.24
Dec-88	18471.00	20100.00	8.82	3.49
Jan-89	7056.00	8600.00	21.88	11.22
Feb-89	11826.00	9705.00	-17.94	7.99
Mar-89	9748.00	12000.00	23.10	9.40
Mar-89	42722.00	46900.00	9.78	-12.93
May-89	10182.00	18275.00	79.48	9.11
May-89	7600.00	9735.00	28.09	10.86
May-89	24325.00	17360.00	-28.63	-0.47
May-89	13200.00	13200.00	0.00	7.06
Jun-89	13870.00	21200.00	52.85	6.61
Jun-89	22512.00	21200.00	-5.83	0.76
Jun-89	8337.00	8250.00	-1.04	10.36
Jun-89	11362.00	14900.00	31.14	8.31
Jun-89	11813.00	16100.00	36.29	8.00
Aug-89	11174.00	10575.00	-5.36	8.44
Sep-89	36746.00	21660.00	-41.05	-8.88
Sep-89	13023.00	14395.00	10.54	7.18
Nov-89	25919.00	22425.00	-13.48	-1.55
Nov-89	7367.00	6450.00	14.70	11.01
Nov-89	19471.00	18500.00	-4.99	2.82
Dec-89	10922.00	13095.00	19.90	8.61
Jan-90	5427.00	4720.00	-13.03	12.33
Feb-90	29716.00	21895.00	-26.32	-4.12
Apr-90	19518.00	14875.00	-23.79	2.78
May-90	10210.00	12875.00	26.10	9.09
Jun-90	30522.00	20000.00	-34.47	-4.67
Jun-90	14173.00	20100.00	41.82	6.40
Jun-90	30522.00	26000.00	-14.82	-4.67
Aug-90	7309.00	9225.00	26.21	11.05
Nov-90	9040.00	9500.00	5.09	9.88
Nov-90	13196.00	12125.00	-8.12	7.07

SHOP C Data in Chronological Order

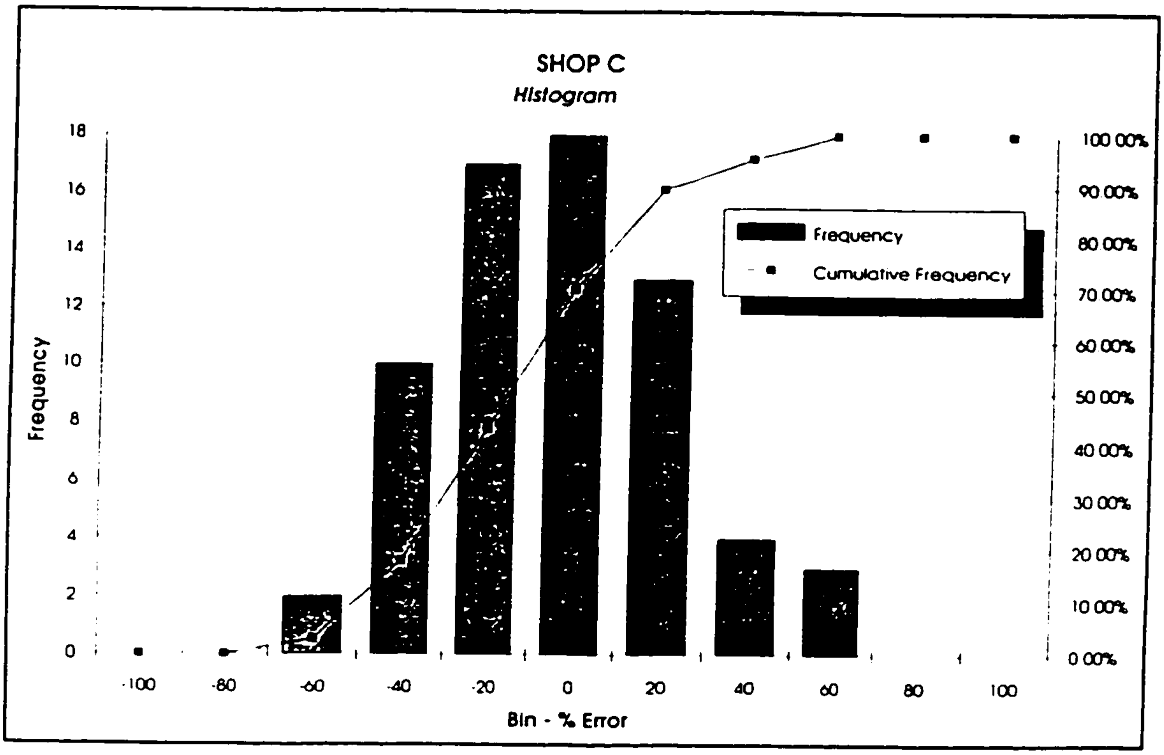
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dec-90	11440.00	11772.00	2.90	8.26
Dec-90	13800.00	13850.00	0.36	6.66
Jan-91	13210.00	10100.00	-23.54	7.06
Jan-91	6213.00	8950.00	44.05	11.79
Jan-91	14808.00	14950.00	0.96	5.97
Feb-91	12228.00	15818.00	29.36	7.72
Feb-91	17360.00	16750.00	-3.51	4.25
Feb-91	9985.00	11500.00	15.17	9.24
Mar-91	19886.00	32600.00	63.93	2.54
Jul-91	15179.00	16235.00	6.96	5.72
Jul-91	19430.00	23500.00	20.95	2.84
Aug-91	8680.00	8000.00	-7.83	10.12
Oct-91	9848.00	14985.00	52.16	9.33
Oct-91	23252.00	24600.00	5.80	0.26
Dec-91	30711.00	23200.00	-24.46	-4.79
Mar-92	9909.00	10850.00	9.50	9.29

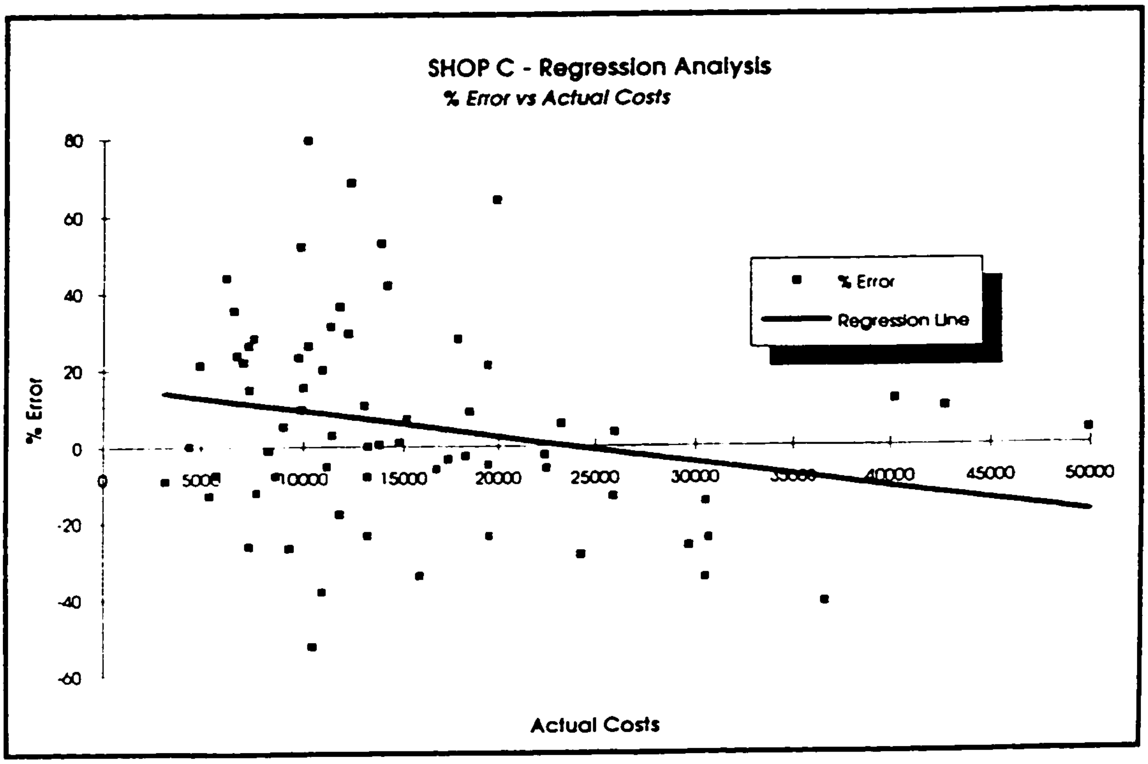
Basic Statistics

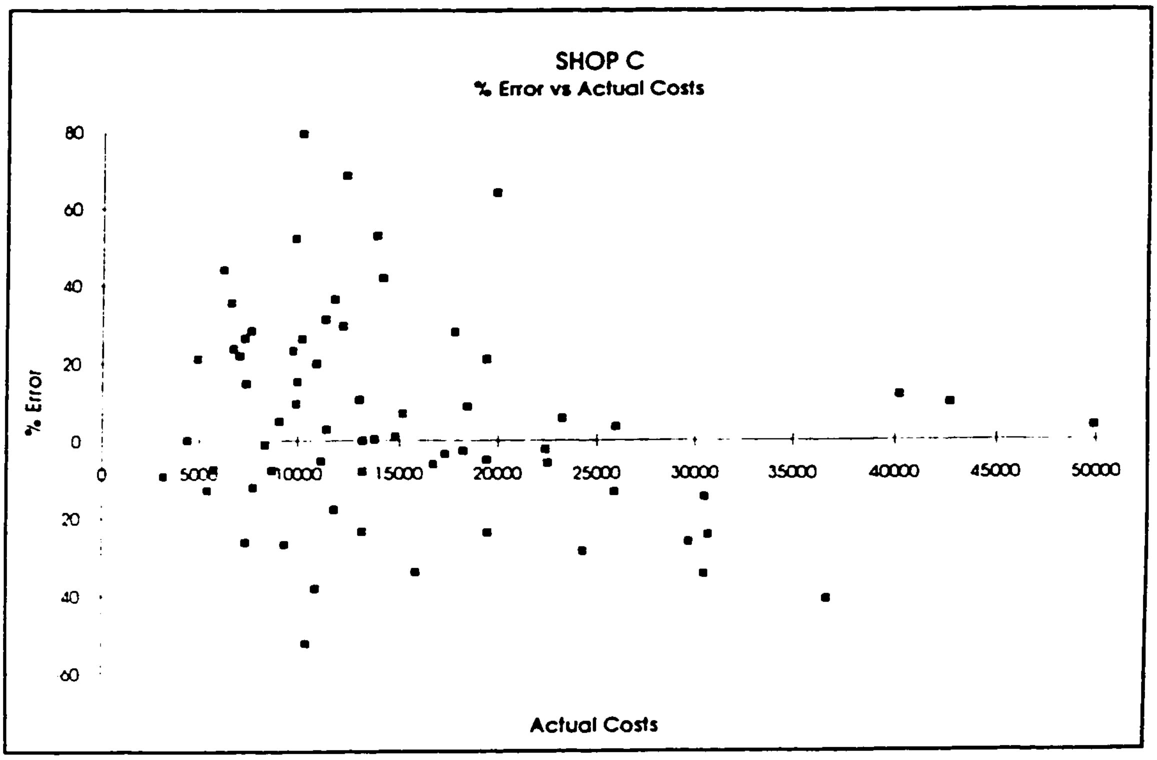
Number of Jobs	67
Mean of % Error	5.49%
Median of % Error	2.90%
Variance of % Error	725.72%
Standard Deviation of % Error	26.94%

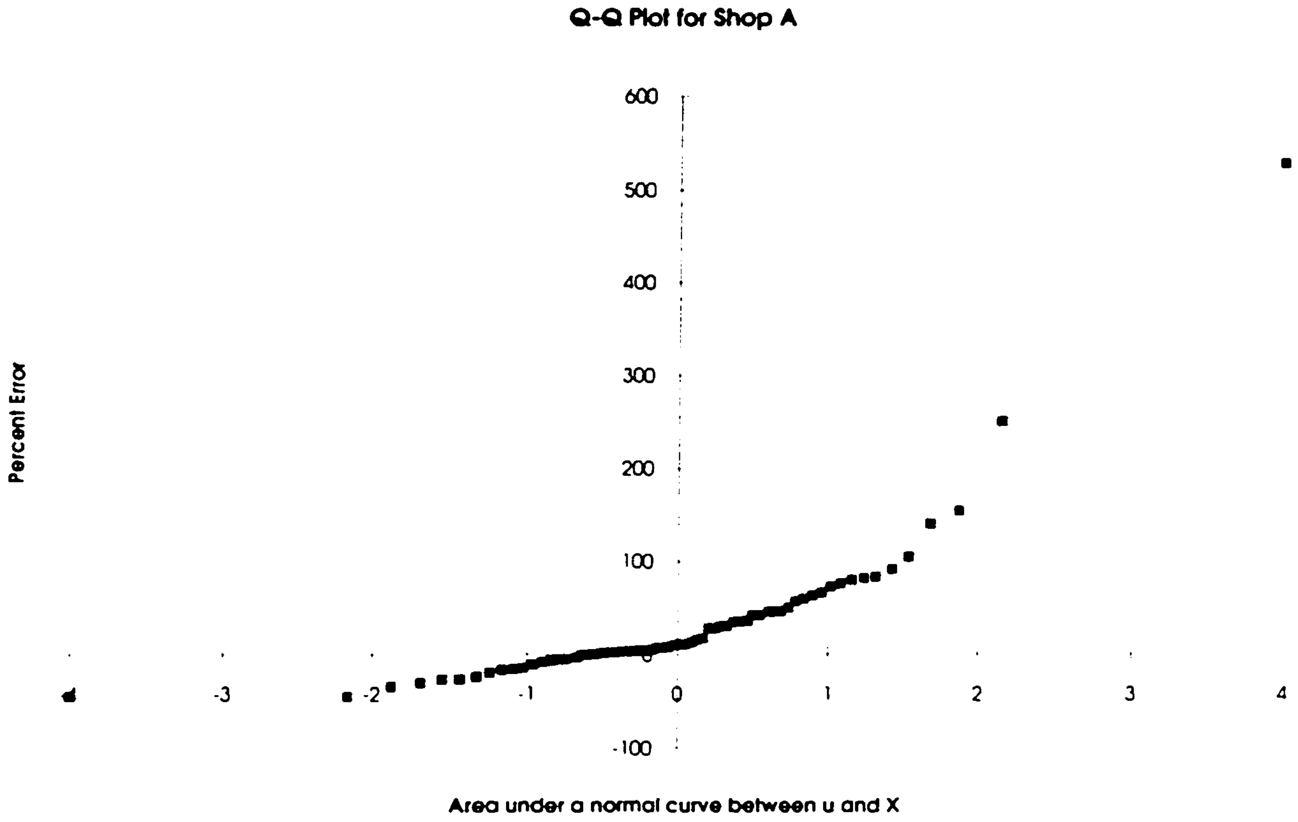
Regression Statistics
(% Error vs. Actual Hours)

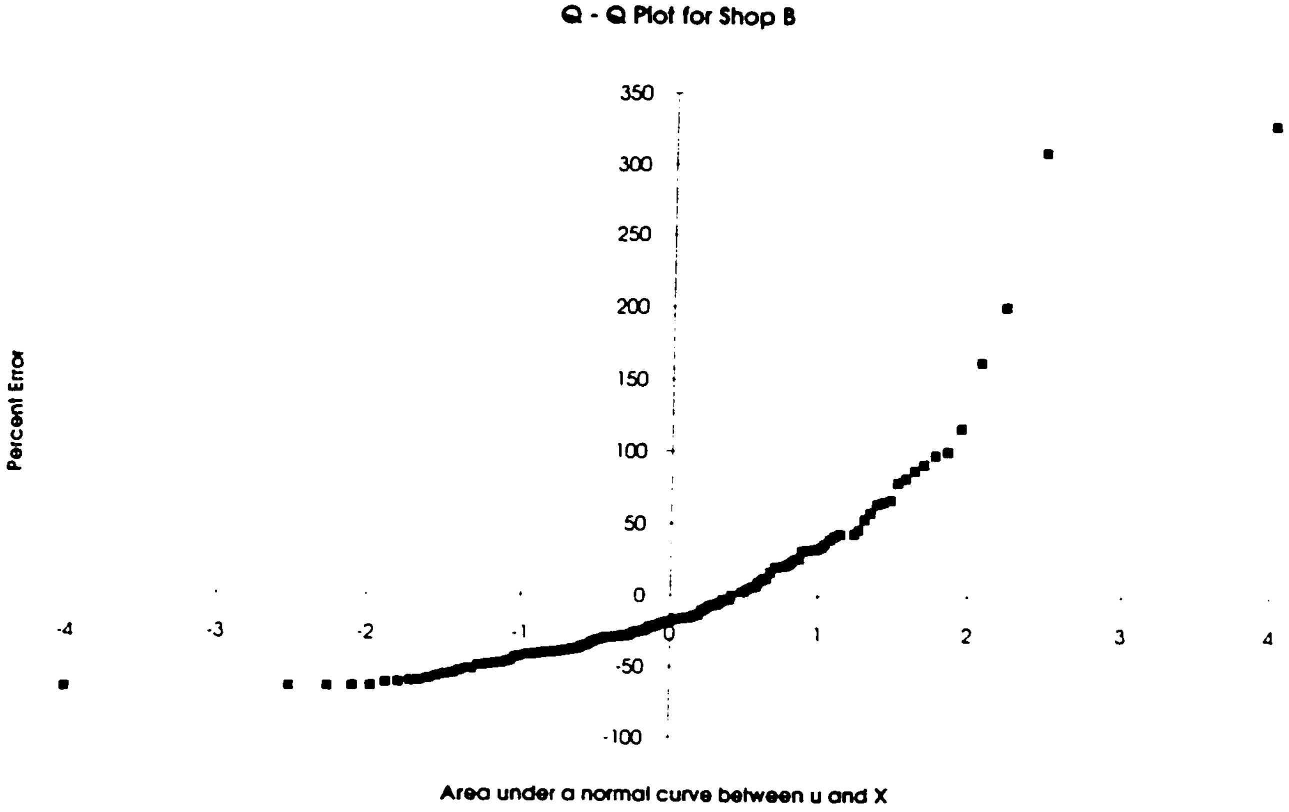
Multiple R	0.2436
R Square	0.0593
Adjusted R Square	0.0448
Standard Error	26.328

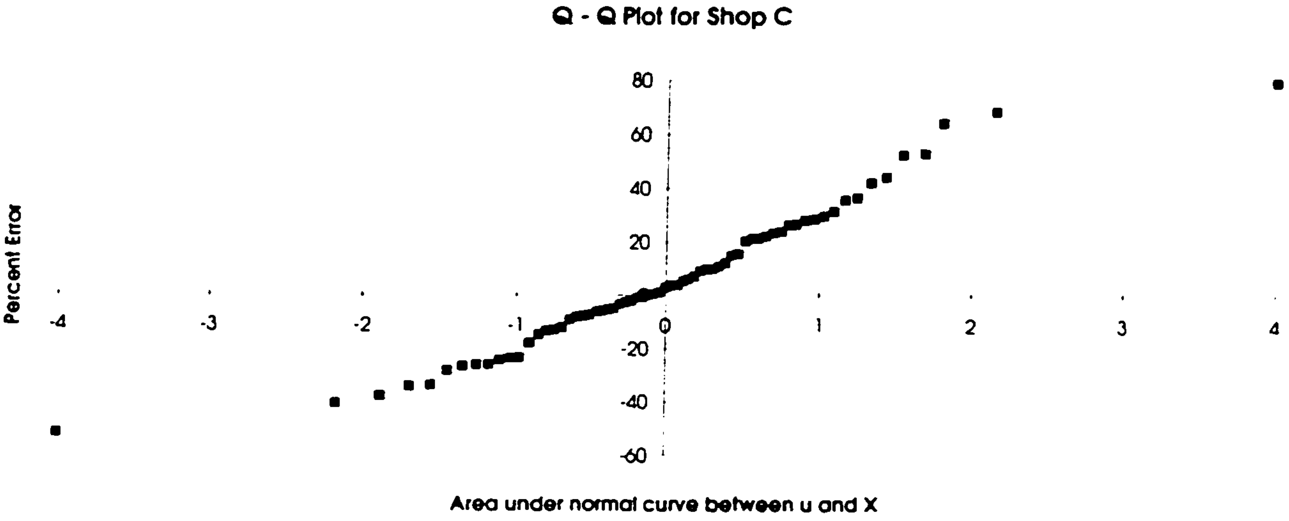

SHOP C
Histogram
Frequency
18
16
14
12
10
8
6
4
2
0
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Frequency
Cumulative Frequency
-100
-80
-60
-40
-20
0
20
40
60
80
100
Bin - % Error


SHOP C - Regression Analysis
% Error vs Actual Costs
% Error
80
60
40
20
0
-20
-40
-60
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
% Error
Regression Line
Actual Costs


SHOP C
% Error vs Actual Costs
% Error
80
60
40
20
0
20
40
60
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Actual Costs


Q-Q Plot for Shop A
600
500
400
300
200
100
0
-100
Percent Error
-4
-3
-2
-1
0
1
2
3
4
Area under a normal curve between u and X


Q - Q Plot for Shop B
350
300
250
200
150
100
50
0
-50
-100
-4
-3
-2
-1
0
1
2
3
4
Percent Error
Area under a normal curve between u and X

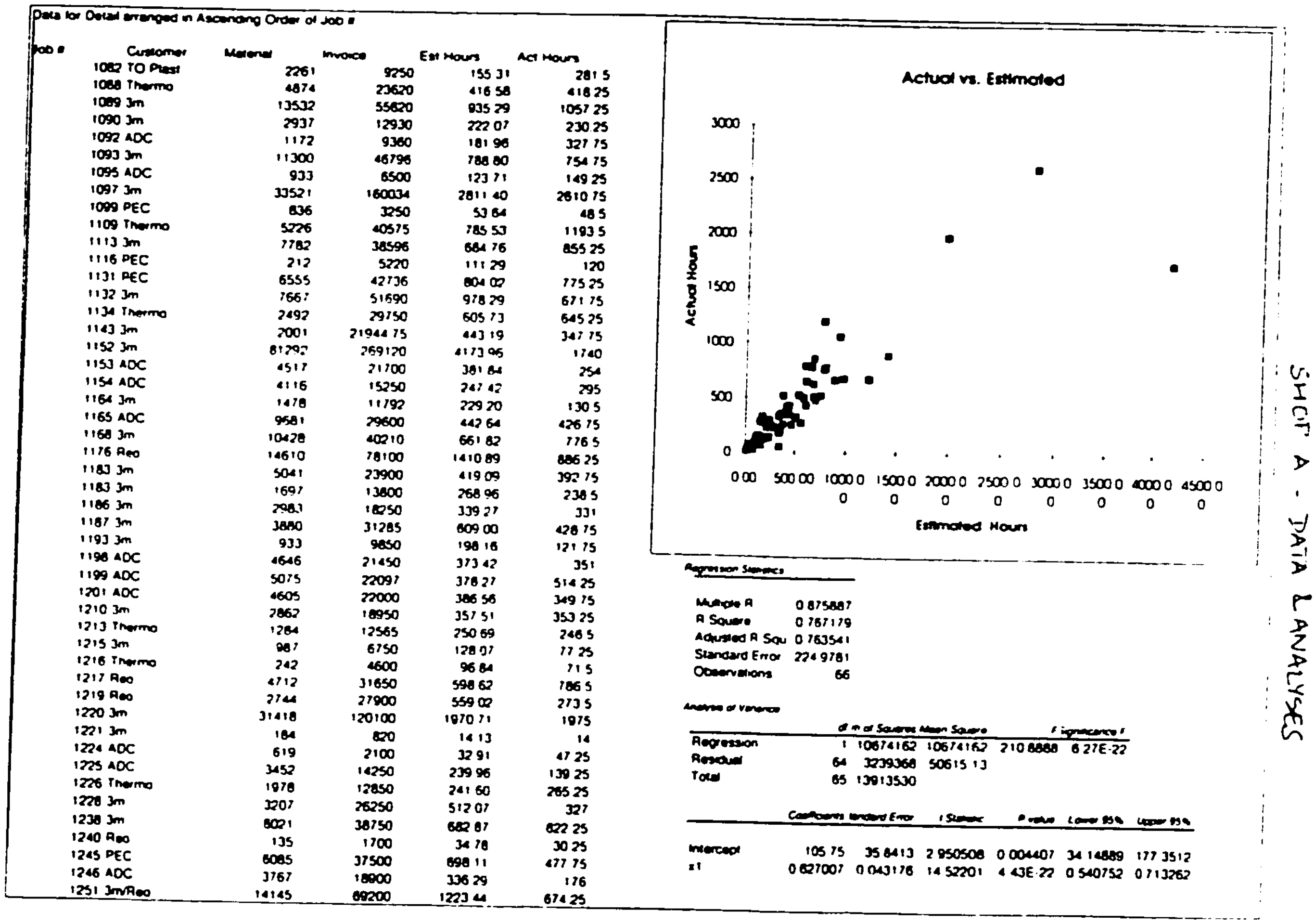

Q - Q Plot for Shop C
Percent Error
80
60
40
20
-20
-40
-60
-4
-3
-2
-1
0
1
2
3
4
Area under normal curve between u and X

The data and analyses in this appendix are arranged in the following order:

Shop A Data, Graphs and Results

Shop B Data, Graphs and Results

Shop C Data, Graphs and Results



Data for Detail arranged in Ascending Order of Job #

Job #	Customer	Material	Invoice	Est Hours	Act Hours
1082	TO Plast	2261	9250	155 31	281 5
1088	Thermo	4874	23620	416 58	418 25
1089	3m	13532	55820	935 29	1057 25
1090	3m	2937	12930	222 07	230 25
1092	ADC	1172	9360	181 96	327 75
1093	3m	11300	46796	788 80	754 75
1095	ADC	933	6500	123 71	149 25
1097	3m	33521	160034	2811 40	2810 75
1099	PEC	836	3250	53 64	48 5
1109	Thermo	5226	40575	785 53	1193 5
1113	3m	7782	38596	684 76	855 25
1116	PEC	212	5220	111 29	120
1131	PEC	6555	42736	804 02	775 25
1132	3m	7667	51690	978 29	671 75
1134	Thermo	2492	29750	605 73	645 25
1143	3m	2001	21944 75	443 19	347 75
1152	3m	81292	269120	4173 96	1740
1153	ADC	4517	21700	381 84	254
1154	ADC	4116	15250	247 42	295
1164	3m	1478	11792	229 20	130 5
1165	ADC	9581	29600	442 64	426 75
1168	3m	10428	40210	661 82	776 5
1176	Reo	14610	78100	1410 89	886 25
1183	3m	5041	23900	419 09	392 75
1183	3m	1697	13800	268 96	238 5
1186	3m	2983	18250	339 27	331
1187	3m	3880	31285	609 00	428 75
1193	3m	933	9850	198 16	121 75
1198	ADC	4646	21450	373 42	351
1199	ADC	5075	22097	378 27	514 25
1201	ADC	4605	22000	386 56	349 75
1210	3m	7862	18950	357 51	353 25
1213	Thermo	1284	12565	250 69	246 5
1215	3m	987	6750	128 07	77 25
1216	Thermo	242	4600	96 84	71 5
1217	Reo	4712	31650	598 62	786 5
1219	Reo	2744	27900	559 02	273 5
1220	3m	31418	120100	1970 71	1975
1221	3m	184	820	14 13	14
1224	ADC	619	2100	32 91	47 25
1225	ADC	3452	14250	239 96	139 25
1226	Thermo	1978	12850	241 60	265 25
1228	3m	3207	26250	512 07	327
1238	3m	8021	38750	682 87	822 25
1240	Reo	135	1700	34 78	30 25
1245	PEC	6085	37500	698 11	477 75
1246	ADC	3767	18900	336 29	176
1251	3m/Reo	14145	69200	1223 44	674 25

Regression Statistics

Multiple R	0 875887
R Square	0 767179
Adjusted R Squ	0 763541
Standard Error	224 9781
Observations	66

Analysis of Variance

	df	m of Squares	Mean Square	F	Significance F
Regression	1	10674162	10674162	210 8888	6 27E-22
Residual	64	3239368	50615 13		
Total	65	13913530			

	Coefficients	tandard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	105 75	35 8413	2 950508	0 004407	34 14889	177 3512
x1	0 627007	0 043176	14 52201	4 43E-22	0 540752	0 713262

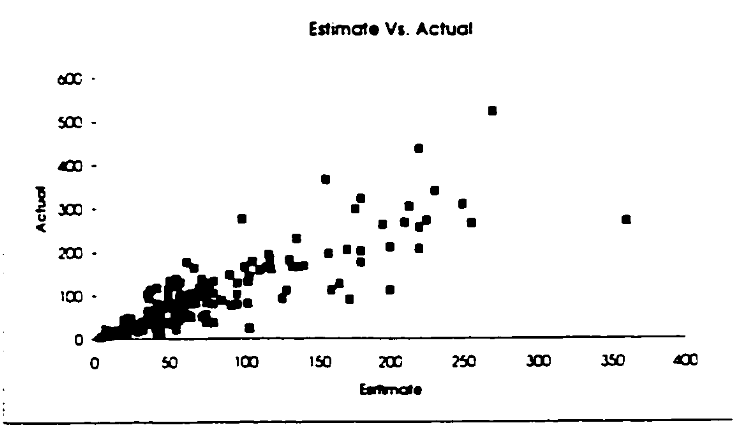
SHOP A - DATA & ANALYSES

1252 3m	5536	36250	682 53	508 5
1253 3m	212	15590	341 73	54 5
1254 3m	706	5552	107 69	83
1256 ADC	9873	49900	889 49	659 5
1257 ADC	14125	16250	47 22	64 25
1258 ADC	11760	15500	83 11	23 75
1261 3m	1889	7295	120 13	92 25
1265 ADC	6302	22250	354 40	197 75
1268 ADC	2142	9500	163 51	64 5
1270 3m	3393	29750	585 71	501
1275 ADC	5989	24500	411 36	399 5
1283 3m	970	14250	295 11	231 25
1285 Unisys	10236	44500	761 42	521 25
1292 ADC	11308	35555	538 82	526 25
1300 3m	194	5800	124 58	126
1303 3m	2643	23640	466 60	255 5
1313 Reo/PH	921	7500	146 20	154 5
1314 PEC	917	3680	61 40	43 5

SHOPA (Contd)

SHOP B DATA & ANALYSES

Estimated	Actual Hours
125	92
80	104
75	57
10	7
50	99
95	79
68	103
68	82
75	99
75	38
14	18
22	22
22	31
5	3 5
90	147
20	24
135	165
80	80
231	339
132	165
20	42
42	117
95	102
54	56
10	8
60	50
32	26
52	34
21	25
29	16
95	127
15	16
55	21
43	58
114	163
77	113
50	71
65	106
36	37
24	47
45	11
200	112
128	110
30	30
58	63
220	206
64	55
56	121
37	94
100	164
8	21
180	175
105	177
33	39
41	37
41	26
55	77
155	365
72	51
140	167
360	269
62	90
16	19
45	58



Regression Statistics

Multiple R	0 848788
R Square	0 720442
Adjusted I	0 718661
Standard	33 62713
Observati	159

Analysis of Variance

	df	um of Squares	ean Square	F	ignificance F
Regression	1	457515 3	457515 3	404 6002	2 64E-45
Residual	157	177533 1	1130 784		
Total	158	635048 4			

	Coefficients	tandard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	18 06477	4 079095	4 428622	1 76E-06	10 00778	26 12176
x1	0 602208	0 029939	20 11468	2E-45	0 543074	0 661343

SHOP B (contd)

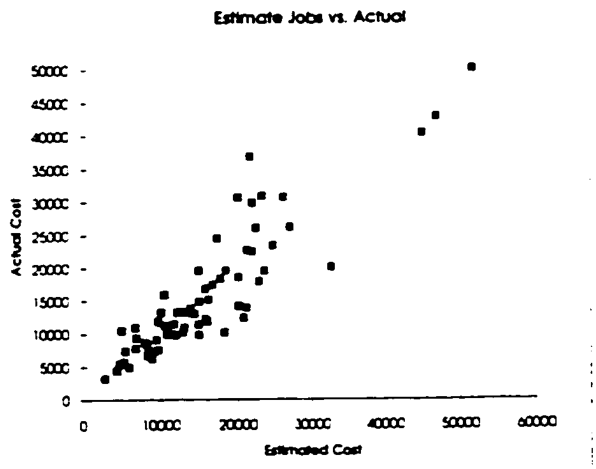
135	230
118	160
23	48
57	95
24	22
55	138
91	70
41	40
58	48
57	41
80	131
70	116
55	74
74	127
28	25
25	25
24	23
172	90
40	38
256	264
159	111
38	34
45	34
36	103
36	43
43	23
45	37
102	81
60	85
210	207
50	38
180	321
42	45
35	33
30	21
102	130
116	193
250	308
220	436
270	521
36	61
157	195
25	44
62	90
58	100
38	41
50	113
70	100
65	80
170	204
195	262
8	9
130	181
110	157
220	256
75	83
103	24
22	41
67	163
51	132
48	75
53	75
58	129
98	275
54	37

SHOP B (contd)

42	71
85	88
165	126
52	80
22	11
72	138
62	176
42	82
65	49
58	81
60	70
74	110
37	64
32	37
80	37
103	142
117	182
225	272
15	9
49	79
33	20
18	11
50	88
50	94
42	14
180	201
176	297
200	211
213	304
38	112

SHCPC DATA & ANALYSES

Date	# of Cov	Act Die	Est Die
Oct-87	14	49915	51800
Mar-89	8	42722	46900
Oct-85	14	40238	44990
Sep-89	8	36746	21660
Dec-91	8	30711	23200
Jun-90	4	30522	20000
Jun-90	4	30522	26000
Feb-90	8	29716	21895
Sep-88	16	25980	26900
Nov-89	8	25919	22425
May-89	8	24325	17360
Oct-91	4	23252	24600
Jun-89	6	22512	21200
Mar-85	10	22407	21900
Mar-91	4	19686	32600
Apr-90	10	19518	14875
Nov-89	8	19471	18500
Jul-91	4	19430	23500
Dec-88	8	18471	20100
May-87	8	18272	17785
Dec-88	8	17837	22800
Feb-91	4	17360	16750
Aug-88	6	16757	15725
Dec-88	4	15893	10485
Jul-91	4	15179	16235
Jan-91	1	14808	14950
Jun-91	4	14173	20100
Jun-89	6	13870	21200
Dec-90	2	13800	13850
Jan-91	2	13210	10100
May-89	4	13200	13200
Nov-90	2	13196	12125
Sep-89	4	13023	14395
Nov-88	4	12338	20780
Feb-9	1	12228	15815
Feb-89	1	11826	9705
Jun-89	4	11813	16100
Dec-90	2	11440	11772
Jun-89	10	11362	14900
Aug-89	4	11174	10575
Dec-89	1	10922	13095
Dec-85	1	10921	6755
Jun-85	1	10476	4990
May-90	2	10210	12875
May-89	2	10182	18275
Feb-91	1	9985	11500
Mar-92	1	9909	10850
Oct-9	4	9848	14985
Mar-89	2	9748	12000
Apr-88	1	9335	6835
Nov-90	4	9040	9500
Aug-9	2	8680	8000
Jun-89	2	8337	8250
Jan-88	4	7749	6800
May-89	8	7600	9735
Jul-86	1	7373	5435
Nov-89	4	7367	8450
Aug-90	1	7309	9225
Jan-89	1	7056	8600
Dec-88	1	6751	8350
Oct-87	1	6609	8950
Jan-91	2	6213	8950
Feb-86	1	5750	5319
Jan-90	1	5427	4720
Dec-86	1	4913	5950
Oct-87	2	4410	4415
Oct-86	2	3186	2890



Regression Statistics

Multiple R	0 896554
R Square	0 80381
Adjusted I	0 800791
Standard	4324 645
Observation	67

Analysis of Variance

	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	4 98E+09	4 98E+09	266 3	1 13E-24
Residual	65	1 22E+09	18702552		
Total	66	6 2E+09			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	1182 232	1025 597	1 152726	0 253181	-866 026	3230 49
x1	0 910623	0 065801	16 31904	7 43E 25	0 799181	1 022066

The data and analyses in this appendix are arranged in the following order:

- Shop C referred to as Shop A in this section
  - Data
  - Histogram
  - Graphs

- Shop D referred to as Shop A in this section
  - Data
  - Histogram
  - Graphs

- Combined
  - Data
  - Histogram
  - Graphs

- Q-Q plots for data sets

SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jan-84	260.00	255.00	-1.92	-8.82
Jan-84	300.00	300.00	0.00	-12.72
Jan-84	325.00	325.00	0.00	-15.15
Mar-84	267.00	276.00	3.37	-9.51
May-84	260.00	255.00	-1.92	-8.82
May-84	225.00	400.00	77.78	-5.42
May-84	305.00	200.00	-34.43	-13.20
Sep-84	82.00	150.00	82.93	6.49
Sep-84	327.00	325.00	-0.61	-15.34
Oct-84	240.00	240.00	0.00	-6.88
Nov-84	275.00	275.00	0.00	-10.28
Nov-84	80.00	80.00	0.00	8.68
Nov-84	225.00	140.00	-37.78	-5.42
Dec-84	180.00	180.00	0.00	-1.04
Jan-85	425.00	200.00	-52.94	-24.88
Feb-85	380.00	255.00	-32.89	-20.50
Feb-85	225.00	225.00	0.00	-5.42
Feb-85	350.00	350.00	0.00	-17.58
Mar-85	600.00	325.00	-45.83	-41.90
Mar-85	555.00	300.00	-45.95	-37.52
Apr-85	255.00	240.00	-5.88	-8.34
Apr-85	257.00	240.00	-6.61	-8.53
May-85	50.00	92.00	84.00	11.60
Jun-85	150.00	130.00	-13.33	1.88
Jun-85	215.00	200.00	-6.98	-4.45
Jul-85	135.00	135.00	0.00	3.33
Sep-85	220.00	160.00	-27.27	-4.93
Oct-85	156.00	160.00	2.56	1.29
Oct-85	428.00	275.00	-35.75	-25.17
Oct-85	410.00	350.00	-14.63	-23.42
Nov-85	90.00	155.00	72.22	7.71
Nov-85	240.00	200.00	-16.67	-6.88
Dec-85	400.00	255.00	-36.25	-22.44
Dec-85	230.00	160.00	-30.43	-5.91
Jan-86	265.00	240.00	-9.43	-9.31
Jan-86	400.00	275.00	-31.25	-22.44
Jan-86	210.00	225.00	7.14	-3.96
Feb-86	250.00	300.00	20.00	-7.85
Feb-86	165.00	255.00	54.55	0.42
Feb-86	276.00	225.00	-18.48	-10.38
Feb-86	554.00	450.00	-18.77	-37.42
Mar-86	200.00	210.00	5.00	-2.99
Mar-86	140.00	125.00	-10.71	2.85
Mar-86	260.00	255.00	-1.92	-8.82
Mar-86	210.00	200.00	-4.76	-3.96

SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mar-86	125.00	125.00	0.00	4.31
Apr-86	250.00	305.00	22.00	-7.85
Apr-86	420.00	275.00	-34.52	-24.39
Apr-86	600.00	350.00	-41.67	-41.90
Apr-86	450.00	450.00	0.00	-27.31
Apr-86	650.00	450.00	-30.77	-46.76
May-86	100.00	100.00	0.00	6.74
May-86	537.00	200.00	-62.76	-35.77
May-86	195.00	185.00	-5.13	-2.50
May-86	57.00	120.00	110.53	10.92
May-86	212.00	160.00	-24.53	-4.16
May-86	330.00	325.00	-1.52	-15.63
Jun-86	288.00	240.00	-16.67	-11.55
Jul-86	232.00	190.00	-18.10	-6.10
Jul-86	125.00	125.00	0.00	4.31
Jul-86	462.00	450.00	-2.60	-28.47
Aug-86	425.00	300.00	-29.41	-24.88
Sep-86	330.00	200.00	-39.39	-15.63
Oct-86	450.00	325.00	-27.78	-27.31
Oct-86	186.00	40.00	-78.49	-1.63
Oct-86	632.00	600.00	-5.06	-45.01
Nov-86	400.00	90.00	-77.50	-22.44
Dec-86	636.00	360.00	-43.40	-45.40
Dec-86	225.00	200.00	-11.11	-5.42
Feb-87	145.00	135.00	-6.90	2.36
Feb-87	225.00	300.00	33.33	-5.42
Mar-87	425.00	225.00	-47.06	-24.88
Mar-87	350.00	180.00	-48.57	-17.58
Mar-87	80.00	60.00	-25.00	8.68
Mar-87	600.00	225.00	-62.50	-41.90
Apr-87	600.00	180.00	-70.00	-41.90
Apr-87	240.00	200.00	-16.67	-6.88
Apr-87	480.00	300.00	-37.50	-30.23
Apr-87	240.00	210.00	-12.50	-6.88
Apr-87	257.00	225.00	-12.45	-8.53
May-87	257.00	325.00	26.46	-8.53
May-87	360.00	180.00	-50.00	-18.55
May-87	514.00	150.00	-70.82	-33.53
May-87	434.00	300.00	-30.88	-25.75
May-87	450.00	400.00	-11.11	-27.31
Jun-87	450.00	180.00	-60.00	-27.31
Jun-87	360.00	360.00	0.00	-18.55
Jul-87	189.00	180.00	-4.76	-1.92
Jul-87	360.00	275.00	-23.61	-18.55
Jul-87	120.00	85.00	-29.17	4.79

SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Aug-87	360.00	225.00	-37.50	-18.55
Sep-87	313.00	255.00	-18.53	-13.98
Sep-87	400.00	400.00	0.00	-22.44
Sep-87	400.00	275.00	-31.25	-22.44
Sep-87	100.00	45.00	-55.00	6.74
Oct-87	315.00	255.00	-19.05	-14.17
Oct-87	360.00	360.00	0.00	-18.55
Oct-87	600.00	450.00	-25.00	-41.90
Oct-87	450.00	255.00	-43.33	-27.31
Jan-88	300.00	300.00	0.00	-12.72
Jan-88	240.00	225.00	-6.25	-6.88
Jan-88	180.00	155.00	-13.89	-1.04
Jan-88	434.00	225.00	-48.16	-25.75
Jan-88	300.00	327.00	9.00	-12.72
Jan-88	210.00	255.00	21.43	-3.96
Jan-88	450.00	450.00	0.00	-27.31
Feb-88	410.00	225.00	-45.12	-23.42
Apr-88	225.00	225.00	0.00	-5.42
Apr-88	225.00	225.00	0.00	-5.42
Apr-88	257.00	200.00	-22.18	-8.53
May-88	200.00	200.00	0.00	-2.99
May-88	550.00	275.00	-50.00	-37.03
May-88	450.00	325.00	-27.78	-27.31
May-88	293.00	225.00	-23.21	-12.03
May-88	211.00	225.00	6.64	-4.06
May-88	75.00	70.00	-6.67	9.17
Jun-88	330.00	300.00	-9.09	-15.63
Jun-88	200.00	180.00	-10.00	-2.99
Aug-88	277.00	200.00	-27.80	-10.48
Aug-88	218.00	225.00	3.21	-4.74
Aug-88	300.00	275.00	-8.33	-12.72
Sep-88	284.00	275.00	-3.17	-11.16
Sep-88	180.00	180.00	0.00	-1.04
Sep-88	265.00	255.00	-3.77	-9.31
Sep-88	450.00	450.00	0.00	-27.31
Nov-88	300.00	300.00	0.00	-12.72
Nov-88	232.00	200.00	-13.79	-6.10
Nov-88	486.00	255.00	-47.53	-30.81
Nov-88	240.00	275.00	14.58	-6.88
Nov-88	212.00	200.00	-5.66	-4.16
Nov-88	390.00	255.00	-34.62	-21.47
Nov-88	185.00	180.00	-2.70	-1.53
Nov-88	225.00	200.00	-11.11	-5.42
Nov-88	190.00	225.00	18.42	-2.02
Nov-88	300.00	240.00	-20.00	-12.72

SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nov-88	400.00	300.00	-25.00	-22.44
Nov-88	550.00	295.00	-46.36	-37.03
Nov-88	400.00	360.00	-10.00	-22.44
Nov-88	435.00	325.00	-25.29	-25.85
Dec-88	158.00	125.00	-20.89	1.10
Dec-88	162.00	125.00	-22.84	0.71
Dec-88	228.00	180.00	-21.05	-5.71
Dec-88	240.00	240.00	0.00	-6.88
Dec-88	350.00	360.00	2.86	-17.58
Dec-88	295.00	255.00	-13.56	-12.23
Dec-88	524.00	300.00	-42.75	-34.51
Dec-88	160.00	160.00	0.00	0.90
Dec-88	550.00	400.00	-27.27	-37.03
Jan-89	330.00	240.00	-27.27	-15.63
Jan-89	530.00	360.00	-32.08	-35.09
Feb-89	400.00	404.00	1.00	-22.44
Mar-89	154.00	140.00	-9.09	1.49
Mar-89	425.00	360.00	-15.29	-24.88
Mar-89	400.00	360.00	-10.00	-22.44
Apr-89	264.00	255.00	-3.41	-9.21
Apr-89	191.00	180.00	-5.76	-2.11
May-89	315.00	180.00	-42.86	-14.17
May-89	462.00	275.00	-40.48	-28.47
May-89	292.00	257.00	-11.99	-11.94
May-89	400.00	400.00	0.00	-22.44
May-89	562.00	450.00	-19.93	-38.20
May-89	600.00	360.00	-40.00	-41.90
May-89	390.00	275.00	-29.49	-21.47
Jun-89	126.00	200.00	58.73	4.21
Jun-89	225.00	138.00	-38.67	-5.42
Jun-89	140.00	225.00	60.71	2.85
Jun-89	284.00	275.00	-3.17	-11.16
Jun-89	280.00	255.00	-8.93	-10.77
Jun-89	425.00	300.00	-29.41	-24.88
Jun-89	830.00	650.00	-21.69	-64.27
Jun-89	420.00	400.00	-4.76	-24.39
Jul-89	200.00	200.00	0.00	-2.99
Jul-89	192.00	160.00	-16.67	-2.21
Aug-89	150.00	106.00	-29.33	1.88
Aug-89	275.00	275.00	0.00	-10.28
Aug-89	600.00	400.00	-33.33	-41.90
Sep-89	400.00	360.00	-10.00	-22.44
Sep-89	265.00	327.00	23.40	-9.31
Nov-89	150.00	105.00	-30.00	1.88
Nov-89	276.00	275.00	-0.36	-10.39

SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nov-89	305.00	225.00	-26.23	-13.20
Nov-89	400.00	300.00	-25.00	-22.44
Nov-89	330.00	325.00	-1.52	-15.63
Nov-89	514.00	360.00	-29.96	-33.53
Nov-89	413.00	400.00	-3.15	-23.71
Dec-89	280.00	275.00	-1.79	-10.77
Dec-89	155.00	155.00	0.00	1.39
Dec-89	160.00	160.00	0.00	0.90
Dec-89	450.00	300.00	-33.33	-27.31
Dec-89	105.00	190.00	80.95	6.25
Dec-89	150.00	135.00	-10.00	1.88
Dec-89	385.00	300.00	-22.08	-20.98
Jan-90	264.00	225.00	-14.77	-9.21
Jan-90	300.00	240.00	-20.00	-12.72
Jan-90	342.00	300.00	-12.28	-16.80
Jan-90	200.00	180.00	-10.00	-2.99
Jan-90	450.00	255.00	-43.33	-27.31
Jan-90	72.00	70.00	-2.78	9.46
Feb-90	360.00	240.00	-33.33	-18.55
Feb-90	327.00	300.00	-8.26	-15.34
Feb-90	275.00	255.00	-7.27	-10.28
Feb-90	360.00	225.00	-37.50	-18.55
Feb-90	220.00	185.00	-15.91	-4.93
Feb-90	195.00	200.00	2.56	-2.50
Feb-90	290.00	275.00	-5.17	-11.74
Feb-90	255.00	330.00	29.41	-8.34
Feb-90	600.00	400.00	-33.33	-41.90
Feb-90	514.00	360.00	-29.96	-33.53
Feb-90	360.00	275.00	-23.61	-18.55
Feb-90	360.00	300.00	-16.67	-18.55
Feb-90	250.00	180.00	-28.00	-7.85
Mar-90	450.00	225.00	-50.00	-27.31
Mar-90	200.00	180.00	-10.00	-2.99
Mar-90	255.00	200.00	-21.57	-8.34
Apr-90	275.00	255.00	-7.27	-10.28
Apr-90	327.00	300.00	-8.26	-15.34
Apr-90	385.00	300.00	-22.08	-20.98
Apr-90	470.00	455.00	-3.19	-29.25
May-90	225.00	225.00	0.00	-5.42
May-90	334.00	240.00	-28.14	-16.02
May-90	375.00	360.00	-4.00	-20.01
May-90	423.00	255.00	-39.72	-24.68
Jun-90	290.00	120.00	-58.62	-11.74
Jun-90	280.00	225.00	-19.64	-10.77
Jun-90	150.00	120.00	-20.00	1.88

SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

Jun-90	345.00	327.00	-5.22	-17.09
Jun-90	423.00	390.00	-7.80	-24.68
Jun-90	345.00	327.00	-5.22	-17.09
Jul-90	400.00	300.00	-25.00	-22.44
Jul-90	327.00	275.00	-15.90	-15.34
Jul-90	545.00	360.00	-33.94	-36.55
Jul-90	493.00	360.00	-26.98	-31.49
Aug-90	251.00	225.00	-10.36	-7.95
Aug-90	180.00	210.00	16.67	-1.04
Aug-90	171.00	160.00	-6.43	-0.17
Aug-90	640.00	360.00	-43.75	-45.79
Aug-90	390.00	360.00	-7.69	-21.47
Sep-90	235.00	180.00	-23.40	-6.39
Sep-90	180.00	163.00	-9.44	-1.04
Sep-90	200.00	180.00	-10.00	-2.99
Sep-90	180.00	180.00	0.00	-1.04
Sep-90	166.00	200.00	20.48	0.32
Sep-90	226.00	225.00	-0.44	-5.52
Oct-90	204.00	171.00	-16.18	-3.38
Oct-90	420.00	360.00	-14.29	-24.39
Oct-90	180.00	180.00	0.00	-1.04
Oct-90	300.00	225.00	-25.00	-12.72
Nov-90	343.00	255.00	-25.66	-16.90
Nov-90	75.00	60.00	-20.00	9.17
Nov-90	313.00	300.00	-4.15	-13.98
Nov-90	167.00	180.00	7.78	0.22
Dec-90	236.00	225.00	-4.66	-6.49
Dec-90	56.00	60.00	7.14	11.02
Dec-90	185.00	171.00	-7.57	-1.53
Dec-90	250.00	180.00	-28.00	-7.85
Dec-90	171.00	160.00	-6.43	-0.17
Dec-90	370.00	360.00	-2.70	-19.53
Dec-90	554.00	360.00	-35.02	-37.42
Dec-90	507.00	325.00	-35.90	-32.85
Jan-91	120.00	90.00	-25.00	4.79
Jan-91	159.00	180.00	13.21	1.00
Jan-91	270.00	240.00	-11.11	-9.80
Jan-91	510.00	360.00	-29.41	-33.14
Jan-91	375.00	360.00	-4.00	-20.01
Jan-91	415.00	275.00	-33.73	-23.90
Feb-91	200.00	225.00	12.50	-2.99
Feb-91	413.00	325.00	-21.31	-23.71
Feb-91	160.00	170.00	6.25	0.90
Feb-91	240.00	225.00	-6.25	-6.88
Feb-91	358.00	300.00	-16.20	-18.36

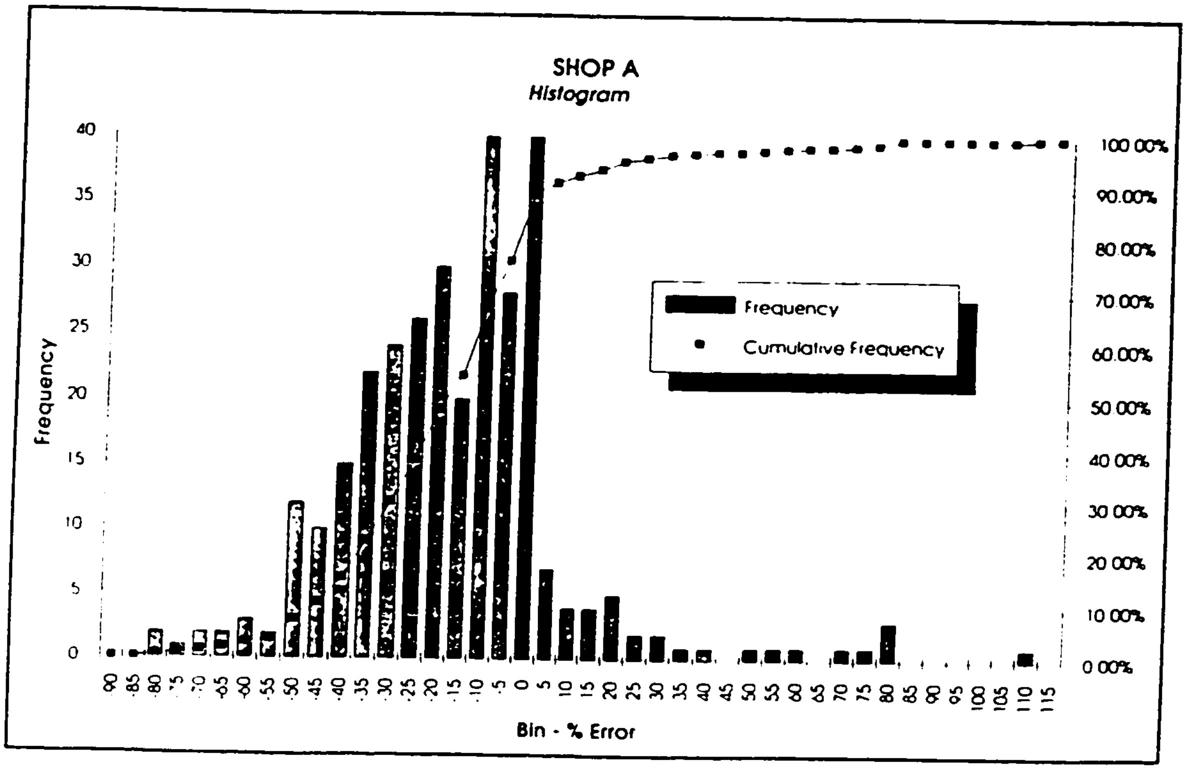
SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

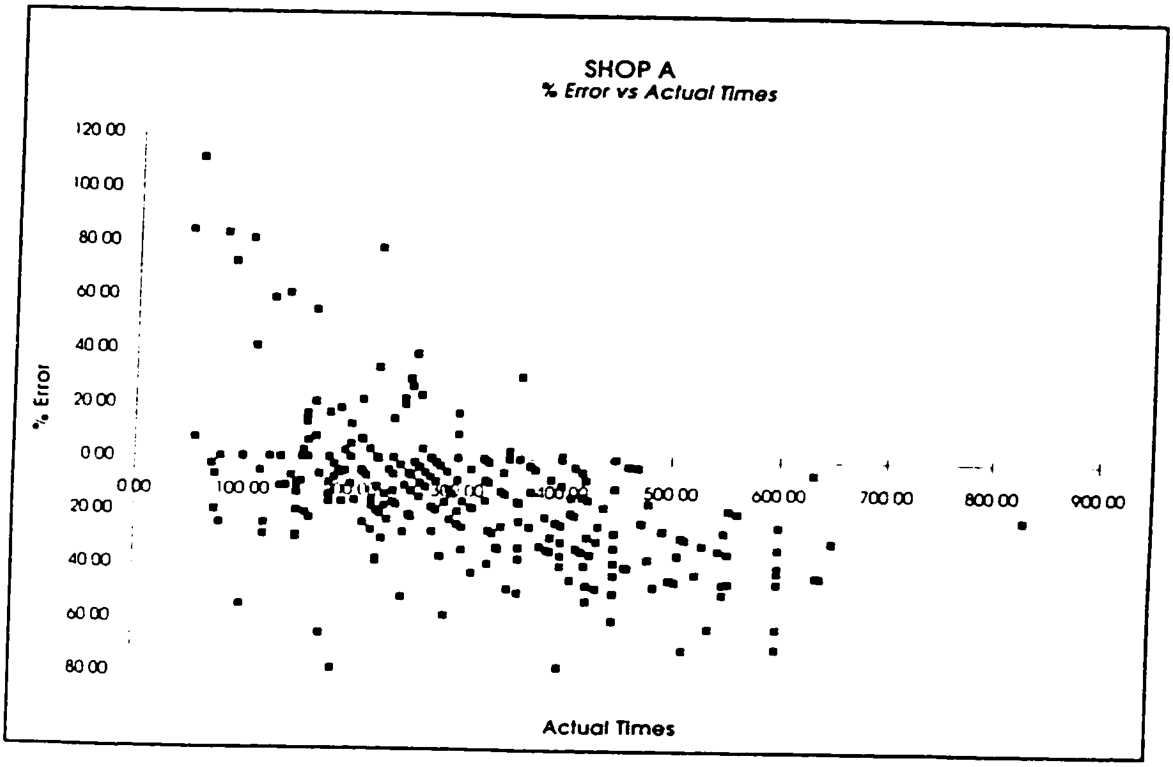
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Feb-91	340.00	225.00	-33.82	-16.61
Feb-91	305.00	255.00	-16.39	-13.20
Feb-91	387.00	255.00	-34.11	-21.18
Feb-91	371.00	325.00	-12.40	-19.62
Feb-91	450.00	275.00	-38.89	-27.31
Mar-91	135.00	120.00	-11.11	3.33
Mar-91	75.00	60.00	-20.00	9.17
Mar-91	180.00	150.00	-16.67	-1.04
Mar-91	346.00	300.00	-13.29	-17.19
Apr-91	270.00	255.00	-5.56	-9.80
Apr-91	247.00	240.00	-2.83	-7.56
Apr-91	500.00	275.00	-45.00	-32.17
May-91	505.00	275.00	-45.54	-32.66
May-91	400.00	360.00	-10.00	-22.44
Jul-91	220.00	180.00	-16.18	-4.93
Jul-91	250.00	180.00	-28.00	-7.85
Jul-91	330.00	325.00	-1.52	-15.63
Jul-91	110.00	155.00	40.91	5.77
Jul-91	225.00	180.00	-20.00	-5.42
Jul-91	360.00	275.00	-23.61	-18.55
Aug-91	116.00	110.00	-5.17	5.18
Aug-91	409.00	325.00	-20.54	-23.32
Aug-91	338.00	225.00	-33.43	-16.41
Aug-91	174.00	60.00	-65.52	-0.46
Aug-91	285.00	180.00	-36.84	-11.26
Aug-91	243.00	200.00	-17.70	-7.17
Aug-91	420.00	275.00	-34.52	-24.39
Aug-91	400.00	240.00	-40.00	-22.44
Aug-91	370.00	275.00	-25.68	-19.53
Sep-91	460.00	275.00	-40.22	-28.28
Oct-91	225.00	180.00	-20.00	-5.42
Oct-91	250.00	120.00	-52.00	-7.85
Oct-91	300.00	350.00	16.67	-12.72
Oct-91	480.00	400.00	-16.67	-30.23
Oct-91	395.00	300.00	-24.05	-21.96
Nov-91	159.00	185.00	16.35	1.00
Nov-91	200.00	225.00	12.50	-2.99
Feb-92	300.00	225.00	-25.00	-12.72
Feb-92	360.00	470.00	30.56	-18.55
Feb-92	474.00	360.00	-24.05	-29.64
Feb-92	420.00	275.00	-34.52	-24.39
Feb-92	440.00	360.00	-18.18	-26.33
Mar-92	400.00	275.00	-31.25	-22.44
Mar-92	260.00	360.00	38.46	-8.82

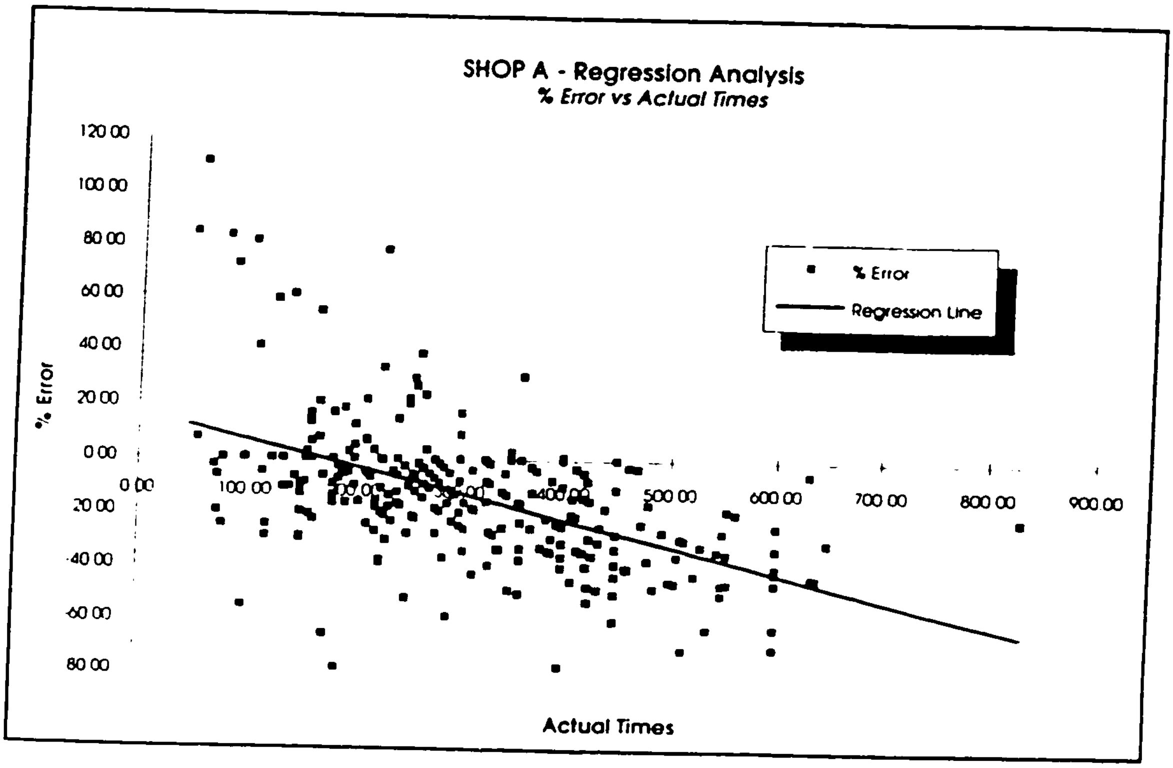
SHOP A (BOBBINS AND NON-BOBBINS)
Arranged in chronological order

Basic Statistics	
Number of Jobs	314
Mean of % Error	-13.80%
Median of % Error	-13.45%
Variance of % Error	622.90%
Standard Deviation of % Error	24.96%

Regression Statistics (% Error vs Actual Times)	
Multiple R	0.52%
R Square	0.28%
Adjusted R Square	0.27%
Standard Error	21.28%


SHOP A
Histogram
Frequency
0
5
10
15
20
25
30
35
40
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
Frequency
Cumulative Frequency
-90 -85 -80 -75 -70 -65 -60 -55 -50 -45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115
Bin - % Error


SHOP A
% Error vs Actual Times
120 00
100 00
80 00
60 00
40 00
20 00
0 00
20 00
40 00
60 00
80 00
% Error
0 00
100 00
200 00
300 00
400 00
500 00
600 00
700 00
800 00
900 00
Actual Times


SHOP A - Regression Analysis
% Error vs Actual Times
% Error
120 00
100 00
80 00
60 00
40 00
20 00
0 00
-20 00
-40 00
-60 00
-80 00
0 00
100 00
200 00
300 00
400 00
500 00
600 00
700 00
800 00
900 00
Actual Times
% Error
Regression Line

SHOP B Data in ascending Job #

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10482	15.00	15.50	3.33	3.48
11234	20.90	18.00	-13.88	2.11
11461	66.50	67.00	0.75	-8.52
11471	40.60	41.00	0.99	-2.48
11563	26.60	27.00	1.50	0.78
11692	46.70	36.00	-22.91	-3.90
11921	35.00	34.00	-2.86	-1.18
11993	46.00	40.00	-13.04	-3.74
12110	24.90	25.00	0.40	1.18
12135	72.20	75.00	3.88	-9.85
12219	23.30	27.00	15.88	1.55
12236	23.00	22.50	-2.17	1.62
12292	34.60	36.00	4.05	-1.09
12294	40.80	41.50	1.72	-2.53
12325	8.70	8.50	-2.30	4.95
12366	12.10	12.50	3.31	4.16
12367	12.30	11.50	-6.50	4.11
12369	20.40	20.50	0.49	2.22
12371	20.00	20.50	2.50	2.32
12429	19.10	20.00	4.71	2.53
12437	36.50	36.00	-1.37	-1.53
12438	17.80	25.00	40.45	2.83
12508	26.90	31.00	15.24	0.71
12520	115.00	115.00	0.00	-19.82
12573	55.50	45.00	-18.92	-5.96
12575	45.00	47.00	4.44	-3.51
12600	13.00	15.00	15.38	3.95
12607	25.20	25.00	-0.79	1.11
12608	13.00	12.50	-3.85	3.95
12614	36.70	37.00	0.82	-1.57
12642	45.10	27.00	-40.13	-3.53
12672	30.00	32.00	6.67	-0.01
12674	33.40	30.00	-10.18	-0.81
12704	48.80	30.00	-38.52	-4.39
12712	14.30	14.00	-2.10	3.65
12715	26.20	27.00	3.05	0.87
12760	34.60	30.00	-13.29	-1.09
12769	56.50	60.00	6.19	-6.19
12775	74.00	70.00	-5.41	-11.27
12815	33.70	30.00	-10.98	-0.88
12816	47.10	45.00	-4.46	-4.00
12827	49.60	50.00	0.81	-4.58
12829	58.60	50.00	-14.68	-6.68
12851	14.00	14.00	0.00	3.72
12877	102.10	90.00	-11.85	-16.82
12881	39.00	40.00	2.56	-2.11
12932	48.30	45.00	-6.83	-4.28
12934	47.30	35.00	-26.00	-4.04
12935	51.80	50.00	-3.47	-5.09
12965	12.50	12.00	-4.00	4.36
13014	28.00	35.00	25.00	[illegible]

SHOP B Data in ascending Job #

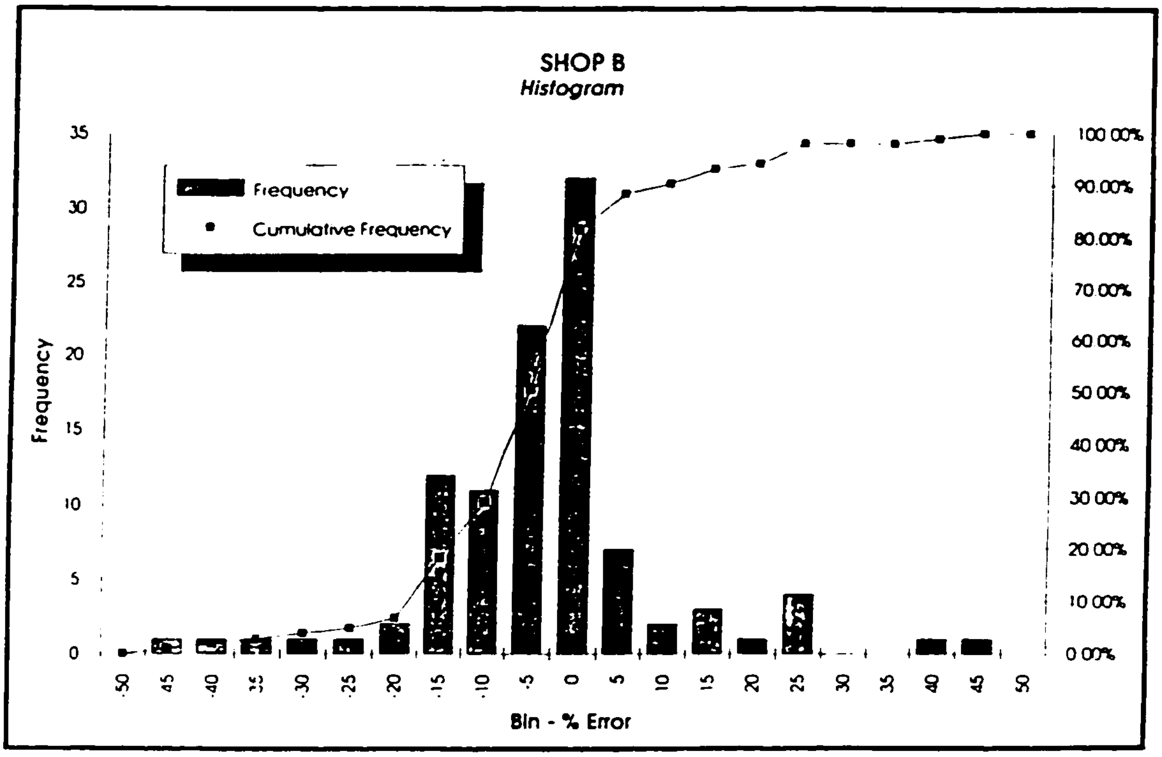
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13055	33.00	33.00	0.00	-0.71
13056	22.90	25.00	9.17	1.64
13057	27.80	25.00	-10.07	0.50
13060	28.50	25.00	-12.28	0.34
13062	10.40	10.00	-3.85	4.55
13063	44.10	40.00	-9.30	-3.30
13064	25.00	25.00	0.00	1.15
13065	40.30	40.00	-0.74	-2.41
13099	28.00	35.00	25.00	0.45
13151	15.40	17.50	13.64	3.39
13155	14.30	17.50	22.38	3.65
13217	62.00	60.00	-3.23	-7.47
13218	14.60	14.50	-0.68	3.58
13230	19.30	18.00	-6.74	2.48
13231	23.10	24.00	3.90	1.59
13240	26.60	25.00	-6.02	0.78
13243	13.00	12.00	-7.69	3.95
13259	15.10	15.00	-0.66	3.46
13279	36.40	32.00	-12.09	-1.50
13285	23.50	21.00	-10.64	1.50
13286	21.60	21.00	-2.78	1.94
13307	34.90	34.00	-2.58	-1.16
13309	17.00	25.00	47.06	3.02
13373	37.70	38.00	0.80	-1.81
13430	31.00	33.00	6.45	-0.25
13432	19.50	20.00	2.56	2.43
13433	31.60	28.00	-11.39	-0.39
13460	18.70	20.00	6.95	2.62
13510	44.10	40.00	-9.30	-3.30
13511	30.90	30.00	-2.91	-0.22
13532	17.50	18.00	2.86	2.90
13533	16.30	17.00	4.29	3.18
13577	17.00	17.00	0.00	3.02
13581	34.30	35.00	2.04	-1.02
13583	10.70	10.50	-1.87	4.48
13586	39.20	50.00	27.55	-2.16
13588	24.30	27.00	11.11	1.32
13617	38.10	35.00	-8.14	-1.90
13619	10.00	10.50	5.00	4.65
13624	13.90	14.50	4.32	3.74
13625	21.70	20.00	-7.83	1.92
13631	11.40	12.00	5.26	4.32
13692	48.30	40.00	-17.18	-4.28
13693	44.00	40.00	-9.09	-3.28
13757	50.20	50.00	-0.40	-4.72
13760	50.10	48.00	-4.19	-4.70
13761	40.50	39.00	-3.70	-2.46
13781	30.30	38.00	25.41	-0.08
13782	47.60	48.00	0.84	-4.11
13785	29.70	31.00	4.38	0.06
13786	44.60	46.00	3.14	-3.42

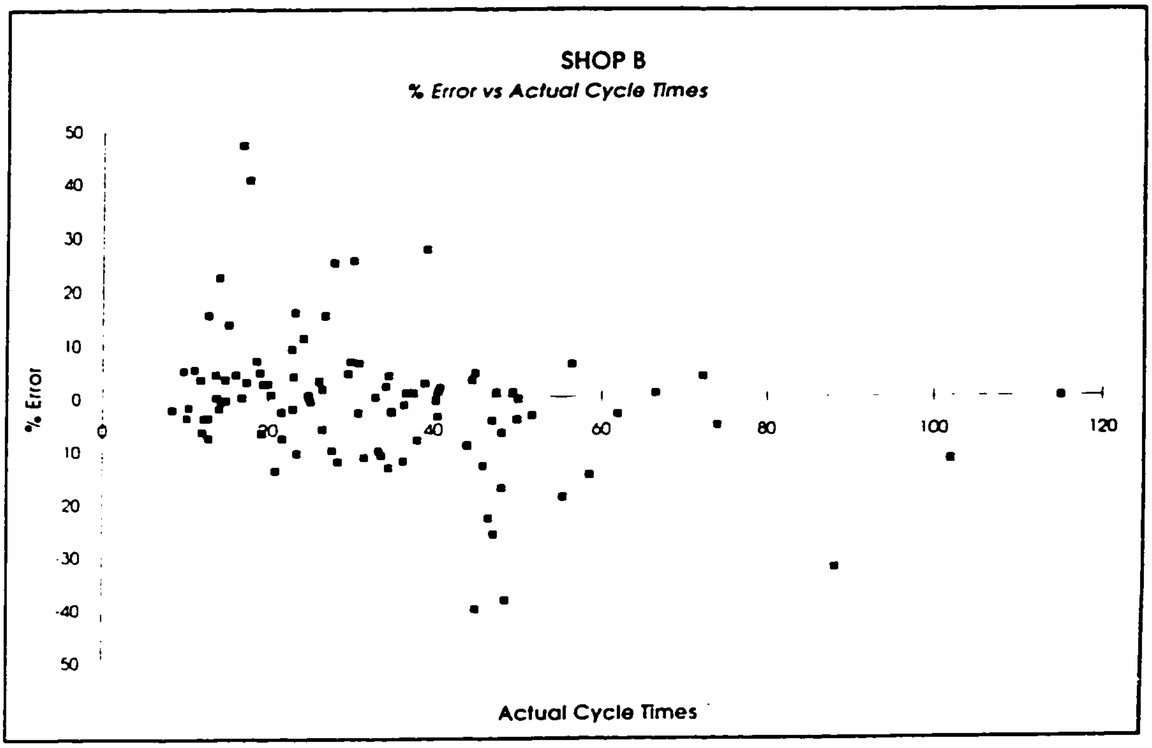
SHOP B Data in ascending Job #

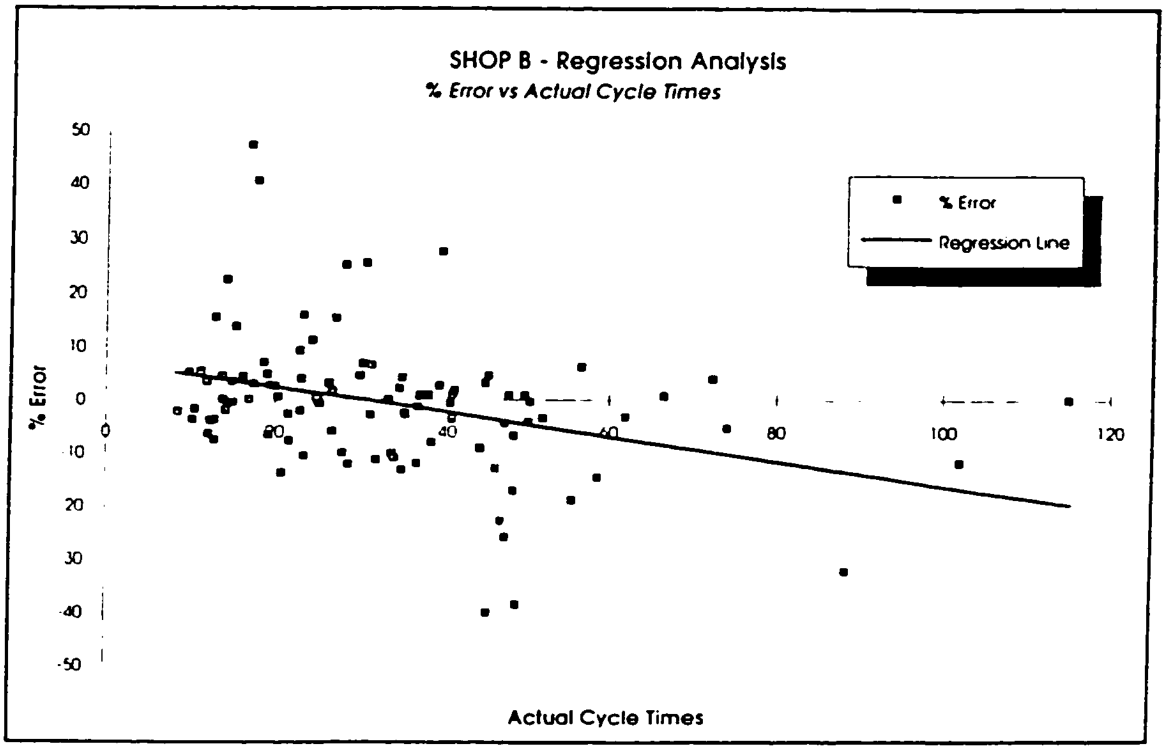
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13903	88.50	60.00	-32.20	-13.65

Basic Statistics	
Number of Jobs	103
Mean of % Error	-0.78%
Median of % Error	-.40%
Variance of % Error	165.76%
Standard Deviation of % Error	12.87%

Regression Statistics (% Error vs Actual Times)	
Multiple R	0.34%
R Square	0.12%
Adjusted R Square	0.11%
Standard Error	12.21%


SHOP B
Histogram
Frequency
Cumulative Frequency
35
30
25
20
15
10
5
0
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
Bin - % Error


SHOP B
% Error vs Actual Cycle Times
% Error
50
40
30
20
10
0
10
20
30
-40
50
0
20
40
60
80
100
120
Actual Cycle Times


SHOP B - Regression Analysis
% Error vs Actual Cycle Times
% Error
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
120
% Error
Regression Line
Actual Cycle Times

COMBINED -
Arranged in ascending Actual Cycle Times

[illegible]	[illegible]	[illegible]	[illegible]
8.70	8.50	-2.30	6.23
10.00	10.50	5.00	6.13
10.40	10.00	-3.85	6.10
10.70	10.50	-1.87	6.08
11.40	12.00	5.26	6.03
12.10	12.50	3.31	5.98
12.30	11.50	-6.50	5.97
12.50	12.00	-4.00	5.95
13.00	15.00	15.38	5.92
13.00	12.50	-3.85	5.92
13.00	12.00	-7.69	5.92
13.90	14.50	4.32	5.85
14.00	14.00	0.00	5.85
14.30	14.00	-2.10	5.82
14.30	17.50	22.38	5.82
14.60	14.50	-0.68	5.80
15.00	15.50	3.33	5.77
15.10	15.00	-0.66	5.77
15.40	17.50	13.64	5.75
16.30	17.00	4.29	5.68
17.00	25.00	47.06	5.63
17.00	17.00	0.00	5.63
17.50	18.00	2.86	5.59
17.80	25.00	40.45	5.57
18.70	20.00	6.95	5.51
19.10	20.00	4.71	5.48
19.30	18.00	-6.74	5.46
19.50	20.00	2.56	5.45
20.00	20.50	2.50	5.41
20.40	20.50	0.49	5.39
20.90	18.00	-13.88	5.35
21.60	21.00	-2.78	5.30
21.70	20.00	-7.83	5.29
22.90	25.00	9.17	5.21
23.00	22.50	-2.17	5.20
23.10	24.00	3.90	5.19
23.30	27.00	15.88	5.18
23.50	21.00	-10.64	5.16
24.30	27.00	11.11	5.11
24.90	25.00	0.40	5.06
25.00	25.00	0.00	5.05
25.20	25.00	-0.79	5.04
26.20	27.00	3.05	4.97
26.60	27.00	1.50	4.94
26.60	25.00	-6.02	4.94

[illegible]	[illegible]	[illegible]	[illegible]
26.90	31.00	15.24	4.92
27.80	25.00	-10.07	4.85
28.00	35.00	25.00	4.84
28.00	35.00	25.00	4.84
28.50	25.00	-12.28	4.80
29.70	31.00	4.38	4.72
30.00	32.00	6.67	4.70
30.30	38.00	25.41	4.67
30.90	30.00	-2.91	4.63
31.00	33.00	6.45	4.62
31.60	28.00	-11.39	4.58
33.00	33.00	0.00	4.48
33.40	30.00	-10.18	4.45
33.70	30.00	-10.98	4.43
34.30	35.00	2.04	4.39
34.60	36.00	4.05	4.36
34.60	30.00	-13.29	4.36
34.90	34.00	-2.58	4.34
35.00	34.00	-2.86	4.34
36.40	32.00	-12.09	4.24
36.50	36.00	-1.37	4.23
36.70	37.00	0.82	4.21
37.70	38.00	0.80	4.14
38.10	35.00	-8.14	4.11
39.00	40.00	2.56	4.05
39.20	50.00	27.55	4.03
40.30	40.00	-0.74	3.95
40.50	39.00	-3.70	3.94
40.60	41.00	0.99	3.93
40.80	41.50	1.72	3.91
44.00	40.00	-9.09	3.74
44.10	40.00	-9.30	3.68
44.10	40.00	-9.30	3.68
44.60	46.00	3.14	3.65
45.00	47.00	4.44	3.62
45.10	27.00	-40.13	3.61
46.00	40.00	-13.04	3.55
46.70	36.00	-22.91	3.49
47.10	45.00	-4.46	3.47
47.30	35.00	-26.00	3.45
47.60	48.00	0.84	3.43
48.30	45.00	-6.83	3.38
48.30	40.00	-17.18	3.38
48.80	30.00	-38.52	3.34
49.60	50.00	0.81	3.24

COMBINED -
Arranged in ascending Actual Cycle Times

[illegible]	[illegible]	[illegible]	[illegible]
50.00	92.00	84.00	3.26
50.10	48.00	-4.19	3.25
50.20	50.00	-0.40	3.24
51.80	50.00	-3.47	3.13
55.50	45.00	-18.92	2.86
56.00	60.00	7.14	2.83
56.50	60.00	6.19	2.79
57.00	120.00	110.53	2.75
58.60	50.00	-14.68	2.64
62.00	60.00	-3.23	2.39
66.50	67.00	0.75	2.07
72.00	70.00	-2.78	1.68
72.20	75.00	3.86	1.66
74.00	70.00	-5.41	1.53
75.00	70.00	-6.67	1.46
75.00	60.00	-20.00	1.46
75.00	60.00	-20.00	1.46
80.00	80.00	0.00	1.10
80.00	60.00	-25.00	1.10
82.00	150.00	82.93	0.96
88.50	60.00	-32.20	0.49
90.00	155.00	72.22	0.38
100.00	100.00	0.00	-0.34
100.00	45.00	-55.00	-0.34
102.10	90.00	-11.85	-0.49
105.00	190.00	80.95	-0.70
110.00	155.00	40.91	-1.06
115.00	115.00	0.00	-1.42
116.00	110.00	-5.17	-1.49
120.00	85.00	-29.17	-1.77
120.00	90.00	-25.00	-1.77
125.00	125.00	0.00	-2.13
125.00	125.00	0.00	-2.13
126.00	200.00	58.73	-2.21
135.00	135.00	0.00	-2.85
135.00	120.00	-11.11	-2.85
140.00	125.00	-10.71	-3.21
140.00	225.00	60.71	-3.21
145.00	135.00	-6.90	-3.57
150.00	130.00	-13.33	-3.93
150.00	106.00	-29.33	-3.93
150.00	105.00	-30.00	-3.93
150.00	135.00	-10.00	-3.93
150.00	120.00	-20.00	-3.93
154.00	140.00	-9.09	-4.22
155.00	155.00	0.00	-4.29
156.00	160.00	2.56	-4.36
158.00	125.00	-20.89	-4.51
159.00	180.00	13.21	-4.58
159.00	185.00	16.35	-4.58
160.00	160.00	0.00	-4.65
160.00	160.00	0.00	-4.65
160.00	170.00	6.25	-4.65
162.00	125.00	-22.84	-4.79
165.00	255.00	54.55	-5.01
166.00	200.00	20.48	-5.08
167.00	180.00	7.78	-5.15
171.00	160.00	-6.43	-5.44
171.00	160.00	-6.43	-5.44
174.00	60.00	-65.52	-5.66
180.00	180.00	0.00	-6.09
180.00	155.00	-13.89	-6.09
180.00	180.00	0.00	-6.09
180.00	210.00	16.67	-6.09
180.00	163.00	-9.44	-6.09
180.00	180.00	0.00	-6.09
180.00	180.00	0.00	-6.09
180.00	150.00	-16.67	-6.09
185.00	180.00	-2.70	-6.45
185.00	171.00	-7.57	-6.45
186.00	40.00	-78.49	-6.52
189.00	180.00	-4.76	-6.74
190.00	225.00	18.42	-6.81
191.00	180.00	-5.76	-6.88
192.00	160.00	-16.67	-6.95
195.00	185.00	-5.13	-7.17
195.00	200.00	2.56	-7.17
200.00	210.00	5.00	-7.53
200.00	200.00	0.00	-7.53
200.00	180.00	-10.00	-7.53
200.00	200.00	0.00	-7.53
200.00	180.00	-10.00	-7.53
200.00	180.00	-10.00	-7.53
200.00	180.00	-10.00	-7.53
200.00	225.00	12.50	-7.53
200.00	225.00	12.50	-7.53
204.00	171.00	-16.18	-7.81
210.00	225.00	7.14	-8.25
210.00	200.00	-4.76	-8.25
210.00	255.00	21.43	-8.25

COMBINED -
Arranged in ascending Actual Cycle Times

[illegible]	[illegible]	[illegible]	[illegible]
211.00	225.00	6.64	-8.32
212.00	160.00	-24.53	-8.39
212.00	200.00	-5.66	-8.39
215.00	200.00	-6.98	-8.60
218.00	225.00	3.21	-8.82
220.00	160.00	-27.27	-8.96
220.00	185.00	-15.91	-8.96
220.00	180.00	-18.18	-8.96
225.00	400.00	77.78	-9.32
225.00	140.00	-37.78	-9.32
225.00	225.00	0.00	-9.32
225.00	200.00	-11.11	-9.32
225.00	300.00	33.33	-9.32
225.00	225.00	0.00	-9.32
225.00	225.00	0.00	-9.32
225.00	200.00	-11.11	-9.32
225.00	138.00	-38.67	-9.32
225.00	225.00	0.00	-9.32
225.00	180.00	-20.00	-9.32
225.00	180.00	-20.00	-9.32
226.00	225.00	-0.44	-9.40
228.00	180.00	-21.05	-9.54
230.00	160.00	-30.43	-9.68
232.00	190.00	-18.10	-9.83
232.00	200.00	-13.79	-9.83
235.00	180.00	-23.40	-10.04
236.00	225.00	-4.66	-10.11
240.00	240.00	0.00	-10.40
240.00	200.00	-16.67	-10.40
240.00	200.00	-16.67	-10.40
240.00	210.00	-12.50	-10.40
240.00	225.00	-6.25	-10.40
240.00	275.00	14.58	-10.40
240.00	240.00	0.00	-10.40
240.00	225.00	-6.25	-10.40
243.00	200.00	-17.70	-10.62
247.00	240.00	-2.83	-10.91
250.00	300.00	20.00	-11.12
250.00	305.00	22.00	-11.12
250.00	180.00	-28.00	-11.12
250.00	180.00	-28.00	-11.12
250.00	180.00	-28.00	-11.12
250.00	120.00	-52.00	-11.12
251.00	225.00	-10.36	-11.19
255.00	240.00	-5.88	-11.48
255.00	330.00	29.41	-11.48
255.00	200.00	-21.57	-11.48
257.00	240.00	-6.61	-11.62
257.00	225.00	-12.45	-11.62
257.00	325.00	26.46	-11.62
257.00	200.00	-22.18	-11.62
260.00	255.00	-1.92	-11.84
260.00	255.00	-1.92	-11.84
260.00	255.00	-1.92	-11.84
260.00	360.00	38.46	-11.84
264.00	255.00	-3.41	-12.13
264.00	225.00	-14.77	-12.13
265.00	240.00	-9.43	-12.20
265.00	255.00	-3.77	-12.20
265.00	327.00	23.40	-12.20
267.00	276.00	3.37	-12.34
270.00	240.00	-11.11	-12.56
270.00	255.00	-5.56	-12.56
275.00	275.00	0.00	-12.92
275.00	275.00	0.00	-12.92
275.00	255.00	-7.27	-12.92
275.00	255.00	-7.27	-12.92
276.00	225.00	-18.48	-12.99
276.00	275.00	-0.36	-12.99
277.00	200.00	-27.80	-13.06
280.00	255.00	-8.93	-13.28
280.00	275.00	-1.79	-13.28
280.00	225.00	-19.64	-13.28
284.00	275.00	-3.17	-13.57
284.00	275.00	-3.17	-13.57
285.00	180.00	-36.84	-13.64
288.00	240.00	-16.67	-13.85
290.00	275.00	-5.17	-14.00
290.00	120.00	-58.62	-14.00
292.00	257.00	-11.99	-14.14
293.00	225.00	-23.21	-14.21
295.00	255.00	-13.56	-14.36
300.00	300.00	0.00	-14.72
300.00	300.00	0.00	-14.72
300.00	327.00	9.00	-14.72
300.00	275.00	-8.33	-14.72
300.00	300.00	0.00	-14.72
300.00	240.00	-20.00	-14.72
300.00	240.00	-20.00	-14.72
300.00	225.00	-25.00	-14.72

COMBINED -
Arranged in ascending Actual Cycle Times

[redacted]	[redacted]	[redacted]	[redacted]
300.00	350.00	16.67	-14.72
300.00	225.00	-25.00	-14.72
305.00	200.00	-34.43	-15.08
305.00	225.00	-26.23	-15.08
305.00	255.00	-16.39	-15.08
313.00	255.00	-18.53	-15.65
313.00	300.00	-4.15	-15.65
315.00	255.00	-19.05	-15.79
315.00	180.00	-42.86	-15.79
325.00	325.00	0.00	-16.51
327.00	325.00	-0.61	-16.66
327.00	300.00	-8.26	-16.66
327.00	300.00	-8.26	-16.66
327.00	275.00	-15.90	-16.66
330.00	325.00	-1.52	-16.87
330.00	200.00	-39.39	-16.87
330.00	300.00	-9.09	-16.87
330.00	240.00	-27.27	-16.87
330.00	325.00	-1.52	-16.87
330.00	325.00	-1.52	-16.87
334.00	240.00	-28.14	-17.16
338.00	225.00	-33.43	-17.45
340.00	225.00	-33.82	-17.59
342.00	300.00	-12.28	-17.74
343.00	255.00	-25.66	-17.81
345.00	327.00	-5.22	-17.95
345.00	327.00	-5.22	-17.95
346.00	300.00	-13.29	-18.02
350.00	350.00	0.00	-18.31
350.00	180.00	-48.57	-18.31
350.00	360.00	2.86	-18.31
358.00	300.00	-16.20	-18.89
360.00	180.00	-50.00	-19.03
360.00	360.00	0.00	-19.03
360.00	275.00	-23.61	-19.03
360.00	225.00	-37.50	-19.03
360.00	360.00	0.00	-19.03
360.00	240.00	-33.33	-19.03
360.00	225.00	-37.50	-19.03
360.00	275.00	-23.61	-19.03
360.00	300.00	-16.67	-19.03
360.00	275.00	-23.61	-19.03
360.00	470.00	30.56	-19.03
370.00	360.00	-2.70	-19.75
370.00	275.00	-25.68	-19.75

[redacted]	[redacted]	[redacted]	[redacted]
371.00	325.00	-12.40	-19.82
375.00	360.00	-4.00	-20.11
375.00	360.00	-4.00	-20.11
380.00	255.00	-32.89	-20.47
385.00	300.00	-22.08	-20.83
385.00	300.00	-22.08	-20.83
387.00	255.00	-34.11	-20.97
390.00	255.00	-34.62	-21.19
390.00	275.00	-29.49	-21.19
390.00	360.00	-7.69	-21.19
395.00	300.00	-24.05	-21.55
400.00	255.00	-36.25	-21.90
400.00	275.00	-31.25	-21.90
400.00	90.00	-77.50	-21.90
400.00	400.00	0.00	-21.90
400.00	275.00	-31.25	-21.90
400.00	300.00	-25.00	-21.90
400.00	360.00	-10.00	-21.90
400.00	404.00	1.00	-21.90
400.00	360.00	-10.00	-21.90
400.00	400.00	0.00	-21.90
400.00	360.00	-10.00	-21.90
400.00	300.00	-25.00	-21.90
400.00	300.00	-25.00	-21.90
400.00	360.00	-10.00	-21.90
400.00	240.00	-40.00	-21.90
400.00	275.00	-31.25	-21.90
409.00	325.00	-20.54	-22.55
410.00	350.00	-14.63	-22.62
410.00	225.00	-45.12	-22.62
413.00	400.00	-3.15	-22.84
413.00	325.00	-21.31	-22.84
415.00	275.00	-33.73	-22.98
420.00	275.00	-34.52	-23.34
420.00	400.00	-4.76	-23.34
420.00	360.00	-14.29	-23.34
420.00	275.00	-34.52	-23.34
420.00	275.00	-34.52	-23.34
423.00	255.00	-39.72	-23.56
423.00	390.00	-7.80	-23.56
425.00	200.00	-52.94	-23.70
425.00	300.00	-29.41	-23.70
425.00	225.00	-47.06	-23.70
425.00	360.00	-15.29	-23.70
425.00	300.00	-29.41	-23.70

COMBINED -
Arranged in ascending Actual Cycle Times

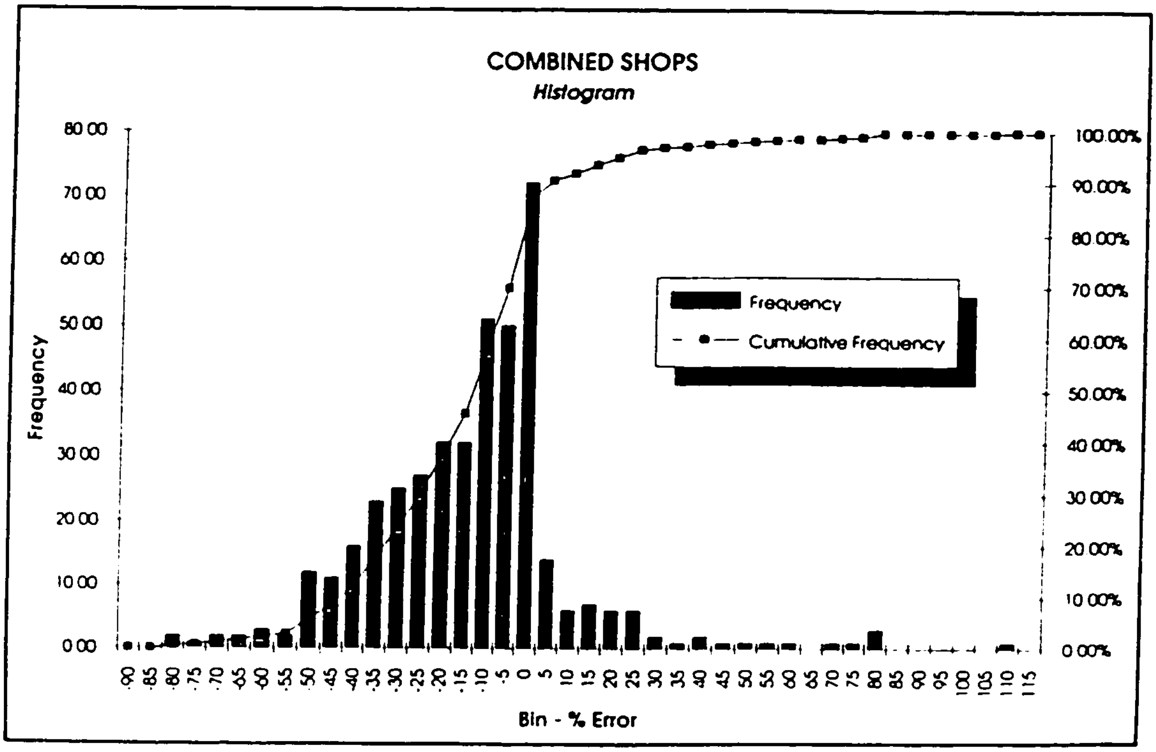
428.00	275.00	-35.75	-23.92
434.00	300.00	-30.88	-24.35
434.00	225.00	-48.16	-24.35
435.00	325.00	-25.29	-24.42
440.00	360.00	-18.18	-24.78
450.00	450.00	0.00	-25.50
450.00	325.00	-27.78	-25.50
450.00	400.00	-11.11	-25.50
450.00	180.00	-60.00	-25.50
450.00	255.00	-43.33	-25.50
450.00	450.00	0.00	-25.50
450.00	325.00	-27.78	-25.50
450.00	450.00	0.00	-25.50
450.00	300.00	-33.33	-25.50
450.00	255.00	-43.33	-25.50
450.00	225.00	-50.00	-25.50
450.00	275.00	-38.89	-25.50
460.00	275.00	-40.22	-26.22
462.00	450.00	-2.60	-26.36
462.00	275.00	-40.48	-26.36
470.00	455.00	-3.19	-26.94
474.00	360.00	-24.05	-27.23
480.00	300.00	-37.50	-27.66
480.00	400.00	-16.67	-27.66
486.00	255.00	-47.53	-28.09
493.00	360.00	-26.98	-28.59
500.00	275.00	-45.00	-29.09
505.00	275.00	-45.54	-29.45
507.00	325.00	-35.90	-29.60
510.00	360.00	-29.41	-29.81
514.00	150.00	-70.82	-30.10
514.00	360.00	-29.96	-30.10
514.00	360.00	-29.96	-30.10
524.00	300.00	-42.75	-30.82
530.00	360.00	-32.08	-31.25
537.00	200.00	-62.76	-31.75
545.00	360.00	-33.94	-32.33
550.00	275.00	-50.00	-32.69
550.00	295.00	-46.36	-32.69
550.00	400.00	-27.27	-32.69
554.00	450.00	-18.77	-32.98
554.00	360.00	-35.02	-32.98
555.00	300.00	-45.95	-33.05
562.00	450.00	-19.93	-33.55
600.00	325.00	-45.83	-36.28
600.00	350.00	-41.67	-36.28
600.00	225.00	-62.50	-36.28
600.00	180.00	-70.00	-36.28
600.00	450.00	-25.00	-36.28
600.00	360.00	-40.00	-36.28
600.00	400.00	-33.33	-36.28
600.00	400.00	-33.33	-36.28
632.00	600.00	-5.06	-38.58
636.00	360.00	-43.40	-38.87
640.00	360.00	-43.75	-39.16
650.00	450.00	-30.77	-39.88
830.00	650.00	-21.69	-52.82

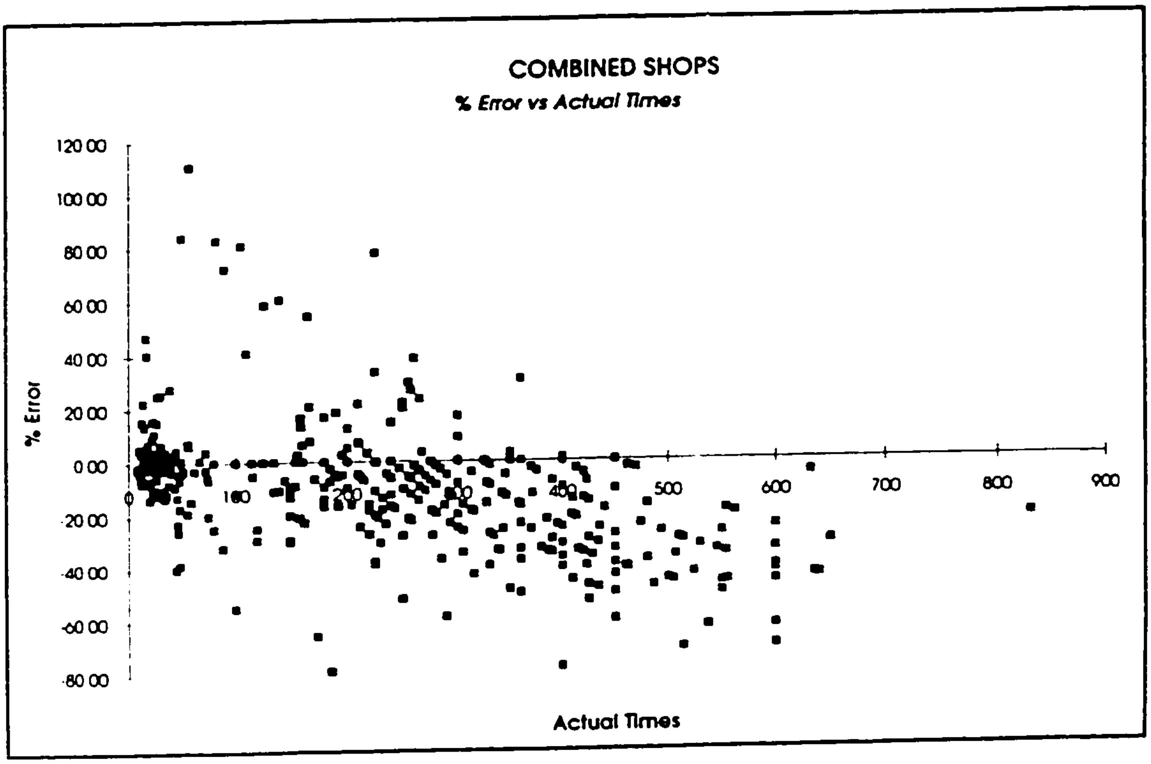
Basic Statistics

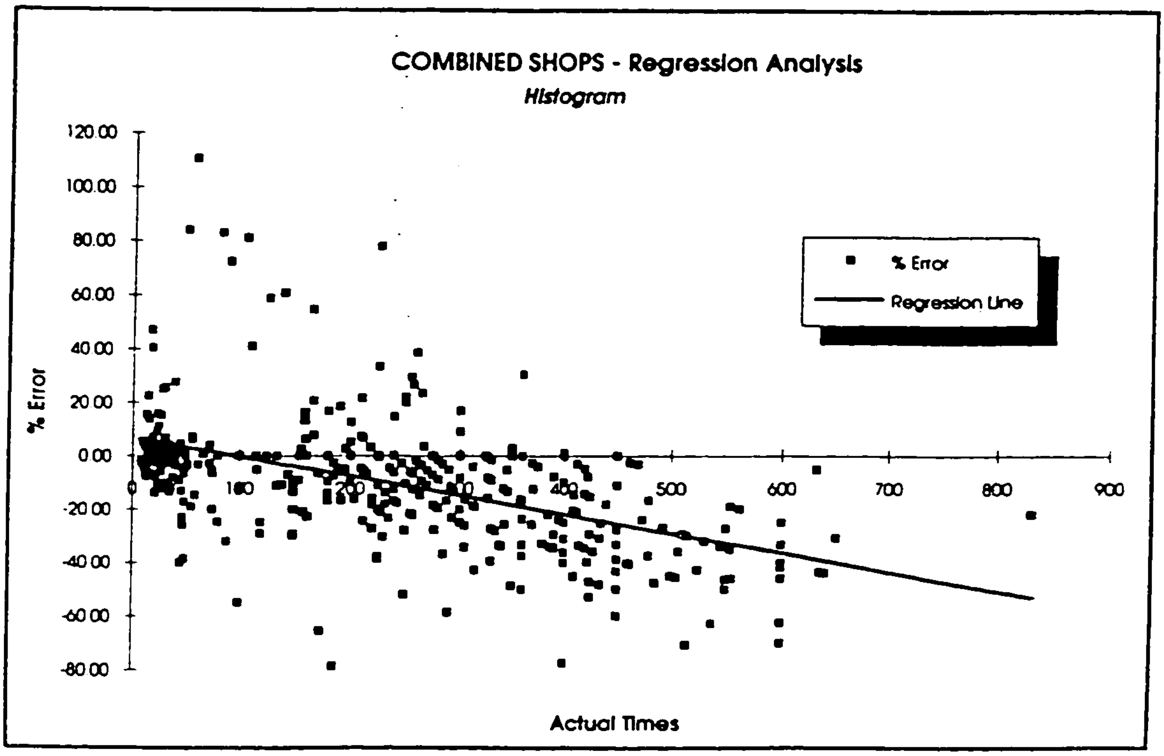
Number of Jobs	417
Mean of % Error	-10.58%
Median of % Error	-8.26
Variance of % Error	541.33%
Standard Deviation of % Error	23.27%

Regression Statistics
(% Error vs Actual Times)

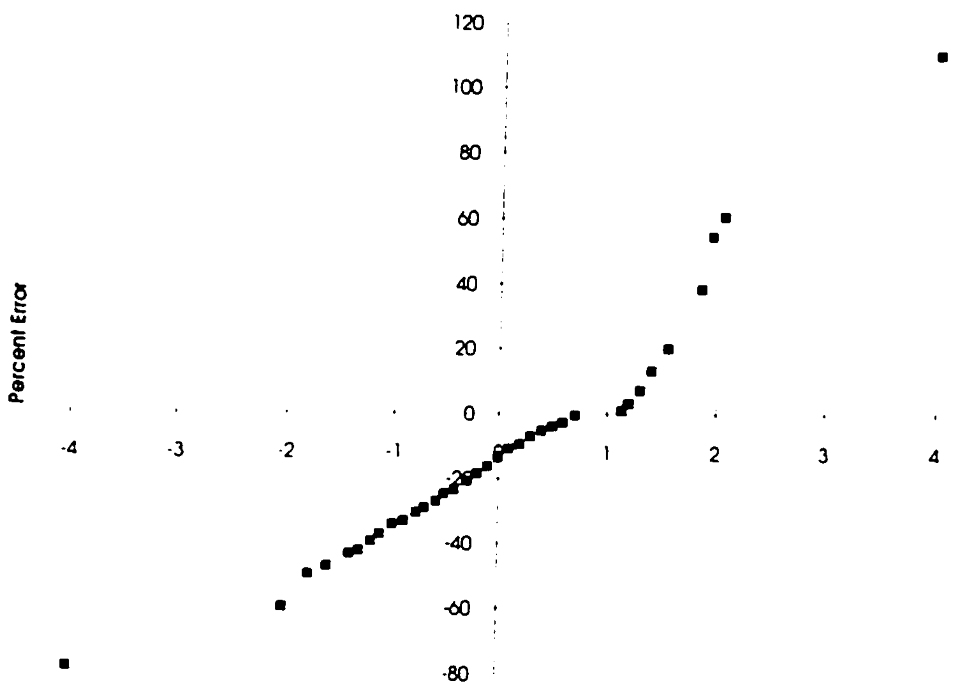
Multiple R	0.52%
R Square	0.27%
Adjusted R Square	0.27%
Standard Error	19.93%


COMBINED SHOPS
Histogram
Frequency
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Frequency
Cumulative Frequency
-90 -85 -80 -75 -70 -65 -60 -55 -50 -45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115
Bin - % Error

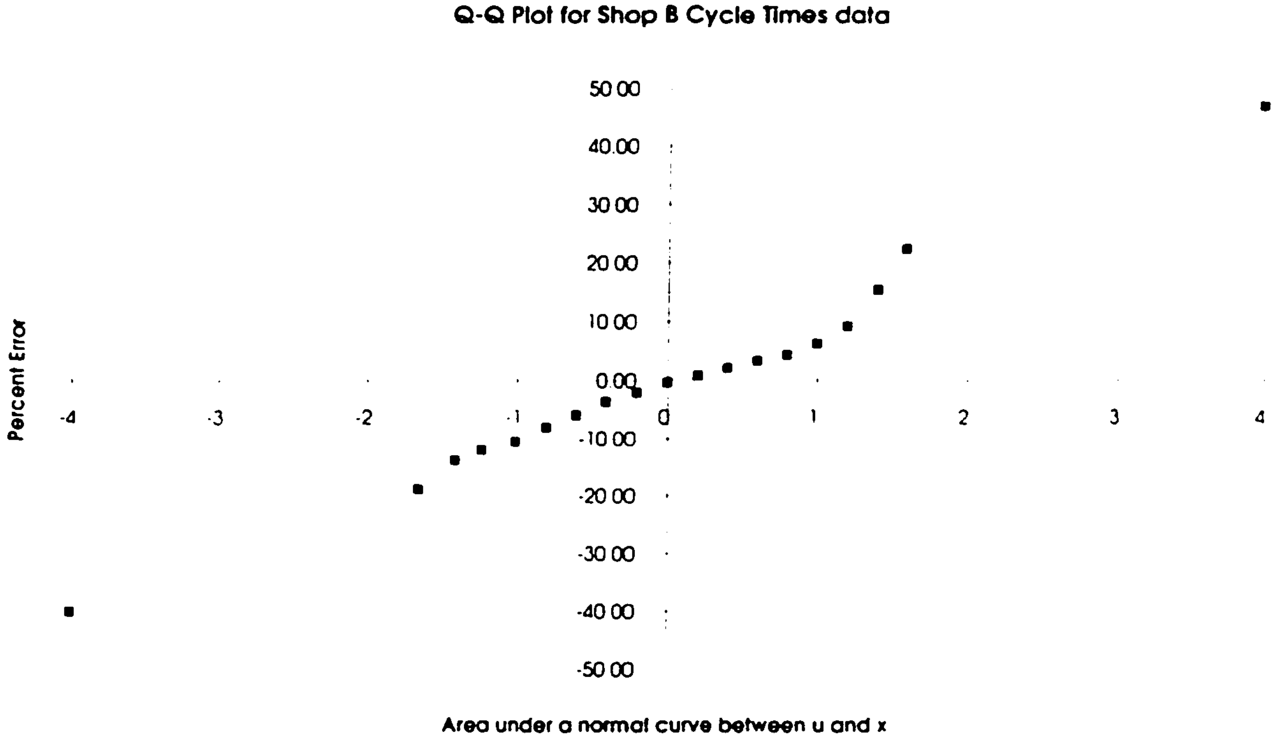

COMBINED SHOPS
% Error vs Actual Times
120 00
100 00
80 00
60 00
40 00
20 00
0 00
-20 00
-40 00
-60 00
-80 00
% Error
0
100
200
300
400
500
600
700
800
900
Actual Times

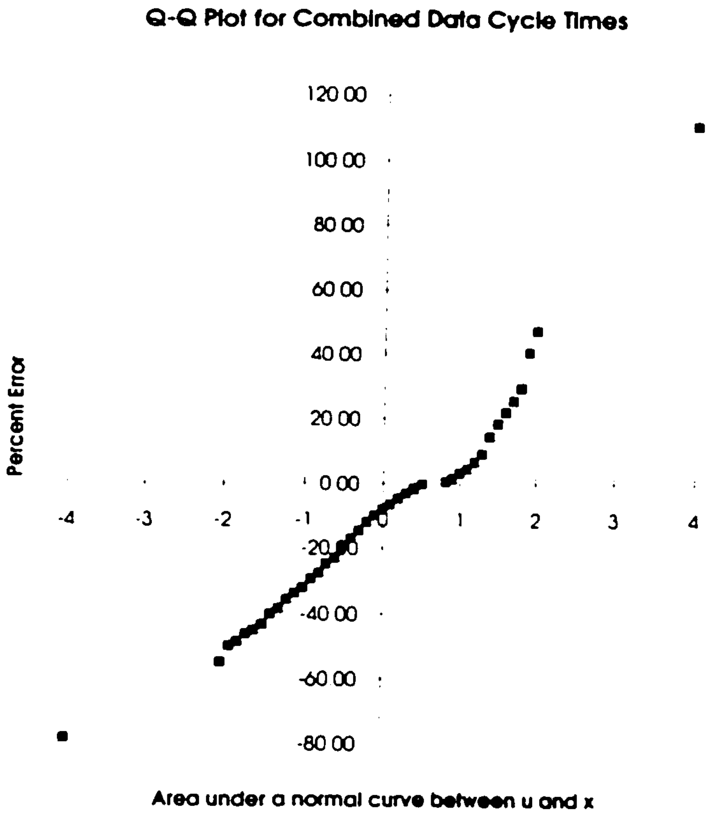

COMBINED SHOPS - Regression Analysis
Histogram
% Error
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0
100
200
300
400
500
600
700
800
900
Actual Times
% Error
Regression Line

Q-Q Plot for Shop A Cycle Time Data



Area under a normal curve between u and x


Q-Q Plot for Shop B Cycle Times data
Percent Error
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-4
-3
-2
-1
0
1
2
3
4
Area under a normal curve between u and x


Q-Q Plot for Combined Data Cycle Times
120 00
100 00
80 00
60 00
40 00
20 00
0 00
-20 00
-40 00
-60 00
-80 00
-4
-3
-2
-1
0
1
2
3
4
Percent Error
Area under a normal curve between u and x

This appendix presents those data points used to develop MGTS algorithms.

Coil	ID	Fill	Cav	Matcode	SPH	Length	Width	Depth	Prim	DIM	Tol	Thick	Side	Under	Part
26414	4467	0	4	5.8	400	1.894	0.817	0.551	10.8	82	3.937	0.051	0	5	1
2025	4503	0	1	5.8	225	2.575	2.575	0.65	9.8	10	2	0.035	0	5	1
3000	4503	0	2	5.8	225	2.575	2.575	0.65	9.8	10	2	0.035	0	5	1
3900	4503	0	4	5.8	225	2.575	2.575	0.65	9.8	10	2	0.035	0	5	1
2520	4504	0	2	5.8	240	1.7	1.7	0.327	17.4	10	2	0.13	0	5	1
3600	4504	0	4	5.8	240	1.7	1.7	0.327	17.4	10	2	0.13	0	5	1
12658	4559	30	8	5.8	580	0.461	0.346	0.339	5.1	40	3.937	0.012	0	5	1
18910	4559	30	16	5.8	580	0.461	0.346	0.339	5.1	40	3.937	0.012	0	5	1
3536	4569	0	7	5.8	200	0.437	0.437	0.408	9.8	10	2	0.02	0	5	1
3536	4597	0	6	5.8	200	0.5	0.5	0.425	10.2	11	2	0.02	0	5	1
26664	4739	15	10	6.8	555	0.634	0.556	0.45	25	53	2	0.04	0	5	1
5936	4757	0	4	5.8	225	1.5	1.33	1.33	4.5	20	5	0.085	0	5	1
7368	4757	0	6	5.8	225	1.5	1.33	1.33	4.5	20	5	0.085	0	5	1
8758	4757	0	8	5.8	225	1.5	1.33	1.33	4.5	20	5	0.085	0	5	1
3828	4759	33	4	5.8	700	0.515	0.46	0.423	13.6	18	2	0.035	0	5	1
3904	4760	33	4	5.8	500	0.3	0.185	0.1	7.5	9	5	0.08	0	5	1
3451	4761	33	1	5.8	765	0.904	0.43	0.43	9	27	2	0.016	0	5	1
47583	4763	0	14	6.8	410	0.93	0.63	0.583	20.5	117	3.937	0.05	0	5	1
6658	4765	0	4	4.5	450	0.625	0.425	0.318	6.4	50	2	0.02	0	5	1
3603	4766	33	1	5.8	537	0.274	0.272	0.204	9.6	38	2	0.014	0	5	1
6741	4767	33	8	5.8	655	0.61	0.516	0.516	4.8	19	7.874	0.039	0	5	1
4516	4768	0	8	5.8	467	0.524	0.524	0.342	4.4	8	1	0.055	0	5	1
11632	4769	20	8	5.8	600	0.663	0.663	0.615	10.4	10	3.937	0.033	0	5	1
2380	4770	15	2	5.8	600	0.595	0.28	0.28	2.8	5	5	0.01	0	5	1
14726	4771	30	8	5.8	510	1.102	1.102	0.925	10.2	42	2.362	0.039	0	5	1
10635	4772	33	4	5.8	800	0.63	0.63	0.61	7.8	36	2	0.037	0	5	1
2142	4773	0	1	4.5	450	1.7	1.7	0.21	2.3	8	5	0.02	0	5	1
4671	4774	20	1	5.8	630	0.79	0.79	0.7	4.4	34	2	0.02	0	5	1
16119	4775	33	8	5.8	735	0.79	0.79	0.7	4.4	34	2	0.02	0	5	1
12966	4777	0	1	6.8	230	1.811	1.632	1.17	12.7	82	1.969	0.154	0	5	1
10741	4793	0	4	5.8	400	1.402	0.733	0.733	5.5	53	2	0.06	0	5	1
17199	4793	0	6	5.8	400	1.402	0.733	0.733	5.5	53	2	0.06	0	5	1
4376	4794	33	2	5.8	570	0.5	0.25	0.25	5	10	4	0.016	0	5	1
5616	4794	33	4	5.8	570	0.5	0.25	0.25	5	10	4	0.016	0	5	1
14121	4795	0	6	5.8	340	1.03	0.835	0.772	9.2	89	3.937	0.063	0	5	1
11138	4797	30	4	5.8	510	0.38	0.33	0.3	7.2	32	2	0.015	0	5	1
10343	4798	20	1	6.8	462	1.25	0.65	0.43	9.6	57	1	0.06	0	5	1
21354	4798	20	4	6.8	462	1.25	0.65	0.43	9.6	57	1	0.06	0	5	1
7073	4799	33	2	5.8	655	1.02	0.695	0.695	7.8	53	4	0.05	0	5	1
10343	4799	33	4	5.8	655	1.02	0.695	0.695	7.8	53	4	0.05	0	5	1
15114	4799	33	8	5.8	655	1.02	0.695	0.695	7.8	53	4	0.05	0	5	1
9471	4802	20	4	6.8	400	0.89	0.836	0.668	5	60	2	0.09	0	5	1
13455	4802	20	8	6.8	400	0.89	0.838	0.668	5	60	2	0.09	0	5	1
2498	4807	33	1	5.8	632	0.445	0.208	0.147	5.7	16	2	0.015	0	5	1
3728	4807	33	2	5.8	632	0.445	0.208	0.147	5.7	16	2	0.015	0	5	1
5374	4807	33	4	5.8	632	0.445	0.208	0.147	5.7	16	2	0.015	0	5	1
5748	4820	0	1	4.5	225	2.2	2.04	0.357	19.6	33	4	0.05	0	5	1
21013	4825	0	8	5.8	450	1.255	1.004	0.783	14.6	54	3.937	0.059	0	5	1
8679	4835	0	4	4.5	450	0.735	0.735	0.378	12.5	22	2	0.038	0	5	1
44331	4838	20	8	6.8	360	0.9	0.77	0.6	18	100	2	0.07	0	5	1
53130	4838	20	12	6.8	360	0.9	0.77	0.6	18	100	2	0.07	0	5	1
57402	4838	20	14	6.8	360	0.9	0.77	0.6	18	100	2	0.07	0	5	1
10455	4841	0	1	5.8	257	1.46	1.46	1.27	14.2	94	10	0.08	0	5	1
7600	4844	0	1	5.8	450	1.043	1.043	1.016	4.2	64	3.937	0.059	0	5	1
20048	4849	33	8	6.8	450	0.366	0.283	0.228	20	51	1.181	0.037	0	5	1
29098	4849	33	16	6.8	450	0.366	0.283	0.228	20	51	1.181	0.037	0	5	1

13819	4852	0	4	5.8	435	1.493	1.125	0.94	4.3	60	7	0.05	0	5	1
13653	4853	0	4	6.8	300	1.693	1.16	0.97	5.3	48	3.937	0.069	0	5	1
18768	4853	0	8	6.8	300	1.691	1.16	0.97	5.3	48	3.937	0.069	0	5	1
7561	4854	20	1	6.8	520	1	0.786	0.672	17.5	66	6	0.06	0	5	1
46567	4857	15	8	5.8	400	0.787	0.739	0.608	12.5	94	3.937	0.098	0	5	1
14000	4859	0	2	4.7	160	1.933	1.312	1.094	10.5	55	3	0.102	0	5	1
17800	4860	0	4	4.7	160	1.933	1.312	1.094	10.5	55	3	0.102	0	5	1
24538	4866	0	6	4.5	280	1.469	1.469	1.228	8	64	3.937	0.127	0	5	1
15118	4867	0	6	4.5	284	1.24	1.24	1.063	8.5	64	3.937	0.122	0	5	1
19977	4868	0	8	5.8	295	1.03	0.835	0.772	11	68	3.937	0.22	0	5	1
7691	4870	33	1	6.8	530	0.635	0.41	0.4	6.5	53	1	0.072	0	5	1
8030	4871	0	4	6.8	514	0.812	0.62	0.5	12.3	27	6	0.9	0	5	1
7412	4872	0	1	4.5	425	0.902	0.819	0.819	17.4	78	3.937	0.102	0	5	1
10080	4872	0	2	4.5	425	0.902	0.819	0.819	17.4	78	3.937	0.102	0	5	1
40353	4875	0	8	6.8	400	0.818	0.73	0.56	22	73	3.937	0.083	0	5	1
10137	4875	0	2	5.8	390	2.525	0.75	0.75	4	11	5	0.05	0	5	1
14388	4876	0	4	5.8	390	2.525	0.75	0.75	4	11	5	0.05	0	5	1
5644	4878	33	1	5.8	72	0.75	0.75	0.345	17.4	21	5	0.035	0	5	1
12876	4880	0	4	5.8	420	1.125	0.988	0.94	4.4	53	2	0.4	0	5	1
29252	4881	30	8	6.8	330	1.113	1.031	0.945	13	70	3.937	0.061	0	5	1
9087	4884	0	2	4.5	425	1.21	0.725	0.725	4.8	22	3	0.025	0	5	1
8784	4886	33	8	5.8	562	0.5	0.16	0.16	7	8	4	0.02	0	5	1
11098	4887	15	2	6.8	400	1.13	0.64	0.54	6.3	57	4	0.035	0	5	1
12385	4889	33	10	5.8	810	0.95	0.92	0.72	13.3	24	2	0.018	0	5	1
38118	4890	20	4	5.8	327	1.834	1.231	1.016	9.5	104	7.874	0.069	0	5	1
12183	4891	30	4	5.8	600	1.11	0.97	0.508	12.5	30	3	0.065	0	5	1
14195	4892	0	4	5.8	765	1.457	1.457	0.189	13	29	8	0.1	0	5	1
30605	4894	0	8	5.8	250	1.558	1.57	1.125	22	104	2	0.25	0	5	1
11905	4895	0	1	5.8	355	2.24	1.914	1.123	4.5	74	6	0.16	0	5	1
20799	4897	0	10	5.8	470	1.09	0.815	0.568	4.5	70	1	0.094	0	5	1
31743	4899	0	4	5.8	345	3.543	1.85	1.533	2.9	60	7.874	0.098	1	0	1
31743	4900	0	4	5.8	345	3.543	1.85	1.533	2.9	60	7.874	0.098	1	0	1
10618	4901	0	2	6	423	0.638	0.353	0.353	6.3	31	2	0.095	0	5	1
49755	5002	0	12	5.8	272	2.52	2.52	0.945	1.5	72	7.874	0.067	0	5	1
31939	5003	0	8	6.8	370	1.951	1.174	0.989	7.8	79	3.937	0.163	0	5	1
9402	5004	0	4	5.8	313	0.575	0.545	0.545	18	21	2	0.12	0	5	1
13724	5006	0	2	5.8	167	1.234	0.96	0.96	5	46	4	0.235	0	5	1
7601	5053	30	1	5.8	390	1.693	1.646	1.52	1.2	93	3.937	0.113	0	5	1
5275	5057	0	2	6.8	375	0.949	0.67	0.67	3	21	3	0.06	0	5	1
17534	5079	33	4	5.8	371	1.575	1.496	0.317	11.6	41	5.512	0.067	0	5	1
20085	5090	30	4	6.8	346	1.179	1	0.776	4.5	74	3.937	0.069	0	5	1
13342	5091	15	2	5.8	510	0.957	0.44	0.44	3.2	24	4	0.028	0	5	1
11898	5092	13	2	5.8	554	1.375	0.678	0.678	3.7	38	4	0.03	0	5	1
14352	5093	15	2	5.8	507	1.778	0.892	0.892	3.1	35	4	0.028	0	5	1
10085	5107	0	1	5.8	450	1.22	1.22	0.94	4.7	102	3.937	0.177	0	5	1
12350	5111	13	4	5.8	387	1.146	1.146	0.167	15	25	4	0.067	0	5	1
14956	5112	13	4	5.8	415	1.173	1.173	0.089	1.7	19	4	0.086	0	5	1
23485	5121	15	4	5.8	395	1.22	1.22	0.94	4.7	116	3.937	0.177	0	5	1
19624	5127	0	4	5.8	360	1.598	0.823	0.546	7	69	3.15	0.05	0	5	1
15331	5138	0	4	5.5	225	1.136	0.65	0.65	4.5	23	4	0.06	0	5	1
8767	5154	0	2	6.8	370	1.15	0.53	0.44	2.3	41	2	0.03	0	5	1
31528	5157	33	10	6	400	1.266	0.259	0.259	5	55	2	0.035	1	0	2
9946	5170	0	4	5.8	480	0.889	0.889	0.167	15	29	4	0.067	0	5	1
9909	5208	0	1	5.8	260	2.127	1.811	1.811	1.5	112	3.937	0.068	0	5	1

The data contained in this appendix is presented in the following order:

Data for Table IV.D-1&2
Data for Table IV.E- 1&2
Data for Table IV.E- 3
Data for Table IV.E- 4&5
Data for Table IV.E- 6&8

Table IV.D-L92

```
                 Statistical Costing Model for the Cost Estimation
                   for the Economic Model for Injection Molding

                               Correlation Analysis

15 'VAR' Variables:  U         X         Y         Z1        Z2        V
                     LENGTH    WIDTH     DEPTH     CAV       COST      DIM
                     TOL       SIDE      PRISM

                                Simple Statistics

Variable                     N            Mean         Std Dev             Sum

U                          110        0.027273        0.163622        3.000000
X                          110       13.230772        7.354168     1455.384954
Y                          110        0.851186        0.427083       93.630463
Z1                         110       55.520936       45.544198     6107.302967
Z2                         110       46.835322       40.257257     5151.885388
V                          110        3.597419        2.484563      395.716115
LENGTH                     110        1.187845        0.642484      130.663000
WIDTH                      110        0.909473        0.523360      100.042000
DEPTH                      110        0.645955        0.360897       71.055000
CAV                        110        4.727273        3.337057      520.000000
COST                       110           14508           11322         1595903
DIM                        110       45.854545       28.783225     5044.000000
TOL                        110        3.452691        1.718454      379.796000
SIDE                       110        0.027273        0.163622        3.000000
PRISM                      110        9.043636        5.486957      994.800000

                            Simple Statistics

Variable               Minimum         Maximum    Label

U                            0        1.000000
X                     2.828427       37.416574
Y                     0.173205        2.330540
Z1                    3.313005      198.658904
Z2                    2.210654      171.473030
V                     0.185237       16.666667
LENGTH                0.274000        3.543000    Length
WIDTH                 0.160000        2.575000    Width
DEPTH                 0.089000        1.811000    Depth
CAV                   1.000000       16.000000    Number of Cavities
COST               2025.000000           57402    Mold Cost
DIM                   5.000000      117.000000    Total Dimensions
TOL                   0.394000       10.000000    Tightest Tolerance
SIDE                         0        1.000000    Side Actions
PRISM                 1.200000       25.000000    Percent Prism
```

Table IV.E-1&2

```
           Statistical Costing Model for the Cost Estimation
              for the Economic Model for Injection Molding

                          Correlation Analysis

   Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 110

                             U           X           Y          Z1          Z2

U                      1.00000     0.11241     0.35186    -0.10660    -0.09194
                        0.0         0.2423      0.0002      0.2677      0.3394

X                      0.11241     1.00000     0.07915     0.50410     0.57799
                        0.2423      0.0         0.4111      0.0001      0.0001

Y                      0.35186     0.07915     1.00000     0.13820     0.17045
                        0.0002      0.4111      0.0         0.1499      0.0750

Z1                    -0.10660     0.50410     0.13820     1.00000     0.95179
                        0.2677      0.0001      0.1499      0.0         0.0001

Z2                    -0.09194     0.57799     0.17045     0.95179     1.00000
                        0.3394      0.0001      0.0750      0.0001      0.0

V                     -0.10759    -0.12194    -0.47221    -0.16369    -0.12196
                        0.2632      0.2044      0.0001      0.0875      0.2043

LENGTH                 0.41789    -0.07726     0.86376     0.09244     0.01361
Length                  0.0001      0.4224      0.0001      0.3368      0.8878

WIDTH                  0.13184    -0.09171     0.71320     0.25822     0.12257
Width                   0.1698      0.3407      0.0001      0.0065      0.2021

DEPTH                  0.21551     0.16860     0.91778     0.15770     0.25877
Depth                   0.0238      0.0783      0.0001      0.0999      0.0063

CAV                    0.06415     0.76682    -0.20391     0.20081     0.24135
Number of Cavities      0.5055      0.0001      0.0326      0.0354      0.0111

COST                   0.25500     0.87056     0.20195     0.57695     0.62883
Mold Cost               0.0072      0.0001      0.0344      0.0001      0.0001

DIM                    0.07293     0.66503     0.39245     0.57014     0.65981
Total Dimensions        0.4490      0.0001      0.0001      0.0001      0.0001

TOL                    0.24112    -0.05878     0.32097     0.07669     0.06866
Tightest Tolerance      0.0112      0.5419      0.0006      0.4259      0.4760

SIDE                   1.00000     0.11241     0.35186    -0.10660    -0.09194
Side Actions            0.0001      0.2423      0.0002      0.2677      0.3394

PRISM                 -0.16688     0.32719    -0.22556     0.82885     0.74611
Percent Prism           0.0814      0.0005      0.0178      0.0001      0.0001
```

Table IV.E-1+2 (cont)

```
              Statistical Costing Model for the Cost Estimation
                 for the Economic Model for Injection Molding

                            Correlation Analysis

   Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 110

                              V      LENGTH       WIDTH       DEPTH         CAV

U                      -0.10759     0.41789     0.13184     0.21551     0.06415
                         0.2632      0.0001      0.1698      0.0238      0.5055

X                      -0.12194    -0.07726    -0.09171     0.16860     0.76682
                         0.2044      0.4224      0.3407      0.0783      0.0001

Y                      -0.47221     0.86376     0.71320     0.91778    -0.20391
                         0.0001      0.0001      0.0001      0.0001      0.0326

Z1                     -0.16369     0.09244     0.25822     0.15770     0.20081
                         0.0875      0.3368      0.0065      0.0999      0.0354

Z2                     -0.12196     0.01361     0.12257     0.25877     0.24135
                         0.2043      0.8878      0.2021      0.0063      0.0111

V                       1.00000    -0.51871    -0.46596    -0.35330     0.13555
                         0.0         0.0001      0.0001      0.0002      0.1580

LENGTH                 -0.51871     1.00000     0.81190     0.60047    -0.27432
Length                   0.0001      0.0         0.0001      0.0001      0.0037

WIDTH                  -0.46596     0.81190     1.00000     0.54619    -0.24493
Width                    0.0001      0.0001      0.0         0.0001      0.0099

DEPTH                  -0.35330     0.60047     0.54619     1.00000    -0.12131
Depth                    0.0002      0.0001      0.0001      0.0         0.2068

CAV                     0.13555    -0.27432    -0.24493    -0.12131     1.00000
Number of Cavities       0.1580      0.0037      0.0099      0.2068      0.0

COST                   -0.17809     0.12459     0.00490     0.20100     0.56679
Mold Cost                0.0627      0.1947      0.9595      0.0352      0.0001

DIM                    -0.24922     0.15349     0.14981     0.49727     0.12480
Total Dimensions         0.0087      0.1094      0.1183      0.0001      0.1939

TOL                     0.45514     0.31592     0.21263     0.27395    -0.10597
Tightest Tolerance       0.0001      0.0008      0.0257      0.0038      0.2706

SIDE                   -0.10759     0.41789     0.13184     0.21551     0.06415
Side Actions             0.2632      0.0001      0.1698      0.0238      0.5055

PRISM                  -0.00906    -0.17328     0.02892    -0.21792     0.28144
Percent Prism            0.9251      0.0702      0.7643      0.0222      0.0029
```

Table IV.E1+2 contd.

```
                 Statistical Costing Model for the Cost Estimation
                    for the Economic Model for Injection Molding

                                Correlation Analysis

       Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 110

                                  COST         DIM         TOL        SIDE       PRISM

U                              0.25500     0.07293     0.24112     1.00000    -0.16688
                                0.0072      0.4490      0.0112      0.0001      0.0814

X                              0.87056     0.66503    -0.05878     0.11241     0.32719
                                0.0001      0.0001      0.5419      0.2423      0.0005

Y                              0.20195     0.39245     0.32097     0.35186    -0.22556
                                0.0344      0.0001      0.0006      0.0002      0.0178

Z1                             0.57695     0.57014     0.07669    -0.10660     0.82885
                                0.0001      0.0001      0.4259      0.2677      0.0001

Z2                             0.62883     0.65981     0.06866    -0.09194     0.74611
                                0.0001      0.0001      0.4760      0.3394      0.0001

V                             -0.17809    -0.24922     0.45514    -0.10759    -0.00906
                                0.0627      0.0087      0.0001      0.2632      0.9251

LENGTH                         0.12459     0.15349     0.31592     0.41789    -0.17328
Length                          0.1947      0.1094      0.0008      0.0001      0.0702

WIDTH                          0.00490     0.14981     0.21263     0.13184     0.02892
Width                           0.9595      0.1183      0.0257      0.1698      0.7643

DEPTH                          0.20100     0.49727     0.27395     0.21551    -0.21792
Depth                           0.0352      0.0001      0.0038      0.0238      0.0222

CAV                            0.56679     0.12480    -0.10597     0.06415     0.28144
Number of Cavities              0.0001      0.1939      0.2706      0.5055      0.0029

COST                           1.00000     0.66109     0.06940     0.25500     0.35116
Mold Cost                       0.0         0.0001      0.4712      0.0072      0.0002

DIM                            0.66109     1.00000     0.07321     0.07293     0.18168
Total Dimensions                0.0001      0.0         0.4472      0.4490      0.0575

TOL                            0.06940     0.07321     1.00000     0.24112    -0.10986
Tightest Tolerance              0.4712      0.4472      0.0         0.0112      0.2532

SIDE                           0.25500     0.07293     0.24112     1.00000    -0.16688
Side Actions                    0.0072      0.4490      0.0112      0.0         0.0814

PRISM                          0.35116     0.18168    -0.10986    -0.16688     1.00000
Percent Prism                   0.0002      0.0575      0.2532      0.0814      0.0
```

```
                                                   The SAS System

                                              Correlation Analysis     - Table IV.E-1&2

                          Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 111

                               COST          ID         CAV     MATCODE        SHOT      LENGTH       WIDTH       DEPTH

COST                        1.00000     0.21711     0.50210     0.32987    -0.16141     0.18071     0.08959     0.21437
Mold Cost                    0.0         0.0221      0.0001      0.0004      0.0906      0.0577      0.3498      0.0239

ID                          0.21711     1.00000    -0.23171     0.06485    -0.01012     0.07217    -0.04866     0.18055
Part Identification#         0.0221      0.0         0.0144      0.4989      0.9161      0.4516      0.6121      0.0579

CAV                         0.50210    -0.23171     1.00000     0.27335     0.06406    -0.28593    -0.22935    -0.09845
Number of Cavities           0.0001      0.0144      0.0         0.0037      0.5041      0.0023      0.0155      0.3040

MATCODE                     0.32987     0.06485     0.27335     1.00000     0.05611    -0.12851    -0.18528    -0.06701
Material Code                0.0004      0.4989      0.0037      0.0         0.5586      0.1789      0.0516      0.4847

SHOT                       -0.16141    -0.01012     0.06406     0.05611     1.00000    -0.47789    -0.54442    -0.40246
Shots per Hour               0.0906      0.9161      0.5041      0.5586      0.0         0.0001      0.0001      0.0001

LENGTH                      0.18071     0.07217    -0.28593    -0.12851    -0.47789     1.00000     0.81887     0.60251
Length                       0.0577      0.4516      0.0023      0.1789      0.0001      0.0         0.0001      0.0001

WIDTH                       0.08959    -0.04866    -0.22935    -0.18528    -0.54442     0.81887     1.00000     0.54464
Width                        0.3498      0.6121      0.0155      0.0516      0.0001      0.0001      0.0         0.0001

DEPTH                       0.21437     0.18055    -0.09845    -0.06701    -0.40246     0.60251     0.54464     1.00000
Depth                        0.0239      0.0579      0.3040      0.4847      0.0001      0.0001      0.0001      0.0

PRISM                       0.29224    -0.21899     0.33109     0.15088    -0.13347    -0.19376    -0.00908    -0.22563
Percent Prism                0.0019      0.0209      0.0004      0.1139      0.1626      0.0416      0.9246      0.0173

DIM                         0.66840     0.30739     0.16608     0.22979    -0.17079     0.17236     0.18134     0.51244
Total Dimensions             0.0001      0.0010      0.0815      0.0153      0.0731      0.0705      0.0568      0.0001

TOL                         0.12883     0.14887    -0.09218    -0.14644    -0.16244     0.34720     0.26524     0.28400
Tightest Tolerance           0.1778      0.1189      0.3359      0.1251      0.0885      0.0002      0.0049      0.0025

THICK                       0.21751     0.28006    -0.03475    -0.00740    -0.32237     0.21558     0.27253     0.45098
Wall Thickness               0.0218      0.0029      0.7173      0.9386      0.0036      0.0231      0.0038      0.0001

SIDE                        0.24045     0.14658    -0.08275    -0.01695    -0.05955     0.40682     0.12201     0.21356
Side Actions                 0.0110      0.1249      0.3879      0.8599      0.5347      0.0001      0.2021      0.0244

UNDERCUT                   -0.24045    -0.14658     0.08275     0.01695     0.05955    -0.40682    -0.12201    -0.21356
Undercut Complexity          0.0110      0.1248      0.3879      0.8599      0.5347      0.0001      0.2021      0.0244

PARTLINE                    0.13639     0.18950    -0.10324     0.00918    -0.01090     0.00972    -0.11731    -0.10356
Parting Line                 0.1535      0.0464      0.2809      0.9238      0.9096      0.9194      0.2201      0.2794
```

Table IV.E-1&2 contd.

```
                                      The SAS System

                                   Correlation Analysis

                Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 111

                          PRISM        DIM        TOL      THICK       SIDE   UNDERCUT   PARTLINE

COST                    0.29224    0.66840    0.12883    0.21751    0.24045   -0.24045    0.13639
Mold Cost                0.0019     0.0001     0.1778     0.0218     0.0110     0.0110     0.1535

ID                     -0.21899    0.30739    0.14887    0.28006    0.14558   -0.14658    0.18950
Part Identification#     0.0209     0.0010     0.1189     0.0029     0.1268     0.1268     0.0464

CAV                     0.33109    0.16608   -0.09218   -0.03475   -0.09275    0.09275   -0.10324
Number of Cavities       0.0004     0.0815     0.3359     0.7173     0.3879     0.3879     0.2809

MATCODE                 0.15088    0.22979   -0.14644   -0.00760   -0.01695    0.01695    0.00919
Material Code            0.1139     0.0153     0.1251     0.9386     0.8599     0.8599     0.9238

SHOT                   -0.13347   -0.17079   -0.16244   -0.32237   -0.05955    0.05955   -0.01090
Shots per Hour           0.1626     0.0731     0.0885     0.0006     0.5347     0.5347     0.9096

LENGTH                 -0.19374    0.17236    0.34720    0.21558    0.40682   -0.40682    0.00972
Length                   0.0416     0.0705     0.0002     0.0231     0.0001     0.0001     0.9194

WIDTH                  -0.00908    0.18134    0.26524    0.27253    0.12201   -0.12201   -0.11731
Width                    0.9246     0.0568     0.0049     0.0038     0.2021     0.2021     0.2201

DEPTH                  -0.22563    0.51244    0.28400    0.45898    0.21356   -0.21356   -0.10356
Depth                    0.0173     0.0001     0.0025     0.0001     0.0244     0.0244     0.2794

PRISM                   1.00000    0.20202   -0.13676    0.03141   -0.16338    0.16338   -0.06912
Percent Prism            0.0        0.0335     0.1523     0.7435     0.0866     0.0866     0.4710

DIM                     0.20202    1.00000    0.07664    0.43459    0.06745   -0.06745    0.02768
Total Dimensions         0.0335     0.0        0.4240     0.0001     0.4818     0.4818     0.7731

TOL                    -0.13676    0.07664    1.00000    0.09748    0.23036   -0.23036   -0.08116
Tightest Tolerance       0.1523     0.4240     0.0        0.3088     0.0150     0.0150     0.3971

THICK                   0.03141    0.43459    0.09748    1.00000    0.02839   -0.02839   -0.05533
Wall Thickness           0.7435     0.0001     0.3088     0.0        0.7674     0.7674     0.5641

SIDE                   -0.16338    0.06745    0.23036    0.02839    1.00000   -1.00000    0.57209
Side Actions             0.0866     0.4818     0.0150     0.7674     0.0        0.0001     0.0001

UNDERCUT                0.16338   -0.06745   -0.23036   -0.02839   -1.00000    1.00000   -0.57208
Undercut Complexity      0.0866     0.4819     0.0150     0.7674     0.0001     0.0        0.0001

PARTLINE               -0.06912    0.02768   -0.08116   -0.05533    0.57208   -0.57208    1.00000
Parting Line             0.4710     0.7731     0.3971     0.5641     0.0001     0.0001     0.0
```

Table IV.E-3

```
                                   Principal Component Analysis

11 Observations
12 Variables

                                        Simple Statistics

                      CAV              MATL            LENGTH             WIDTH             DEPTH             PRISM

Mean         4.693693694       5.735135135       1.199846847      0.9239819820      0.6486486486       8.975675676
StD          3.426614531       0.676441041       0.651936503      0.5429392730      0.3603718950       3.500690922

                      DIM               TOL              WALL              SIDE             UNDER              PART

Mean         44.54054054       3.492522523      0.0674684685      0.0270270270       4.864864865       1.009009009
StD          29.27138963       1.761347293      0.0562028501      0.1628975952       0.814487976       0.094915808

                                        Covariance Matrix

                     CAV              MATL            LENGTH             WIDTH             DEPTH             PRISM

CAV           11.7414971         0.6335872        -0.6387473        -0.4266965        -0.1215722         6.2497543
MATL           3.6335872         0.4579725        -0.0566709        -0.0680466        -0.0163348         0.5622260
LENGTH        -0.6387473        -0.0566709         0.4250212         0.2898496         0.1415545        -0.6958456
WIDTH         -0.4266965        -0.0680466         0.2898496         0.2947831         0.1065649        -0.0271704
DEPTH         -0.1215722        -0.0163348         0.1415545         0.1065649         0.1298679        -0.4479250
PRISM          6.2497543         0.5622260        -0.6958456        -0.0271704        -0.4479250        30.3456757
DIM           14.6579853         4.5499263         3.2892381         2.0819553         5.4055007        32.5750860
TOL           -0.5563385        -0.1744749         0.3986873         0.2536471         0.1802640        -1.3269499
WALL          -0.0066916        -0.0002812         0.0078989         0.0083162         0.0092962         0.0097233
SIDE          -0.0441916        -0.0018673         0.0432042         0.0107914         0.0125369        -0.1466093
UNDER          0.2309582         0.0093366        -0.2160209        -0.0539570        -0.0626843         0.7330467
PART          -0.0335790         0.0005897         0.0006014        -0.0060453        -0.0035423        -0.0361425

                     DIM               TOL              WALL              SIDE             UNDER              PART

CAV           14.6579853        -0.5563385        -0.0066916        -0.0441916         0.2309582        -0.0335790
MATL           4.5499263        -0.1744749        -0.0002812        -0.0018673         0.0093366         0.0005897
LENGTH         3.2892381         0.3986873         0.0078989         0.0432042        -0.2160209         0.0006014
WIDTH          2.0819553         0.2536471         0.0083162         0.0107914        -0.0539570        -0.0060453
DEPTH          5.4055007         0.1802640         0.0092962         0.0125369        -0.0626843        -0.0035423
PRISM         32.5750860        -1.3269499         0.0097233        -0.1466093         0.7330467        -0.0361425
DIM          856.8142506         3.9512514         0.7149627         0.3216216        -1.6081081         0.0769042
TOL            3.9512514         3.1023443         0.0096501         0.0660948        -0.3304742        -0.0135684
WALL           0.7149627         0.0094501         0.0031580         0.0002600        -0.0012998        -0.0002952
SIDE           0.3216216         0.0660948         0.0002600         0.0265356        -0.1326781        -0.0008452
UNDER         -1.6081081        -0.3304742        -0.0012998        -0.1326781         0.6633907        -0.0442260
PART           0.0769042        -0.0135684        -0.0002952        -0.0008452        -0.0442260         0.0090090
                 GROUP TECHNOLOGY VARIABLES FOR BOBBIN TYPE PARTS (COVARIANCE)    17:03 Friday, November 20, 1992
                                                                                                                2

                                   Principal Component Analysis
```

Table IV.E-3 contd.

```
                     Total Variance = 904.01329638

                 Eigenvalues of the Covariance Matrix

             Eigenvalue     Difference     Proportion     Cumulative

    PRIN1       858.535        827.671       0.949692        0.94969
    PRIN2        30.864         21.012       0.034141        0.98383
    PRIN3         9.853          6.756       0.010899        0.99473
    PRIN4         3.097          2.381       0.003426        0.99816
    PRIN5         0.716          0.232       0.000792        0.99895
    PRIN6         0.484          0.116       0.000535        0.99948
    PRIN7         0.367          0.318       0.000406        0.99989
    PRIN8         0.049          0.007       0.000054        0.99995
    PRIN9         0.042          0.038       0.000047        0.99999
    PRIN10        0.005          0.003       0.000005        1.00000
    PRIN11        0.002          0.002       0.000002        1.00000
    PRIN12        0.000                      0.000000        1.00000

                              Eigenvectors

          PRIN1     PRIN2     PRIN3     PRIN4     PRIN5     PRIN6     PRIN7     PRIN8     PRIN9     PRIN10    PRIN11    PRIN12

CAV     0.019474  0.279299  0.954510  0.064160  0.041581  0.066623  -.011219  -.007726  -.004540  0.003606  0.001185  0.000000
MATL    0.005335  0.017537  0.044972  -.058746  -.016132  -.500907  0.859277  0.027126  0.062568  0.003553  0.002892  0.000000
LENGTH  0.003747  -.033548  -.049614  0.129089  0.452473  0.444781  0.330749  -.048859  -.800739  0.040000  0.018504  0.000000
WIDTH   0.003366  -.009757  -.046868  0.087798  0.248979  0.534997  0.283940  -.285090  0.692044  -.024207  -.019105  0.000000
DEPTH   0.004259  -.023161  -.004970  0.045073  0.107967  0.187389  0.072187  0.952621  0.173541  0.068223  -.055932  0.000000
PRISM   0.039481  0.955937  -.284608  0.051858  0.022116  -.004569  -.003600  0.010986  -.007650  0.001270  -.000477  0.000000
DIM     0.979944  -.042773  -.007517  -.008741  -.005501  -.001849  -.006457  -.005550  -.001897  -.000605  -.000503  0.000000
TOL     0.004944  -.059542  -.033379  0.973700  -.196284  -.091992  0.011991  -.010005  0.006330  0.000319  0.000220  0.000000
WALL    0.000097  -.009790  -.001594  0.001801  0.082581  0.013631  0.001690  0.049323  0.035172  -.007720  0.990022  0.000000
SIDE    0.000167  -.009719  -.001070  0.024155  0.161489  -.090696  -.049922  -.001901  0.027922  -.016252  -.000160  0.980301
UNDER   -.001137  0.028594  0.005350  -.120774  -.807445  0.453481  0.249610  0.009505  -.139610  0.001259  0.000000  0.194116
PART    0.000187  -.001543  -.002219  -.004212  0.050317  -.054268  -.035990  -.070027  0.044021  0.993011  -.010299  -.000000
```

Table IV.E-445

```
                                E M I M
              Statistical Costing Model for the Cost Estimation
                 for the Economic Model for Injection Molding

 N = 111      Regression Models for Dependent Variable: COST

Number in     R-square    Variables in Model
  Model

      1      0.44676504   DIM
      1      0.25210278   CAV
      1      0.08540134   PRISM
      1      0.05781555   SIDE
      1      0.05781555   UNDERCUT
      1      0.04731158   THICK
      1      0.04595392   DEPTH
      1      0.03265691   LENGTH
      1      0.01659818   TOL
      1      0.00802595   WIDTH
-------------------------------------
      2      0.60405528   CAV DIM
      2      0.48510664   DIM SIDE
      2      0.48510664   DIM UNDERCUT
      2      0.47252767   PRISM DIM
      2      0.46903473   DEPTH DIM
      2      0.45332969   DIM THICK
      2      0.45282370   DIM TOL
      2      0.45118709   LENGTH DIM
      2      0.44779890   WIDTH DIM
      2      0.36662073   CAV LENGTH
      2      0.33217442   CAV SIDE
      2      0.33217442   CAV UNDERCUT
      2      0.32237462   CAV DEPTH
      2      0.30737494   CAV THICK
      2      0.29635081   CAV WIDTH
      2      0.28303137   CAV TOL
      2      0.26993174   CAV PRISM
      2      0.17073492   PRISM SIDE
      2      0.17073492   PRISM UNDERCUT
      2      0.16818815   DEPTH PRISM
      2      0.14392643   LENGTH PRISM
      2      0.12884743   PRISM THICK
      2      0.11443793   PRISM TOL
      2      0.10223957   THICK SIDE
      2      0.10223957   THICK UNDERCUT
      2      0.09391071   WIDTH PRISM
      2      0.08566041   DEPTH UNDERCUT
      2      0.08566041   DEPTH SIDE
      2      0.06609266   LENGTH THICK
      2      0.06604940   LENGTH SIDE
      2      0.06604940   LENGTH UNDERCUT
      2      0.06393085   DEPTH THICK
      2      0.06351186   SIDE TOL
      2      0.06351186   UNDERCUT TOL
      2      0.06150040   WIDTH SIDE
      2      0.06150040   WIDTH UNDERCUT
      2      0.05900699   THICK TOL
      2      0.05097678   DEPTH TOL
      2      0.05012615   LENGTH DEPTH
```

Table IV.E-4+5 (cont)

```
                                  E M I M
                Statistical Costing Model for the Cost Estimation
                 for the Economic Model for Injection Molding

Number in      R-square    Variables in Model
  Model

       2      0.04833392   WIDTH THICK
       2      0.04700322   WIDTH DEPTH
       2      0.04300664   LENGTH WIDTH
       2      0.03762357   LENGTH TOL
       2      0.01990152   WIDTH TOL
 ----------------------------------------
       3      0.65916588   CAV DIM SIDE
       3      0.65916588   CAV DIM UNDERCUT
       3      0.64450438   CAV LENGTH DIM
       3      0.61865838   CAV DIM TOL
       3      0.60994709   CAV WIDTH DIM
       3      0.60825467   CAV DEPTH DIM
       3      0.60567839   CAV PRISM DIM
       3      0.60517881   CAV DIM THICK
       3      0.52481939   PRISM DIM SIDE
       3      0.52481939   PRISM DIM UNDERCUT
       3      0.52290959   DEPTH DIM SIDE
       3      0.52290959   DEPTH DIM UNDERCUT
       3      0.50823620   LENGTH DEPTH DIM
       3      0.49163885   DIM THICK UNDERCUT
       3      0.49163885   DIM THICK SIDE
       3      0.48806647   WIDTH DIM SIDE
       3      0.48806647   WIDTH DIM UNDERCUT
       3      0.48629033   DIM UNDERCUT TOL
       3      0.48629033   DIM SIDE TOL
       3      0.48528536   LENGTH DIM SIDE
       3      0.48528536   LENGTH DIM UNDERCUT
       3      0.48484450   DEPTH DIM TOL
       3      0.48410613   LENGTH PRISM DIM
       3      0.48337397   PRISM DIM TOL
       3      0.48134668   DEPTH PRISM DIM
       3      0.47759731   PRISM DIM THICK
       3      0.47313297   WIDTH PRISM DIM
       3      0.47312124   LENGTH WIDTH DIM
       3      0.47221792   WIDTH DEPTH DIM
       3      0.47041932   DEPTH DIM THICK
       3      0.46035921   DIM THICK TOL
       3      0.45978779   LENGTH DIM THICK
       3      0.45572965   WIDTH DIM TOL
       3      0.45463552   LENGTH DIM TOL
       3      0.45354844   WIDTH DIM THICK
       3      0.39608226   CAV LENGTH PRISM
       3      0.39428100   CAV LENGTH THICK
       3      0.39244279   CAV LENGTH UNDERCUT
       3      0.39244279   CAV LENGTH SIDE
       3      0.38412415   CAV THICK SIDE
       3      0.38412415   CAV THICK UNDERCUT
       3      0.37802011   CAV LENGTH WIDTH
       3      0.37671843   CAV DEPTH UNDERCUT
       3      0.37671843   CAV DEPTH SIDE
       3      0.37251046   CAV LENGTH DEPTH
       3      0.37096521   CAV LENGTH TOL
       3      0.35509163   CAV WIDTH SIDE
```

TABLE IV.E-445 (cont..)

```
                              E M A -
        Statistical Costing Model for the Cost Estimation
           for the Economic Model for Injection Molding

Number in      R-square    Variables in Model
  Model

      3       0.36505160   CAV WIDTH UNDERCUT
      3       0.36325501   CAV PRISM SIDE
      3       0.36325501   CAV PRISM UNDERCUT
      3       0.35928640   CAV DEPTH PRISM
      3       0.34544696   CAV SIDE TOL
      3       0.34544696   CAV UNDERCUT TOL
      3       0.33872743   CAV DEPTH THICK
      3       0.33371662   CAV DEPTH TOL
      3       0.33117895   CAV THICK TOL
      3       0.33052353   CAV WIDTH THICK
      3       0.32879163   CAV WIDTH DEPTH
      3       0.32249276   CAV PRISM THICK
      3       0.31247490   CAV WIDTH TOL
      3       0.31039978   CAV WIDTH PRISM
      3       0.30687103   CAV PRISM TOL
      3       0.22741718   DEPTH PRISM UNDERCUT
      3       0.22741718   DEPTH PRISM SIDE
      3       0.21018507   PRISM THICK SIDE
      3       0.21018507   PRISM THICK UNDERCUT
      3       0.19022363   LENGTH PRISM SIDE
      3       0.19022363   LENGTH PRISM UNDERCUT
      3       0.18300313   PRISM SIDE TOL
      3       0.18300313   PRISM UNDERCUT TOL
      3       0.18290689   LENGTH WIDTH PRISM
      3       0.17786557   DEPTH PRISM TOL
      3       0.17643982   LENGTH DEPTH PRISM
      3       0.17489410   WIDTH DEPTH PRISM
      3       0.17467567   DEPTH PRISM THICK
      3       0.17398197   WIDTH PRISM SIDE
      3       0.17398197   WIDTH PRISM UNDERCUT
      3       0.16983858   LENGTH PRISM THICK
      3       0.15313142   LENGTH PRISM TOL
      3       0.15127805   PRISM THICK TOL
      3       0.13019773   WIDTH PRISM THICK
      3       0.11679893   WIDTH PRISM TOL
      3       0.10832521   DEPTH THICK SIDE
      3       0.10832521   DEPTH THICK UNDERCUT
      3       0.10537711   THICK SIDE TOL
      3       0.10537711   THICK UNDERCUT TOL
      3       0.10424479   LENGTH THICK SIDE
      3       0.10424479   LENGTH THICK UNDERCUT
      3       0.10225311   WIDTH THICK SIDE
      3       0.10225311   WIDTH THICK UNDERCUT
      3       0.08691038   DEPTH UNDERCUT TOL
      3       0.08691038   DEPTH SIDE TOL
      3       0.08680148   WIDTH DEPTH UNDERCUT
      3       0.08680148   WIDTH DEPTH SIDE
      3       0.08570872   LENGTH DEPTH UNDERCUT
      3       0.08570872   LENGTH DEPTH SIDE
      3       0.08433095   LENGTH WIDTH THICK
      3       0.07044537   LENGTH THICK TOL
      3       0.06976839   LENGTH DEPTH THICK
      3       0.06972232   DEPTH THICK TOL
```

TABLE IV.E-495 (cont...)

```
                                S M I M
          Statistical Costing Model for the Cost Estimation
             for the Economic Model for Injection Molding

Number in      R-square    Variables in Model
  Model

      3      0.06872717   LENGTH UNDERCUT TOL
      3      0.06872717   LENGTH SIDE TOL
      3      0.06699549   LENGTH WIDTH UNDERCUT
      3      0.06699549   LENGTH WIDTH SIDE
      3      0.06540449   WIDTH SIDE TOL
      3      0.06540449   WIDTH UNDERCUT TOL
      3      0.06526070   WIDTH DEPTH THICK
      3      0.06387606   LENGTH WIDTH DEPTH
      3      0.05902903   WIDTH THICK TOL
      3      0.05343452   LENGTH DEPTH TOL
      3      0.05278651   WIDTH DEPTH TOL
      3      0.04748371   LENGTH WIDTH TOL
-------------------------------------------------
      4      0.69813084   CAV LENGTH DEPTH DIM
      4      0.67441894   CAV LENGTH DIM UNDERCUT
      4      0.67441894   CAV LENGTH DIM SIDE
      4      0.67179995   CAV DEPTH DIM SIDE
      4      0.67179995   CAV DEPTH DIM UNDERCUT
      4      0.66743832   CAV LENGTH WIDTH DIM
      4      0.66539401   CAV PRISM DIM SIDE
      4      0.66539401   CAV PRISM DIM UNDERCUT
      4      0.66424797   CAV DIM UNDERCUT TOL
      4      0.66424797   CAV DIM SIDE TOL
      4      0.66228543   CAV WIDTH DIM SIDE
      4      0.66228543   CAV WIDTH DIM UNDERCUT
      4      0.66009900   CAV DIM THICK SIDE
      4      0.66009900   CAV DIM THICK UNDERCUT
      4      0.65176544   CAV LENGTH PRISM DIM
      4      0.65013320   CAV LENGTH DIM THICK
      4      0.64975583   CAV LENGTH DIM TOL
      4      0.62891763   CAV DEPTH DIM TOL
      4      0.62442690   CAV WIDTH DEPTH DIM
      4      0.62184899   CAV PRISM DIM TOL
      4      0.62110314   CAV WIDTH DIM TOL
      4      0.62032042   CAV DIM THICK TOL
      4      0.61239388   CAV WIDTH DIM THICK
      4      0.61134491   CAV WIDTH PRISM DIM
      4      0.60860910   CAV DEPTH PRISM DIM
      4      0.60849472   CAV DEPTH DIM THICK
      4      0.60672732   CAV PRISM DIM THICK
      4      0.54179700   DEPTH PRISM DIM SIDE
      4      0.54179700   DEPTH PRISM DIM UNDERCUT
      4      0.53823268   LENGTH DEPTH DIM SIDE
      4      0.53823268   LENGTH DEPTH DIM UNDERCUT
      4      0.53027599   DEPTH DIM SIDE TOL
      4      0.53027599   DEPTH DIM UNDERCUT TOL
      4      0.52943994   PRISM DIM THICK SIDE
      4      0.52943994   PRISM DIM THICK UNDERCUT
      4      0.52826883   PRISM DIM SIDE TOL
      4      0.52826883   PRISM DIM UNDERCUT TOL
      4      0.52720833   WIDTH PRISM DIM SIDE
      4      0.52720833   WIDTH PRISM DIM UNDERCUT
      4      0.52608847   WIDTH DEPTH DIM SIDE
```

TABLE IVE-445 (cont..)

```
                                   C M I M
                  Statistical Costing Model for the Cost Estimation
                    for the Economic Model for Injection Molding
Number in
  Model        R-square     Variables in Model

     4       0.52608847   WIDTH DEPTH DIM UNDERCUT
     4       0.52536409   LENGTH PRISM DIM SIDE
     4       0.52536409   LENGTH PRISM DIM UNDERCUT
     4       0.52467643   LENGTH WIDTH PRISM DIM
     4       0.52451512   LENGTH WIDTH DEPTH DIM
     4       0.52335464   DEPTH DIM THICK SIDE
     4       0.52335464   DEPTH DIM THICK UNDERCUT
     4       0.52048964   LENGTH DEPTH PRISM DIM
     4       0.51537691   LENGTH DEPTH DIM TOL
     4       0.50914337   LENGTH DEPTH DIM THICK
     4       0.49862378   DEPTH PRISM DIM TOL
     4       0.49327617   DIM THICK UNDERCUT TOL
     4       0.49327617   DIM THICK SIDE TOL
     4       0.49304712   WIDTH DIM THICK UNDERCUT
     4       0.49304712   WIDTH DIM THICK SIDE
     4       0.49181267   LENGTH PRISM DIM THICK
     4       0.49175550   LENGTH WIDTH DIM SIDE
     4       0.49175550   LENGTH WIDTH DIM UNDERCUT
     4       0.49163930   LENGTH DIM THICK UNDERCUT
     4       0.49163930   LENGTH DIM THICK SIDE
     4       0.49044779   WIDTH DIM SIDE TOL
     4       0.49044779   WIDTH DIM UNDERCUT TOL
     4       0.48957254   LENGTH PRISM DIM TOL
     4       0.48938957   PRISM DIM THICK TOL
     4       0.48684288   LENGTH DIM SIDE TOL
     4       0.48684288   LENGTH DIM UNDERCUT TOL
     4       0.48650013   WIDTH DEPTH DIM TOL
     4       0.48613386   WIDTH PRISM DIM TOL
     4       0.48607164   DEPTH DIM THICK TOL
     4       0.48331320   DEPTH PRISM DIM THICK
     4       0.48250705   WIDTH DEPTH PRISM DIM
     4       0.47808693   LENGTH WIDTH DIM THICK
     4       0.47764649   WIDTH PRISM DIM THICK
     4       0.47596258   LENGTH WIDTH DIM TOL
     4       0.47391420   WIDTH DEPTH DIM THICK
     4       0.46344641   LENGTH DIM THICK TOL
     4       0.46170344   WIDTH DIM THICK TOL
     4       0.42876089   CAV LENGTH PRISM UNDERCUT
     4       0.42876089   CAV LENGTH PRISM SIDE
     4       0.42433333   CAV DEPTH PRISM UNDERCUT
     4       0.42433333   CAV DEPTH PRISM SIDE
     4       0.42398254   CAV LENGTH THICK UNDERCUT
     4       0.42398254   CAV LENGTH THICK SIDE
     4       0.42174236   CAV LENGTH WIDTH PRISM
     4       0.41995226   CAV LENGTH PRISM THICK
     4       0.41311856   CAV LENGTH WIDTH THICK
     4       0.41140297   CAV PRISM THICK SIDE
     4       0.41140297   CAV PRISM THICK UNDERCUT
     4       0.40788295   CAV LENGTH DEPTH PRISM
     4       0.40250714   CAV LENGTH PRISM TOL
     4       0.39957117   CAV LENGTH DEPTH UNDERCUT
     4       0.39957117   CAV LENGTH DEPTH SIDE
     4       0.39955644   CAV WIDTH THICK SIDE
```

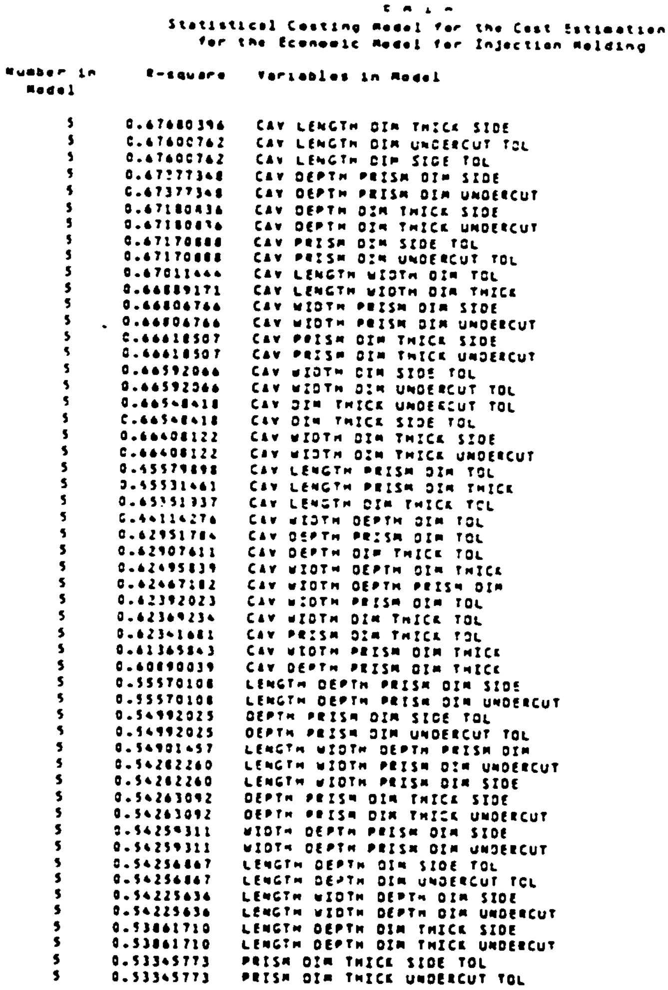
Table IV.E-4&5 (cont..)

```
                                   E M I M
                 Statistical Costing Model for the Cost Estimation
                   for the Economic Model for Injection Molding

  Number in      R-square    Variables in Model
    Model

       4         0.39955644    CAV WIDTH THICK UNDERCUT
       4         0.39830082    CAV DEPTH THICK UNDERCUT
       4         0.39830082    CAV DEPTH THICK SIDE
       4         0.39810722    CAV LENGTH THICK TOL
       4         0.39489314    CAV LENGTH UNDERCUT TOL
       4         0.39489314    CAV LENGTH SIDE TOL
       4         0.39454556    CAV LENGTH WIDTH UNDERCUT
       4         0.39454556    CAV LENGTH WIDTH SIDE
       4         0.39433430    CAV LENGTH DEPTH THICK
       4         0.39312430    CAV THICK SIDE TOL
       4         0.39312430    CAV THICK UNDERCUT TOL
       4         0.39087553    CAV WIDTH PRISM SIDE
       4         0.39087553    CAV WIDTH PRISM UNDERCUT
       4         0.38597951    CAV LENGTH WIDTH DEPTH
       4         0.38338357    CAV WIDTH DEPTH UNDERCUT
       4         0.38338357    CAV WIDTH DEPTH SIDE
       4         0.38188401    CAV LENGTH WIDTH TOL
       4         0.38109217    CAV DEPTH UNDERCUT TOL
       4         0.38109217    CAV DEPTH SIDE TOL
       4         0.38028250    CAV PRISM SIDE TOL
       4         0.38028250    CAV PRISM UNDERCUT TOL
       4         0.37593935    CAV LENGTH DEPTH TOL
       4         0.37324835    CAV DEPTH PRISM TOL
       4         0.37063536    CAV WIDTH SIDE TOL
       4         0.37063536    CAV WIDTH UNDERCUT TOL
       4         0.36895082    CAV DEPTH PRISM THICK
       4         0.36075168    CAV WIDTH DEPTH PRISM
       4         0.35138844    CAV PRISM THICK TOL
       4         0.35114234    CAV DEPTH THICK TOL
       4         0.34536357    CAV WIDTH THICK TOL
       4         0.34448287    CAV WIDTH DEPTH THICK
       4         0.34343255    CAV WIDTH PRISM THICK
       4         0.33822984    CAV WIDTH DEPTH TOL
       4         0.33124919    CAV WIDTH PRISM TOL
       4         0.23662549    DEPTH PRISM THICK UNDERCUT
       4         0.23662549    DEPTH PRISM THICK SIDE
       4         0.23512814    WIDTH DEPTH PRISM UNDERCUT
       4         0.23512814    WIDTH DEPTH PRISM SIDE
       4         0.23066618    DEPTH PRISM UNDERCUT TOL
       4         0.23066618    DEPTH PRISM SIDE TOL
       4         0.22857836    LENGTH WIDTH DEPTH PRISM
       4         0.22744977    LENGTH DEPTH PRISM UNDERCUT
       4         0.22744977    LENGTH DEPTH PRISM SIDE
       4         0.21947285    LENGTH WIDTH PRISM THICK
       4         0.21946150    LENGTH PRISM THICK SIDE
       4         0.21946150    LENGTH PRISM THICK UNDERCUT
       4         0.21860613    PRISM THICK SIDE TOL
       4         0.21860613    PRISM THICK UNDERCUT TOL
       4         0.21019584    WIDTH PRISM THICK SIDE
       4         0.21019584    WIDTH PRISM THICK UNDERCUT
       4         0.20527334    LENGTH WIDTH PRISM UNDERCUT
       4         0.20527334    LENGTH WIDTH PRISM SIDE
       4         0.19589380    LENGTH PRISM SIDE TOL
```

TABLE IV.E-45 (cont..)

```
                              E M I M
          Statistical Costing Model for the Cost Estimation
             for the Economic Model for Injection Molding

Number in     R-square   Variables in Model
  Model

    4        0.19589380   LENGTH PRISM UNDERCUT TOL
    4        0.19151798   LENGTH WIDTH PRISM TOL
    4        0.18742643   WIDTH DEPTH PRISM TOL
    4        0.18479067   DEPTH PRISM THICK TOL
    4        0.18412326   LENGTH DEPTH PRISM THICK
    4        0.18393127   WIDTH PRISM SIDE TOL
    4        0.18393127   WIDTH PRISM UNDERCUT TOL
    4        0.18283011   LENGTH DEPTH PRISM TOL
    4        0.18149784   WIDTH DEPTH PRISM THICK
    4        0.17714613   LENGTH PRISM THICK TOL
    4        0.15127840   WIDTH PRISM THICK TOL
    4        0.10985088   DEPTH THICK SIDE TOL
    4        0.10985088   DEPTH THICK UNDERCUT TOL
    4        0.10980388   WIDTH DEPTH THICK UNDERCUT
    4        0.10980388   WIDTH DEPTH THICK SIDE
    4        0.10833063   LENGTH DEPTH THICK SIDE
    4        0.10833063   LENGTH DEPTH THICK UNDERCUT
    4        0.10814710   LENGTH WIDTH THICK UNDERCUT
    4        0.10814710   LENGTH WIDTH THICK SIDE
    4        0.10631874   LENGTH THICK SIDE TOL
    4        0.10631874   LENGTH THICK UNDERCUT TOL
    4        0.10546624   WIDTH THICK SIDE TOL
    4        0.10546624   WIDTH THICK UNDERCUT TOL
    4        0.08877681   LENGTH WIDTH DEPTH THICK
    4        0.08843558   WIDTH DEPTH UNDERCUT TOL
    4        0.08843558   WIDTH DEPTH SIDE TOL
    4        0.08800138   LENGTH WIDTH THICK TOL
    4        0.08777774   LENGTH WIDTH DEPTH UNDERCUT
    4        0.08777774   LENGTH WIDTH DEPTH SIDE
    4        0.08709370   LENGTH DEPTH UNDERCUT TOL
    4        0.08709370   LENGTH DEPTH SIDE TOL
    4        0.07340226   LENGTH DEPTH THICK TOL
    4        0.07197777   WIDTH DEPTH THICK TOL
    4        0.06969597   LENGTH WIDTH UNDERCUT TOL
    4        0.06969597   LENGTH WIDTH SIDE TOL
    4        0.06658855   LENGTH WIDTH DEPTH TOL
------------------------------------------------------
    5        0.72258675   CAV LENGTH DEPTH DIM SIDE
    5        0.72258675   CAV LENGTH DEPTH DIM UNDERCUT
    5        0.71381188   CAV LENGTH WIDTH DEPTH DIM
    5        0.70478694   CAV LENGTH DEPTH DIM TOL
    5        0.69813247   CAV LENGTH DEPTH PRISM DIM
    5        0.69813086   CAV LENGTH DEPTH DIM THICK
    5        0.68860034   CAV WIDTH DEPTH DIM SIDE
    5        0.68860034   CAV WIDTH DEPTH DIM UNDERCUT
    5        0.68279352   CAV LENGTH PRISM DIM UNDERCUT
    5        0.68279352   CAV LENGTH PRISM DIM SIDE
    5        0.68200331   CAV DEPTH DIM SIDE TOL
    5        0.68200331   CAV DEPTH DIM UNDERCUT TOL
    5        0.68155108   CAV LENGTH WIDTH DIM UNDERCUT
    5        0.68155108   CAV LENGTH WIDTH DIM SIDE
    5        0.68075443   CAV LENGTH WIDTH PRISM DIM
    5        0.67680396   CAV LENGTH DIM THICK UNDERCUT
```

TABLE IV.E-4&5-(Cont..)



```
         Statistical Costing Model for the Cost Estimation
           for the Economic Model for Injection Molding

Number in     R-square    Variables in Model
  Model

     5        0.67680396  CAV LENGTH DIM THICK SIDE
     5        0.67600762  CAV LENGTH DIM UNDERCUT TOL
     5        0.67600762  CAV LENGTH DIM SIDE TOL
     5        0.67377348  CAV DEPTH PRISM DIM SIDE
     5        0.67377348  CAV DEPTH PRISM DIM UNDERCUT
     5        0.67180436  CAV DEPTH DIM THICK SIDE
     5        0.67180436  CAV DEPTH DIM THICK UNDERCUT
     5        0.67170888  CAV PRISM DIM SIDE TOL
     5        0.67170888  CAV PRISM DIM UNDERCUT TOL
     5        0.67011444  CAV LENGTH WIDTH DIM TOL
     5        0.66889171  CAV LENGTH WIDTH DIM THICK
     5        0.66806766  CAV WIDTH PRISM DIM SIDE
     5        0.66806766  CAV WIDTH PRISM DIM UNDERCUT
     5        0.66618507  CAV PRISM DIM THICK SIDE
     5        0.66618507  CAV PRISM DIM THICK UNDERCUT
     5        0.66592066  CAV WIDTH DIM SIDE TOL
     5        0.66592066  CAV WIDTH DIM UNDERCUT TOL
     5        0.66548418  CAV DIM THICK UNDERCUT TOL
     5        0.66548418  CAV DIM THICK SIDE TOL
     5        0.66408122  CAV WIDTH DIM THICK SIDE
     5        0.66408122  CAV WIDTH DIM THICK UNDERCUT
     5        0.65579898  CAV LENGTH PRISM DIM TOL
     5        0.65531461  CAV LENGTH PRISM DIM THICK
     5        0.65351337  CAV LENGTH DIM THICK TOL
     5        0.64114276  CAV WIDTH DEPTH DIM TOL
     5        0.62951784  CAV DEPTH PRISM DIM TOL
     5        0.62907611  CAV DEPTH DIM THICK TOL
     5        0.62495839  CAV WIDTH DEPTH DIM THICK
     5        0.62467182  CAV WIDTH DEPTH PRISM DIM
     5        0.62392023  CAV WIDTH PRISM DIM TOL
     5        0.62369234  CAV WIDTH DIM THICK TOL
     5        0.62341681  CAV PRISM DIM THICK TOL
     5        0.61365843  CAV WIDTH PRISM DIM THICK
     5        0.60890039  CAV DEPTH PRISM DIM THICK
     5        0.55570108  LENGTH DEPTH PRISM DIM SIDE
     5        0.55570108  LENGTH DEPTH PRISM DIM UNDERCUT
     5        0.54992025  DEPTH PRISM DIM SIDE TOL
     5        0.54992025  DEPTH PRISM DIM UNDERCUT TOL
     5        0.54901457  LENGTH WIDTH DEPTH PRISM DIM
     5        0.54282260  LENGTH WIDTH PRISM DIM UNDERCUT
     5        0.54282260  LENGTH WIDTH PRISM DIM SIDE
     5        0.54263092  DEPTH PRISM DIM THICK SIDE
     5        0.54263092  DEPTH PRISM DIM THICK UNDERCUT
     5        0.54259311  WIDTH DEPTH PRISM DIM SIDE
     5        0.54259311  WIDTH DEPTH PRISM DIM UNDERCUT
     5        0.54256867  LENGTH DEPTH DIM SIDE TOL
     5        0.54256867  LENGTH DEPTH DIM UNDERCUT TOL
     5        0.54225636  LENGTH WIDTH DEPTH DIM SIDE
     5        0.54225636  LENGTH WIDTH DEPTH DIM UNDERCUT
     5        0.53861710  LENGTH DEPTH DIM THICK SIDE
     5        0.53861710  LENGTH DEPTH DIM THICK UNDERCUT
     5        0.53345773  PRISM DIM THICK SIDE TOL
     5        0.53345773  PRISM DIM THICK UNDERCUT TOL
```

TABLE IV.E-45 (cont..)

```
                              E M I M
          Statistical Costing Model for the Cost Estimation
            for the Economic Model for Injection Molding

Number in      R-square    Variables in Model
  Model

     5        0.53244808   WIDTH PRISM DIM SIDE TOL
     5        0.53244808   WIDTH PRISM DIM UNDERCUT TOL
     5        0.53235784   WIDTH DEPTH DIM SIDE TOL
     5        0.53235784   WIDTH DEPTH DIM UNDERCUT TOL
     5        0.53070282   DEPTH DIM THICK SIDE TOL
     5        0.53070282   DEPTH DIM THICK UNDERCUT TOL
     5        0.53069989   LENGTH WIDTH DEPTH DIM TOL
     5        0.53066662   LENGTH PRISM DIM THICK SIDE
     5        0.53066662   LENGTH PRISM DIM THICK UNDERCUT
     5        0.53065367   WIDTH PRISM DIM THICK SIDE
     5        0.53065367   WIDTH PRISM DIM THICK UNDERCUT
     5        0.52967037   LENGTH WIDTH PRISM DIM TOL
     5        0.52864748   LENGTH DEPTH PRISM DIM TOL
     5        0.52833510   LENGTH PRISM DIM SIDE TOL
     5        0.52833510   LENGTH PRISM DIM UNDERCUT TOL
     5        0.52764997   LENGTH WIDTH PRISM DIM THICK
     5        0.52671554   WIDTH DEPTH DIM THICK SIDE
     5        0.52671554   WIDTH DEPTH DIM THICK UNDERCUT
     5        0.52467377   LENGTH WIDTH DEPTH DIM THICK
     5        0.52187597   LENGTH DEPTH PRISM DIM THICK
     5        0.51423511   LENGTH DEPTH DIM THICK TOL
     5        0.50042803   DEPTH PRISM DIM THICK TOL
     5        0.49886813   WIDTH DEPTH PRISM DIM TOL
     5        0.49769953   LENGTH PRISM DIM THICK TOL
     5        0.49653957   LENGTH WIDTH DIM THICK UNDERCUT
     5        0.49653957   LENGTH WIDTH DIM THICK SIDE
     5        0.49558524   WIDTH DIM THICK SIDE TOL
     5        0.49558524   WIDTH DIM THICK UNDERCUT TOL
     5        0.49339077   LENGTH DIM THICK SIDE TOL
     5        0.49339077   LENGTH DIM THICK UNDERCUT TOL
     5        0.49336953   LENGTH WIDTH DIM UNDERCUT TOL
     5        0.49336953   LENGTH WIDTH DIM SIDE TOL
     5        0.49077506   WIDTH PRISM DIM THICK TOL
     5        0.48794714   WIDTH DEPTH DIM THICK TOL
     5        0.48465612   WIDTH DEPTH PRISM DIM THICK
     5        0.48112089   LENGTH WIDTH DIM THICK TOL
     5        0.45621958   CAV LENGTH PRISM THICK UNDERCUT
     5        0.45621958   CAV LENGTH PRISM THICK SIDE
     5        0.45490324   CAV LENGTH WIDTH PRISM THICK
     5        0.44345843   CAV LENGTH DEPTH PRISM UNDERCUT
     5        0.44345843   CAV LENGTH DEPTH PRISM SIDE
     5        0.44070172   CAV LENGTH WIDTH DEPTH PRISM
     5        0.43824025   CAV LENGTH WIDTH PRISM UNDERCUT
     5        0.43824025   CAV LENGTH WIDTH PRISM SIDE
     5        0.43751019   CAV DEPTH PRISM THICK UNDERCUT
     5        0.43751019   CAV DEPTH PRISM THICK SIDE
     5        0.43274827   CAV LENGTH PRISM UNDERCUT TOL
     5        0.43274827   CAV LENGTH PRISM SIDE TOL
     5        0.42999865   CAV DEPTH PRISM UNDERCUT TOL
     5        0.42999865   CAV DEPTH PRISM SIDE TOL
     5        0.42957246   CAV LENGTH WIDTH THICK UNDERCUT
     5        0.42957246   CAV LENGTH WIDTH THICK SIDE
     5        0.42782195   CAV LENGTH WIDTH PRISM TOL
```

TABLE IV.E-4&5 (cont..)

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                              E M I M
          Statistical Costing Model for the Cost Estimation
             for the Economic Model for Injection Molding

Number in     R-square    Variables in Model
  Model

      5     0.42590810    CAV LENGTH THICK UNDERCUT TOL
      5     0.42590810    CAV LENGTH THICK SIDE TOL
      5     0.42564993    CAV LENGTH PRISM THICK TOL
      5     0.42547369    CAV WIDTH DEPTH PRISM UNDERCUT
      5     0.42547369    CAV WIDTH DEPTH PRISM SIDE
      5     0.42410044    CAV LENGTH DEPTH THICK UNDERCUT
      5     0.42410044    CAV LENGTH DEPTH THICK SIDE
      5     0.42383536    CAV WIDTH PRISM THICK SIDE
      5     0.42383536    CAV WIDTH PRISM THICK UNDERCUT
      5     0.42348978    CAV PRISM THICK SIDE TOL
      5     0.42348978    CAV PRISM THICK UNDERCUT TOL
      5     0.42197302    CAV LENGTH DEPTH PRISM THICK
      5     0.41629608    CAV LENGTH WIDTH THICK TOL
      5     0.41329739    CAV LENGTH WIDTH DEPTH THICK
      5     0.41292069    CAV LENGTH DEPTH PRISM TOL
      5     0.40435517    CAV WIDTH THICK SIDE TOL
      5     0.40435517    CAV WIDTH THICK UNDERCUT TOL
      5     0.40420241    CAV WIDTH DEPTH THICK SIDE
      5     0.40420241    CAV WIDTH DEPTH THICK UNDERCUT
      5     0.40316001    CAV DEPTH THICK UNDERCUT TOL
      5     0.40316001    CAV DEPTH THICK SIDE TOL
      5     0.40256152    CAV LENGTH WIDTH DEPTH UNDERCUT
      5     0.40256152    CAV LENGTH WIDTH DEPTH SIDE
      5     0.40123929    CAV LENGTH DEPTH UNDERCUT TOL
      5     0.40123929    CAV LENGTH DEPTH SIDE TOL
      5     0.39945899    CAV WIDTH PRISM SIDE TOL
      5     0.39945899    CAV WIDTH PRISM UNDERCUT TOL
      5     0.39810869    CAV LENGTH DEPTH THICK TOL
      5     0.39702778    CAV LENGTH WIDTH UNDERCUT TOL
      5     0.39702778    CAV LENGTH WIDTH SIDE TOL
      5     0.38880364    CAV LENGTH WIDTH DEPTH TOL
      5     0.38652194    CAV WIDTH DEPTH UNDERCUT TOL
      5     0.38652194    CAV WIDTH DEPTH SIDE TOL
      5     0.38359999    CAV DEPTH PRISM THICK TOL
      5     0.37371198    CAV WIDTH DEPTH PRISM TOL
      5     0.37043379    CAV WIDTH DEPTH PRISM THICK
      5     0.36266837    CAV WIDTH PRISM THICK TOL
      5     0.35500219    CAV WIDTH DEPTH THICK TOL
      5     0.25065596    LENGTH WIDTH DEPTH PRISM UNDERCUT
      5     0.25065596    LENGTH WIDTH DEPTH PRISM SIDE
      5     0.24451137    WIDTH DEPTH PRISM THICK UNDERCUT
      5     0.24451137    WIDTH DEPTH PRISM THICK SIDE
      5     0.24170880    LENGTH WIDTH PRISM THICK UNDERCUT
      5     0.24170880    LENGTH WIDTH PRISM THICK SIDE
      5     0.24090639    LENGTH WIDTH DEPTH PRISM THICK
      5     0.24014201    WIDTH DEPTH PRISM UNDERCUT TOL
      5     0.24014201    WIDTH DEPTH PRISM SIDE TOL
      5     0.24005591    DEPTH PRISM THICK UNDERCUT TOL
      5     0.24005591    DEPTH PRISM THICK SIDE TOL
      5     0.23675150    LENGTH DEPTH PRISM THICK UNDERCUT
      5     0.23675150    LENGTH DEPTH PRISM THICK SIDE
      5     0.23390478    LENGTH WIDTH DEPTH PRISM TOL
      5     0.23068682    LENGTH DEPTH PRISM UNDERCUT TOL
```

TABLE IV.E-4&5 (cont..)

```
                                E M I M
          Statistical Costing Model for the Cost Estimation
             for the Economic Model for Injection Molding

Number in      R-square    Variables in Model
  Model

     5        0.23068682   LENGTH DEPTH PRISM SIDE TOL
     5        0.22694131   LENGTH WIDTH PRISM THICK TOL
  .  5        0.22423165   LENGTH PRISM THICK SIDE TOL
     5        0.22423165   LENGTH PRISM THICK UNDERCUT TOL
     5        0.21894600   WIDTH PRISM THICK SIDE TOL
     5        0.21894600   WIDTH PRISM THICK UNDERCUT TOL
     5        0.21140855   LENGTH WIDTH PRISM UNDERCUT TOL
     5        0.21140855   LENGTH WIDTH PRISM SIDE TOL
     5        0.19456458   WIDTH DEPTH PRISM THICK TOL
     5        0.19065665   LENGTH DEPTH PRISM THICK TOL
     5        0.11257448   LENGTH WIDTH DEPTH THICK UNDERCUT
     5        0.11257448   LENGTH WIDTH DEPTH THICK SIDE
     5        0.11181610   WIDTH DEPTH THICK UNDERCUT TOL
     5        0.11181610   WIDTH DEPTH THICK SIDE TOL
     5        0.11023279   LENGTH WIDTH THICK UNDERCUT TOL
     5        0.11023279   LENGTH WIDTH THICK SIDE TOL
     5        0.10987335   LENGTH DEPTH THICK UNDERCUT TOL
     5        0.10987335   LENGTH DEPTH THICK SIDE TOL
     5        0.09170824   LENGTH WIDTH DEPTH THICK TOL
     5        0.08914983   LENGTH WIDTH DEPTH UNDERCUT TOL
     5        0.08914983   LENGTH WIDTH DEPTH SIDE TOL
------------------------------------------------------------------
     6        0.72723803   CAV LENGTH WIDTH DEPTH DIM SIDE
     6        0.72723803   CAV LENGTH WIDTH DEPTH DIM UNDERCUT
     6        0.72678573   CAV LENGTH DEPTH DIM SIDE TOL
     6        0.72678573   CAV LENGTH DEPTH DIM UNDERCUT TOL
     6        0.72297572   CAV LENGTH DEPTH PRISM DIM SIDE
     6        0.72297572   CAV LENGTH DEPTH PRISM DIM UNDERCUT
     6        0.72267254   CAV LENGTH DEPTH DIM THICK SIDE
     6        0.72267254   CAV LENGTH DEPTH DIM THICK UNDERCUT
     6        0.71956311   CAV LENGTH WIDTH DEPTH DIM TOL
     6        0.71541611   CAV LENGTH WIDTH DEPTH PRISM DIM
     6        0.71412148   CAV LENGTH WIDTH DEPTH DIM THICK
     6        0.70479732   CAV LENGTH DEPTH PRISM DIM TOL
     6        0.70478770   CAV LENGTH DEPTH DIM THICK TOL
     6        0.69813251   CAV LENGTH DEPTH PRISM DIM THICK
     6        0.69591091   CAV WIDTH DEPTH DIM SIDE TOL
     6        0.69591091   CAV WIDTH DEPTH DIM UNDERCUT TOL
     6        0.69494301   CAV LENGTH WIDTH PRISM DIM UNDERCUT
     6        0.69494301   CAV LENGTH WIDTH PRISM DIM SIDE
     6        0.68870400   CAV WIDTH DEPTH PRISM DIM SIDE
     6        0.68870400   CAV WIDTH DEPTH PRISM DIM UNDERCUT
     6        0.68862246   CAV WIDTH DEPTH DIM THICK SIDE
     6        0.68862246   CAV WIDTH DEPTH DIM THICK UNDERCUT
     6        0.68503014   CAV LENGTH PRISM DIM THICK UNDERCUT
     6        0.68503014   CAV LENGTH PRISM DIM THICK SIDE
     6        0.68499414   CAV LENGTH PRISM DIM UNDERCUT TOL
     6        0.68499414   CAV LENGTH PRISM DIM SIDE TOL
     6        0.68448451   CAV LENGTH WIDTH PRISM DIM TOL
     6        0.68418120   CAV DEPTH PRISM DIM SIDE TOL
     6        0.68418120   CAV DEPTH PRISM DIM UNDERCUT TOL
     6        0.68317826   CAV LENGTH WIDTH DIM UNDERCUT TOL
     6        0.68317826   CAV LENGTH WIDTH DIM SIDE TOL
```

TABLE IV.E495 (cont..)

```
                                  E M I M
                Statistical Costing Model for the Cost Estimation
                  for the Economic Model for Injection Molding

Number in     R-square    Variables in Model
  Model

     6        0.68294535   CAV LENGTH WIDTH DIM THICK UNDERCUT
     6        0.68294535   CAV LENGTH WIDTH DIM THICK SIDE
     6        0.68201672   CAV DEPTH DIM THICK SIDE TOL
     6        0.68201672   CAV DEPTH DIM THICK UNDERCUT TOL
     6        0.68177823   CAV LENGTH WIDTH PRISM DIM THICK
     6        0.67849916   CAV LENGTH DIM THICK UNDERCUT TOL
     6        0.67849916   CAV LENGTH DIM THICK SIDE TOL
     6        0.67377363   CAV DEPTH PRISM DIM THICK SIDE
     6        0.67377363   CAV DEPTH PRISM DIM THICK UNDERCUT
     6        0.67288315   CAV WIDTH PRISM DIM UNDERCUT TOL
     6        0.67288315   CAV WIDTH PRISM DIM SIDE TOL
     6        0.67280009   CAV PRISM DIM THICK UNDERCUT TOL
     6        0.67280009   CAV PRISM DIM THICK SIDE TOL
     6        0.67167036   CAV LENGTH WIDTH DIM THICK TOL
     6        0.66960413   CAV WIDTH PRISM DIM THICK SIDE
     6        0.66960413   CAV WIDTH PRISM DIM THICK UNDERCUT
     6        0.66782309   CAV WIDTH DIM THICK SIDE TOL
     6        0.66782309   CAV WIDTH DIM THICK UNDERCUT TOL
     6        0.65949088   CAV LENGTH PRISM DIM THICK TOL
     6        0.64152255   CAV WIDTH DEPTH DIM THICK TOL
     6        0.64117857   CAV WIDTH DEPTH PRISM DIM TOL
     6        0.62973083   CAV DEPTH PRISM DIM THICK TOL
     6        0.62632684   CAV WIDTH PRISM DIM THICK TOL
     6        0.62515798   CAV WIDTH DEPTH PRISM DIM THICK
     6        0.56663498   LENGTH WIDTH DEPTH PRISM DIM SIDE
     6        0.56663498   LENGTH WIDTH DEPTH PRISM DIM UNDERCUT
     6        0.56074899   LENGTH DEPTH PRISM DIM SIDE TOL
     6        0.56074899   LENGTH DEPTH PRISM DIM UNDERCUT TOL
     6        0.55643912   LENGTH DEPTH PRISM DIM THICK SIDE
     6        0.55643912   LENGTH DEPTH PRISM DIM THICK UNDERCUT
     6        0.55621539   LENGTH WIDTH DEPTH PRISM DIM TOL
     6        0.55073685   DEPTH PRISM DIM THICK SIDE TOL
     6        0.55073685   DEPTH PRISM DIM THICK UNDERCUT TOL
     6        0.55016993   WIDTH DEPTH PRISM DIM SIDE TOL
     6        0.55016993   WIDTH DEPTH PRISM DIM UNDERCUT TOL
     6        0.54927764   LENGTH WIDTH DEPTH PRISM DIM THICK
     6        0.54656988   LENGTH WIDTH DEPTH DIM SIDE TOL
     6        0.54656988   LENGTH WIDTH DEPTH DIM UNDERCUT TOL
     6        0.54614999   LENGTH WIDTH PRISM DIM UNDERCUT TOL
     6        0.54614999   LENGTH WIDTH PRISM DIM SIDE TOL
     6        0.54566546   LENGTH WIDTH PRISM DIM THICK UNDERCUT
     6        0.54566546   LENGTH WIDTH PRISM DIM THICK SIDE
     6        0.54352831   WIDTH DEPTH PRISM DIM THICK SIDE
     6        0.54352831   WIDTH DEPTH PRISM DIM THICK UNDERCUT
     6        0.54294514   LENGTH DEPTH DIM THICK SIDE TOL
     6        0.54294514   LENGTH DEPTH DIM THICK UNDERCUT TOL
     6        0.54239558   LENGTH WIDTH DEPTH DIM THICK SIDE
     6        0.54239558   LENGTH WIDTH DEPTH DIM THICK UNDERCUT
     6        0.53602540   WIDTH PRISM DIM THICK SIDE TOL
     6        0.53602540   WIDTH PRISM DIM THICK UNDERCUT TOL
     6        0.53383397   LENGTH PRISM DIM THICK SIDE TOL
     6        0.53383397   LENGTH PRISM DIM THICK UNDERCUT TOL
     6        0.53293004   WIDTH DEPTH DIM THICK SIDE TOL
```

TABLE IV.E-495 (cont..)

```
                              E M I M
          Statistical Costing Model for the Cost Estimation
            for the Economic Model for Injection Molding

Number in      R-square    Variables in Model
  Model

      6      0.53293004    WIDTH DEPTH DIM THICK UNDERCUT TOL
      6      0.53279914    LENGTH WIDTH PRISM DIM THICK TOL
      6      0.53085195    LENGTH WIDTH DEPTH DIM THICK TOL
      6      0.52999037    LENGTH DEPTH PRISM DIM THICK TOL
      6      0.50075895    WIDTH DEPTH PRISM DIM THICK TOL
      6      0.49830271    LENGTH WIDTH DIM THICK UNDERCUT TOL
      6      0.49830271    LENGTH WIDTH DIM THICK SIDE TOL
      6      0.47133223    CAV LENGTH WIDTH PRISM THICK UNDERCUT
      6      0.47133223    CAV LENGTH WIDTH PRISM THICK SIDE
      6      0.46008620    CAV LENGTH WIDTH PRISM THICK TOL
      6      0.45948449    CAV LENGTH PRISM THICK UNDERCUT TOL
      6      0.45948449    CAV LENGTH PRISM THICK SIDE TOL
      6      0.45929970    CAV LENGTH WIDTH DEPTH PRISM THICK
      6      0.45911769    CAV LENGTH DEPTH PRISM THICK UNDERCUT
      6      0.45911769    CAV LENGTH DEPTH PRISM THICK SIDE
      6      0.45728491    CAV LENGTH WIDTH DEPTH PRISM UNDERCUT
      6      0.45728491    CAV LENGTH WIDTH DEPTH PRISM SIDE
      6      0.44615867    CAV LENGTH DEPTH PRISM UNDERCUT TOL
      6      0.44615867    CAV LENGTH DEPTH PRISM SIDE TOL
      6      0.44502723    CAV LENGTH WIDTH DEPTH PRISM TOL
      6      0.44349347    CAV DEPTH PRISM THICK UNDERCUT TOL
      6      0.44349347    CAV DEPTH PRISM THICK SIDE TOL
      6      0.44255437    CAV LENGTH WIDTH PRISM UNDERCUT TOL
      6      0.44255437    CAV LENGTH WIDTH PRISM SIDE TOL
      6      0.43866000    CAV WIDTH DEPTH PRISM THICK UNDERCUT
      6      0.43866000    CAV WIDTH DEPTH PRISM THICK SIDE
      6      0.43151114    CAV LENGTH WIDTH THICK UNDERCUT TOL
      6      0.43151114    CAV LENGTH WIDTH THICK SIDE TOL
      6      0.43136556    CAV WIDTH PRISM THICK SIDE TOL
      6      0.43136556    CAV WIDTH PRISM THICK UNDERCUT TOL
      6      0.43054009    CAV WIDTH DEPTH PRISM UNDERCUT TOL
      6      0.43054009    CAV WIDTH DEPTH PRISM SIDE TOL
      6      0.42976304    CAV LENGTH WIDTH DEPTH THICK UNDERCUT
      6      0.42976304    CAV LENGTH WIDTH DEPTH THICK SIDE
      6      0.42716283    CAV LENGTH DEPTH PRISM THICK TOL
      6      0.42594977    CAV LENGTH DEPTH THICK UNDERCUT TOL
      6      0.42594977    CAV LENGTH DEPTH THICK SIDE TOL
      6      0.41635610    CAV LENGTH WIDTH DEPTH THICK TOL
      6      0.40782551    CAV WIDTH DEPTH THICK SIDE TOL
      6      0.40782551    CAV WIDTH DEPTH THICK UNDERCUT TOL
      6      0.40421309    CAV LENGTH WIDTH DEPTH UNDERCUT TOL
      6      0.40421309    CAV LENGTH WIDTH DEPTH SIDE TOL
      6      0.38405606    CAV WIDTH DEPTH PRISM THICK TOL
      6      0.26297086    LENGTH WIDTH DEPTH PRISM THICK UNDERCUT
      6      0.26297086    LENGTH WIDTH DEPTH PRISM THICK SIDE
      6      0.25407938    LENGTH WIDTH DEPTH PRISM UNDERCUT TOL
      6      0.25407938    LENGTH WIDTH DEPTH PRISM SIDE TOL
      6      0.24977693    WIDTH DEPTH PRISM THICK UNDERCUT TOL
      6      0.24977693    WIDTH DEPTH PRISM THICK SIDE TOL
      6      0.24688801    LENGTH WIDTH PRISM THICK UNDERCUT TOL
      6      0.24688801    LENGTH WIDTH PRISM THICK SIDE TOL
      6      0.24634855    LENGTH WIDTH DEPTH PRISM THICK TOL
      6      0.24005657    LENGTH DEPTH PRISM THICK UNDERCUT TOL
```

TABLE IV-E-475 (cont..)

```
                                E M I M
           Statistical Costing Model for the Cost Estimation
              for the Economic Model for Injection Molding

Number in     R-square    Variables in Model
  Model

     6       0.24005657   LENGTH DEPTH PRISM THICK SIDE TOL
     6       0.11410667   LENGTH WIDTH DEPTH THICK UNDERCUT TOL
     6       0.11410667   LENGTH WIDTH DEPTH THICK SIDE TOL
---------------------------------------------------------------
     7       0.73141300   CAV LENGTH WIDTH DEPTH DIM SIDE TOL
     7       0.73141300   CAV LENGTH WIDTH DEPTH DIM UNDERCUT TOL
     7       0.72891999   CAV LENGTH WIDTH DEPTH PRISM DIM SIDE
     7       0.72891999   CAV LENGTH WIDTH DEPTH PRISM DIM UNDERCUT
     7       0.72756089   CAV LENGTH WIDTH DEPTH DIM THICK SIDE
     7       0.72756089   CAV LENGTH WIDTH DEPTH DIM THICK UNDERCUT
     7       0.72728750   CAV LENGTH DEPTH PRISM DIM SIDE TOL
     7       0.72728750   CAV LENGTH DEPTH PRISM DIM UNDERCUT TOL
     7       0.72687509   CAV LENGTH DEPTH DIM THICK SIDE TOL
     7       0.72687509   CAV LENGTH DEPTH DIM THICK UNDERCUT TOL
     7       0.72303590   CAV LENGTH DEPTH PRISM DIM THICK SIDE
     7       0.72303590   CAV LENGTH DEPTH PRISM DIM THICK UNDERCUT
     7       0.72144019   CAV LENGTH WIDTH DEPTH PRISM DIM TOL
     7       0.71989056   CAV LENGTH WIDTH DEPTH DIM THICK TOL
     7       0.71566772   CAV LENGTH WIDTH DEPTH PRISM DIM THICK
     7       0.70479768   CAV LENGTH DEPTH PRISM DIM THICK TOL
     7       0.69741159   CAV LENGTH WIDTH PRISM DIM UNDERCUT TOL
     7       0.69741159   CAV LENGTH WIDTH PRISM DIM SIDE TOL
     7       0.69614984   CAV WIDTH DEPTH PRISM DIM SIDE TOL
     7       0.69614984   CAV WIDTH DEPTH PRISM DIM UNDERCUT TOL
     7       0.69592261   CAV WIDTH DEPTH DIM THICK SIDE TOL
     7       0.69592261   CAV WIDTH DEPTH DIM THICK UNDERCUT TOL
     7       0.69591599   CAV LENGTH WIDTH PRISM DIM THICK UNDERCUT
     7       0.69591599   CAV LENGTH WIDTH PRISM DIM THICK SIDE
     7       0.68873239   CAV WIDTH DEPTH PRISM DIM THICK SIDE
     7       0.68873239   CAV WIDTH DEPTH PRISM DIM THICK UNDERCUT
     7       0.68734644   CAV LENGTH PRISM DIM THICK UNDERCUT TOL
     7       0.68734644   CAV LENGTH PRISM DIM THICK SIDE TOL
     7       0.68559319   CAV LENGTH WIDTH PRISM DIM THICK TOL
     7       0.68465319   CAV LENGTH WIDTH DIM THICK UNDERCUT TOL
     7       0.68465319   CAV LENGTH WIDTH DIM THICK SIDE TOL
     7       0.68418125   CAV DEPTH PRISM DIM THICK SIDE TOL
     7       0.68418125   CAV DEPTH PRISM DIM THICK UNDERCUT TOL
     7       0.67450675   CAV WIDTH PRISM DIM THICK UNDERCUT TOL
     7       0.67450675   CAV WIDTH PRISM DIM THICK SIDE TOL
     7       0.64154490   CAV WIDTH DEPTH PRISM DIM THICK TOL
     7       0.57181096   LENGTH WIDTH DEPTH PRISM DIM SIDE TOL
     7       0.57181096   LENGTH WIDTH DEPTH PRISM DIM UNDERCUT TOL
     7       0.56687265   LENGTH WIDTH DEPTH PRISM DIM THICK SIDE
     7       0.56687265   LENGTH WIDTH DEPTH PRISM DIM THICK UNDERCUT
     7       0.56149364   LENGTH DEPTH PRISM DIM THICK SIDE TOL
     7       0.56149364   LENGTH DEPTH PRISM DIM THICK UNDERCUT TOL
     7       0.55647176   LENGTH WIDTH DEPTH PRISM DIM THICK TOL
     7       0.55104431   WIDTH DEPTH PRISM DIM THICK SIDE TOL
     7       0.55104431   WIDTH DEPTH PRISM DIM THICK UNDERCUT TOL
     7       0.54912299   LENGTH WIDTH PRISM DIM THICK UNDERCUT TOL
     7       0.54912299   LENGTH WIDTH PRISM DIM THICK SIDE TOL
     7       0.54670482   LENGTH WIDTH DEPTH DIM THICK SIDE TOL
     7       0.54670482   LENGTH WIDTH DEPTH DIM THICK UNDERCUT TOL
```

INITIAL RESULTS

```
                                                 The SAS System

                         Backward Elimination Procedure for Dependent Variable COST

Step 0    All Variables Entered     R-square = 0.73359237   C(p) = 10.00000000
NOTE: The model is not of full rank. A subset of the model which is of full rank is chosen.

                                   DF        Sum of Squares        Mean Square          F    Prob>F

                 Regression         9      11277142922.275    1253015880.2528      30.90    0.0001
                 Error            101       4095349170.8242    40548011.592319
                 Total            110      15372492093.099

                              Parameter          Standard          Type II
                 Variable      Estimate             Error   Sum of Squares          F    Prob>F

                 INTERCEP  -8183.07495254    2304.32411967   511346736.02637     12.61    0.0006
                 CAV        1550.85364257     198.16770491   2483393040.4923     61.25    0.0001
                 LENGTH     7914.59335135    2100.94854276   575434561.19930     14.19    0.0003
                 WIDTH     -3458.94435276    2247.97062453   96000248.603035      2.37    0.1270
                 DEPTH    -10086.53363543    2763.53577919   540161041.75463     13.32    0.0004
                 PRISM       111.83112598     133.51865794   28445324.001723      0.70    0.4043
                 DIM         271.29835026      27.59945630   3917966316.9442     96.63    0.0001
                 THICK      4039.68108005   12770.16744699   4057612.2100179      0.10    0.7524
                 SIDE       9526.51750034    4485.49356656   182901077.12507      4.51    0.0361
                 TOL         481.39716192     372.29859604   67794398.918636      1.67    0.1989

Bounds on condition number:     5.089276,     192.8985
------------------------------------------------------------------------------------------------------

Step 1    Variable THICK Removed     R-square = 0.73332942   C(p) =  8.10006933

                                   DF        Sum of Squares        Mean Square          F    Prob>F

                 Regression         8      11273085310.065    1409135663.7581      35.06    0.0001
                 Error            102       4099406783.0341    40190262.578767
                 Total            110      15372492093.099

                              Parameter          Standard          Type II
                 Variable      Estimate             Error   Sum of Squares          F    Prob>F

                 INTERCEP  -8127.27874009    2287.40573410   507369951.02564     12.62    0.0006
                 CAV        1545.94348539     196.68541758   2482925820.9170     61.78    0.0001
                 LENGTH     7843.97879665    2079.81991666   571665785.42623     14.22    0.0003
                 WIDTH     -3382.00060127    2224.90045282   92863925.013562      2.31    0.1316
                 DEPTH     -9865.08833288    2661.58448010   552131200.30859     13.74    0.0003
                 PRISM       113.67066157     132.80221079   29444691.540399      0.73    0.3940
                 DIM         273.27187403      26.73262389   4199789635.9584    104.50    0.0001
                 SIDE       9522.59025797    4465.65117871   182751708.70114      4.55    0.0354
                 TOL         481.30500084     370.65247661   67768485.358044      1.69    0.1970

Bounds on condition number:     5.031922,     149.3405
------------------------------------------------------------------------------------------------------
```

```
                                                          The SAS System     INITIAL RESULTS contd.
Step 2   Variable PRISM Removed        R-square = 0.73141303    C(p) =  6.92623790

                                   DF         Sum of Squares        Mean Square             F      Prob>F

               Regression           7       11243640618.524    1606234374.0749        40.07      0.0001
               Error              103        4128851474.5747   40085936.646356
               Total              110       15372492093.099

                              Parameter           Standard            Type II
               Variable        Estimate              Error     Sum of Squares             F      Prob>F

               INTERCEP    -7295.93814926     2068.81763436    498688033.52845        12.44      0.0006
               CAV          1591.66114620      189.04832968   2841499451.2199         70.89      0.0001
               LENGTH       7578.37249478     2053.86957408    545755610.67537        13.61      0.0004
               WIDTH       -2835.41567313     2128.52245453     71132697.629633        1.77      0.1858
               DEPTH      -10678.57187368     2482.08759316    741488242.93962        18.50      0.0001
               DIM           281.08523961       25.09315837   5029878119.7573        125.48      0.0001
               SIDE         9507.14492809     4459.81503030    182162329.27933         4.54      0.0354
               TOL           467.97427710      369.84416618     64179814.076516        1.60      0.2086

Bounds on condition number:      4.919908,      112.1855
----------------------------------------------------------------------------------------------------------

Step 3   Variable TOL Removed          R-square = 0.72723903    C(p) =  6.40904829

                                   DF         Sum of Squares        Mean Square             F      Prob>F

               Regression           6       11179460804.448    1863243467.4080        46.21      0.0001
               Error              104        4193031288.6512   40317608.544723
               Total              110       15372492093.099

                              Parameter           Standard            Type II
               Variable        Estimate              Error     Sum of Squares             F      Prob>F

               INTERCEP    -6176.65181907     1875.18748174    437433072.24245        10.85      0.0014
               CAV          1592.25263918      189.59325418   2843629146.0036         70.53      0.0001
               LENGTH       7859.54873329     2047.70469033    593957452.70869        14.73      0.0002
               WIDTH       -2842.75213526     2134.65644452     71501767.078482        1.77      0.1859
               DEPTH      -10327.70345077     2474.47419928    702322241.85591        17.42      0.0001
               DIM           279.75248258       25.14338590   4991087043.7984        123.79      0.0001
               SIDE        10069.37197007     4450.43019250    206393276.68512         5.12      0.0257

Bounds on condition number:      4.842316,      88.55013
----------------------------------------------------------------------------------------------------------

Step 4   Variable WIDTH Removed        R-square = 0.72258475    C(p) =  6.17243357

                                   DF         Sum of Squares        Mean Square             F      Prob>F

               Regression           5       11107959037.369    2221591807.4739        54.70      0.0001
               Error              105        4264533055.7297   40614600.530759
               Total              110       15372492093.099

                              Parameter           Standard            Type II
               Variable        Estimate              Error     Sum of Squares             F      Prob>F

               INTERCEP    -6142.10314864     1881.90128739    432636063.64004        10.65      0.0015
               CAV          1589.45144041      190.27856252   2833981369.4228         69.79      0.0001
```

```
                                         The SAS System        INITIAL RESULTS contd.

                     LENGTH       5753.29921568   1314.51251560  780719577.16101       19.22   0.0001
                     DEPTH      -10574.59561803   2476.59088663  740459283.07649       18.23   0.0001
                     DIM           278.95731361     25.22870584  4965554398.8022      122.26   0.0001
                     SIDE        12447.72399355   4091.35393001  375948178.51493        9.26   0.0030

Bounds on condition number:      2.157351,      39.89927
------------------------------------------------------------------------------------------------------------

All variables left in the model are significant at the 0.1000 level.

                     Summary of Backward Elimination Procedure for Dependent Variable COST

                          Variable    Number    Partial      Model
                     Step Removed         In       R**2       R**2         C(p)           F   Prob>F

                        1 THICK            8     0.0003     0.7333       8.1001      0.1001   0.7524
                        2 PRISM            7     0.0019     0.7314       6.8262      0.7326   0.3940
                        3 TOL              6     0.0042     0.7272       6.4090      1.6011   0.2086
                        4 WIDTH            5     0.0047     0.7226       6.1724      1.7735   0.1859
```

Table IV.E-6&8

```
N = 110     Regression Models for Dependent Variable: COST


Number in      R-square   Variables in Model
  Model

       1      0.75787225   X
       1      0.39542192   Z2
       1      0.33286741   Z1
       1      0.06502515   U
       1      0.04078465   Y
       1      0.03171460   V
 ------------------------
       2      0.78344001   X Z1
       2      0.78288175   U X
       2      0.78158214   X Z2
       2      0.77568644   X Y
       2      0.76312423   X V
       2      0.49410780   U Z2
       2      0.43419110   U Z1
       2      0.40585756   Z2 V
       2      0.40467156   Y Z2
       2      0.40036435   Z1 Z2
       2      0.34809497   Y Z1
       2      0.34005710   Z1 V
       2      0.08798625   U V
       2      0.07939962   U Y
       2      0.04959127   Y V
 --------------------------
       3      0.82033147   U X Z1
       3      0.81827753   U X Z2
       3      0.79638908   X Y Z1
       3      0.79394290   X Y Z2
       3      0.78992156   U X Y
       3      0.78633311   X Z1 V
       3      0.78620849   U X V
       3      0.78552725   X Z2 V
       3      0.78358078   X Z1 Z2
       3      0.77581627   X Y V
       3      0.49831494   U Z2 V
       3      0.49668513   U Z1 Z2
       3      0.49464534   U Y Z2
       3      0.43617829   U Z1 V
       3      0.43421899   U Y Z1
       3      0.41348734   Z1 Z2 V
       3      0.40891144   Y Z2 V
       3      0.40862231   Y Z1 Z2
       3      0.34909022   Y Z1 V
       3      0.09107721   U Y V
 ----------------------------
       4      0.82253835   U X Y Z1
       4      0.82127919   U X Z1 V
       4      0.82074846   U X Z1 Z2
       4      0.82004431   U X Z2 V
```

TABLE IX-E-678

```
Number in     R-square    Variables in Model
  Model

        4    0.79410289    X  Y  Z2  V
        4    0.79036487    U  X  Y  V
        4    0.78671452    X  Z1  Z2  V
        4    0.50220287    U  Z1  Z2  V
        4    0.50178594    U  Y  Z2  V
        4    0.49737738    U  Y  Z1  Z2
        4    0.43644888    U  Y  Z1  V
        4    0.41514846    Y  Z1  Z2  V
 ---------------------------------
        5    0.82270640    U  X  Y  Z1  Z2
        5    0.82265408    U  X  Y  Z1  V
        5    0.82189394    U  X  Z1  Z2  V
        5    0.82058764    U  X  Y  Z2  V
        5    0.79690252    X  Y  Z1  Z2  V
        5    0.50701180    U  Y  Z1  Z2  V
 -----------------------------------
        6    0.82290863    U  X  Y  Z1  Z2  V
 -------------------------------------
```

Table IX E-648

```
                                        The SAS System 13:35 Thursday, June 3, 1993   1

                     Forward Selection Procedure for Dependent Variable COST

Step 1   Variable X Entered          R-square = 0.75787225    C(p) = 34.82649906

                  DF         Sum of Squares      Mean Square           F     Prob>F

 Regression        1       10588573821.563  10588573821.563      338.05     0.0001
 Error           108       3382875610.6274  31322922.320625
 Total           109       13971449432.191

                 Parameter         Standard           Type II
 Variable         Estimate            Error    Sum of Squares          F     Prob>F

 INTERCEP    -3223.76649670    1102.21322424   267952734.73626       8.55     0.0042
 X            1340.20714509      72.89274938   10588573821.563     338.05     0.0001

Bounds on condition number:              1,             1
---------------------------------------------------------------------------------------

Step 2   Variable Z1 Entered         R-square = 0.78344001    C(p) = 21.95576094

                  DF         Sum of Squares      Mean Square           F     Prob>F

 Regression        2       10945792510.016  5472896255.0081      193.54     0.0001
 Error           107       3025656922.1746  28277167.496959
 Total           109       13971449432.191

                 Parameter         Standard           Type II
 Variable         Estimate            Error    Sum of Squares          F     Prob>F

 INTERCEP    -3878.03976152    1063.31038190   376132024.05184      13.30     0.0004
 X            1196.52450656      80.19299432   6295152287.4588     222.62     0.0001
 Z1             46.02417973      12.94902065   357218688.45280      12.63     0.0006

Bounds on condition number:      1.340697,      5.362787
---------------------------------------------------------------------------------------

Step 3   Variable U Entered          R-square = 0.82033147    C(p) =  2.49892488

                  DF         Sum of Squares      Mean Square           F     Prob>F

 Regression        3       11461219704.852  3820406568.2839      161.33     0.0001
 Error           106       2510229727.3393  23681412.522069
 Total           109       13971449432.191

                 Parameter         Standard           Type II
 Variable         Estimate            Error    Sum of Squares          F     Prob>F

 INTERCEP    -3951.08465144     973.20003365   390333693.91171      16.48     0.0001
 U           13623.65577082    2920.20808380   515427194.83533      21.77     0.0001
 X            1129.00665866      74.80092488   5394940685.7659     227.81     0.0001
 Z1             56.73732610      12.07056590   523226906.74401      22.09     0.0001

Bounds on condition number:      1.392836,      11.50412
---------------------------------------------------------------------------------------
```

Table IV E-6&8 contd

```
Step 4   Variable Y Entered          R-square = 0.82253835   C(p) =  3.21535806

                      DF         Sum of Squares       Mean Square          F    Prob>F

 Regression            4       11492053013.458  2873013253.3646     121.67    0.0001
 Error               105       2479396418.7327  23613299.226026
 Total               109       13971449432.191

                     Parameter         Standard           Type II
 Variable             Estimate            Error    Sum of Squares          F    Prob>F

 INTERCEP      -4993.13110931    1332.66159985   331484207.39264      14.04    0.0003
 U             12266.20761149    3148.69336251   358357547.14469      15.18    0.0002
 X              1134.73219949      74.86114385  5425384353.1714     229.76    0.0001
 Y              1357.81472975    1188.25263498   30833308.606626       1.31    0.2558
 Z1               53.99172244      12.29034743   455703869.13276      19.30    0.0001

Bounds on condition number:      1.44632,      21.03784
-------------------------------------------------------------------------------

No other variable met the 0.5000 significance level for entry into the model.

     Summary of Forward Selection Procedure for Dependent Variable COST

        Variable     Number    Partial     Model
 Step   Entered          In       R**2      R**2        C(p)          F    Prob>F

   1    X                 1     0.7579    0.7579     34.8265   338.0455    0.0001
   2    Z1                2     0.0256    0.7834     21.9558    12.6328    0.0006
   3    U                 3     0.0369    0.8203      2.4989    21.7651    0.0001
   4    Y                 4     0.0022    0.8225      3.2154     1.3058    0.2558
```

DATA USED FOR TABLES IV.F-8&9 and all IV.F

Cost	ID	FRL	Cov	Matcode	SPH	Length	Width	Depth	Perim	DBM	Ia	Thick	Side	Under	Port
26414	4467	0	4	6	400	1.894	0.817	0.551	10.8	82	3.937	0.051	0	5	
7025	4503	0	1	6	225	2.575	2.575	0.65	9.8	10	2	0.035	0	5	
3000	4503	0	2	6	225	2.575	2.575	0.65	9.8	10	2	0.035	0	5	
3900	4503	0	4	6	225	2.575	2.575	0.65	9.8	10	2	0.035	0	5	
2520	4504	0	2	6	240	1.7	1.7	0.327	17.4	10	2	0.13	0	5	
3400	4504	0	4	6	240	1.7	1.7	0.327	17.4	10	2	0.13	0	5	
12658	4559	30	8	6	580	0.461	0.346	0.339	5.1	40	3.937	0.012	0	5	
18910	4559	30	16	6	580	0.461	0.346	0.339	5.1	40	3.937	0.012	0	5	
3536	4569	0	7	6	200	0.437	0.437	0.408	9.8	10	2	0.02	0	5	
3536	4597	0	6	6	200	0.5	0.5	0.475	10.2	11	2	0.02	0	5	
25004	4739	15	10	6.2	555	0.634	0.556	0.45	25	53	2	0.04	0	5	
5936	4757	0	4	6	225	1.5	1.33	1.33	4.5	20	5	0.085	0	5	
7368	4757	0	6	6	225	1.5	1.33	1.33	4.5	20	5	0.085	0	5	
8758	4757	0	8	6	225	1.5	1.33	1.33	4.5	20	5	0.085	0	5	
3428	4759	33	4	6	700	0.515	0.46	0.423	13.6	18	2	0.035	0	5	
3934	4760	33	4	6	500	0.3	0.185	0.1	7.5	9	5	0.08	0	5	
3451	4761	33	1	6	765	0.904	0.43	0.43	9	22	2	0.016	0	5	
47883	4763	0	14	6.2	410	0.93	0.63	0.583	20.5	117	3.937	0.05	0	5	
6654	4765	0	4	8.1	450	0.625	0.425	0.318	6.4	50	2	0.02	0	5	
3607	4766	33	1	6	537	0.274	0.272	0.204	9.6	38	2	0.014	0	5	
6741	4767	33	8	6	655	0.61	0.516	0.516	4.8	19	7.874	0.039	0	5	
4516	4768	0	8	6	461	0.524	0.524	0.342	4.4	8	1	0.055	0	5	
11632	4769	20	8	6	600	0.663	0.663	0.615	10.4	30	3.937	0.033	0	5	
2380	4770	15	2	6	600	0.595	0.28	0.28	2.8	5	5	0.01	0	5	
14726	4771	30	8	6	510	1.102	1.102	0.925	10.2	42	2.162	0.039	0	5	
10635	4772	33	4	6	800	0.63	0.63	0.61	7.8	36	2	0.037	0	5	
2142	4773	0	1	8.1	450	1.7	1.7	0.21	2.3	8	5	0.07	0	5	
[illegible]	4774	20	1	6	630	0.79	0.79	0.7	4.4	34	2	0.07	0	5	
16119	4775	33	8	6	735	0.79	0.79	0.7	4.4	34	2	0.07	0	5	
12996	[illegible]	0	1	6.2	230	1.811	1.632	[illegible]	[illegible]	82	1.969	0.154	0	5	
10741	4791	0	4	6	400	1.402	0.733	0.733	5.5	53	2	0.06	0	5	
[illegible]	4791	0	6	6	470	1.402	0.733	0.733	5.5	53	2	0.06	0	5	
[illegible]	4794	33	2	6	570	0.5	0.25	0.25	5	10	4	0.016	0	5	
5016	4794	33	4	6	570	0.5	0.25	0.25	5	10	4	0.016	0	5	
[illegible]	4795	0	6	6	340	1.03	0.835	0.772	9.2	89	3.937	0.063	0	5	
11138	4797	30	4	6	510	0.38	0.33	0.3	7.2	32	2	0.015	0	5	
10343	4798	20	1	6.2	462	1.25	0.65	0.43	9.6	57	1	0.06	0	5	
21354	4798	20	4	6.2	462	1.25	0.65	0.43	9.6	57	1	0.06	0	5	
7073	4799	33	2	6	655	1.02	0.695	0.695	7.8	53	4	0.05	0	5	
10343	4799	33	4	6	655	1.02	0.695	0.695	7.8	53	4	0.05	0	5	
15114	4799	33	8	6	655	1.02	0.695	0.695	7.8	53	4	0.05	0	5	
[illegible]	4802	20	4	6.2	400	0.89	0.838	0.668	5	60	2	0.09	0	5	
13455	4802	20	8	6.2	400	0.89	0.838	0.668	5	60	2	0.09	0	5	
2498	4807	33	1	6	632	0.445	0.208	0.147	5.7	16	2	0.015	0	5	
3728	4807	33	2	6	632	0.445	0.208	0.147	5.7	16	2	0.015	0	5	
5324	4807	33	4	6	632	0.445	0.208	0.147	5.7	16	2	0.015	0	5	
5748	4820	0	1	8.1	225	2.2	2.04	0.357	19.6	33	4	0.05	0	5	
21013	4825	0	8	6	450	1.255	1.004	0.783	14.6	54	3.937	0.059	0	5	
8679	4835	0	4	8.1	450	0.735	0.735	0.378	12.5	22	2	0.038	0	5	
44333	4838	20	8	6.2	360	0.9	0.77	0.6	18	100	2	0.07	0	5	
53130	4838	20	12	6.2	360	0.9	0.77	0.6	18	100	2	0.07	0	5	
57402	4838	20	14	6.2	360	0.9	0.77	0.6	18	100	2	0.07	0	5	
10455	4841	0	1	6	257	1.46	1.46	1.27	14.2	94	10	0.08	0	5	
[illegible]	4844	0	1	6	450	1.043	1.043	1.016	4.2	64	3.937	0.059	0	5	
[illegible]	4849	33	8	6.2	450	0.366	0.283	0.228	20	51	1.181	0.037	0	5	
[illegible]	4849	33	16	6.2	450	0.366	0.283	0.228	20	51	1.181	0.037	0	5	

TABLE FOR IV.F-8+9 (CONT.) and all IV.F

★ Suspect point →

[illegible]	4852	0	4	6	435	1 493	1 125	0 94	4 3	60	2	0 05	0	5
11653	4853	0	4	6.2	300	1 693	1 16	0 97	5 3	48	3 937	0 059	0	5
18708	4853	0	8	6.2	300	1 693	1 16	0 97	5 3	48	3 937	0 059	0	5
7561	4854	20	1	6.2	600	1	0 786	0 672	17 5	66	6	0 06	0	5
40507	4857	15	8	6	400	0 787	0 739	0 608	12 5	94	3 937	0 098	0	5
14000	4860	0	2	4.5	160	1 933	1 312	1 094	10 5	55	3	0 102	0	5
17800	4860	0	4	4.6	160	1 933	1 312	1 094	10 5	55	3	0 102	0	5
24538	4866	0	6	8.1	280	1 469	1 469	1 228	8	64	3 937	0 122	0	5
15118	4867	0	6	8.1	284	1 24	1 24	1 063	8 5	64	3 937	0 122	0	5
19977	4868	0	8	6	295	1 03	0 835	0 772	11	68	3 937	0 22	0	5
7691	4870	33	1	6.2	530	0 635	0 41	0 4	6 5	53	1	0 072	0	5
8030	4871	0	4	6.2	514	0 817	0 62	0 5	12 3	27	6	0 9	0	5
7412	4872	0	1	8.1	425	0 902	0 819	0 819	17 4	78	3 937	0 102	0	5
10080	4872	0	2	8.1	425	0 902	0 819	0 819	17 4	78	3 937	0 102	0	5
40053	4875	0	8	6.2	400	0 818	0 73	0 56	22	73	3 937	0 083	0	5
10137	4876	0	2	6	390	2 525	0 75	0 75	4	11	5	0 06	0	5
14388	4876	0	4	6	390	2 525	0 75	0 75	4	11	5	0 06	0	5
5644	4878	33	1	6	720	0 75	0 75	0 345	17 4	21	5	0 035	0	5
[illegible]	4880	0	4	6	470	1 125	0 958	0 94	4 4	53	2	0 4	0	5
29252	4881	30	8	6.2	330	1 113	1 031	0 945	13	70	3 937	0 051	0	5
9087	4884	0	2	8.1	425	1 21	0 725	0 725	4 8	22	3	0 025	0	5
8284	4886	33	8	6	562	0 5	0 16	0 16	7	8	4	0 02	0	5
11098	4887	15	2	6.2	400	1 13	0 64	0 54	6 3	57	4	0 035	0	5
12385	4890	33	10	6	830	0 95	0 92	0 72	13 3	24	2	0 018	0	5
38118	4890	20	4	6	327	1 834	1 231	1 016	9 5	104	7 874	0 059	0	5
17183	4891	30	4	6	600	1 11	0 97	0 508	12 5	30	3	0 055	0	5
14195	4892	0	4	6	265	1 457	1 457	0 189	13	29	8	0 1	0	5
30905	4894	0	8	6	250	1 558	1 51	1 125	22	104	2	0 25	0	5
11906	4895	0	1	6	355	2 24	1 914	1 123	4 5	74	6	0 16	0	5
20299	4897	0	10	6	470	1 09	0 815	0 568	4 5	70	3	0 094	0	5
31743	4899	0	4	6	345	3 543	1 85	1 533	2 9	60	7 874	0 098	1	0
31743	4900	0	4	6	345	3 543	1 85	1 533	2 9	60	7 874	0 098	1	0
10618	4901	0	2	5.3	423	0 638	0 353	0 353	6 3	31	2	0 095	0	5
49755	5002	0	12	6	272	2 52	2 52	0 945	1 5	72	7 874	0 067	0	5
31939	5003	0	8	6.2	370	1 953	1 174	0 989	7 8	79	3 937	0 163	0	5
9407	5004	0	4	6	313	0 575	0 545	0 545	18	21	2	0 12	0	5
13724	5006	0	2	6	157	1 234	0 96	0 96	5	46	4	0 235	0	5
7601	5053	30	1	6	390	1 693	1 646	1 52	1 2	93	3 937	0 113	0	5
6275	5057	0	2	6.2	375	0 949	0 67	0 67	3	21	3	0 06	0	5
17534	5079	33	4	6	371	1 575	1 496	0 317	11 6	41	5 512	0 067	0	5
20085	5090	30	4	6.2	340	1 179	1	0 776	4 5	74	3 937	0 059	0	5
13342	5091	15	2		510	0 957	0 44	0 44	3 2	24	4	0 028	0	5
11898	5092	13	2	6	554	1 375	0 678	0 678	3 7	38	4	0 03	0	5
14352	5093	15	2	6	507	1 778	0 892	0 892	3 1	35	4	0 028	0	5
10085	5107	0	1	6	450	1 22	1 22	0 94	4 7	102	3 937	0 177	0	5
12350	5111	13	4	6	387	1 146	1 146	0 167	15	25	4	0 067	0	5
14956	5112	13	4	6	415	1 173	1 173	0 089	1 7	19	4	0 086	0	5
23485	5121	15	4	6	395	1 22	1 22	0 94	4 7	116	3 937	0 177	0	5
19624	5127	0	4	6	360	1 598	0 823	0 546	7	69	3 15	0 05	0	5
15331	5138	0	4	6.6	225	1 136	0 65	0 65	4 5	23	4	0 06	0	5
8767	5154	0	2	6	370	1 15	0 53	0 44	2 3	41	2	0 03	0	5
[illegible]	5157	33	10	5.3	400	1 266	0 259	0 259	5	55	2	0 035	1	0
[illegible]	5170	0	4	6	480	0 889	0 889	0 167	15	29	4	0 067	0	5
9909	5208	0	1	6	260	2 127	1 811	1 811	1 5	112	3 937	0 058	0	5

DATA FOR TABLES IV F-1-2

```
[illegible]                                                   Page 1

                  - -  Correlation Coefficients  - -

            SPH         CAV         DIM        LENGTH      WIDTH       DEPTH

SPH        1.0000       .0225      -.2274      -.5473      -.5785      -.4548
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .        P= .816     P= .017     P= .000     P= .000     P= .000

CAV         .0225      1.0000       .2182      -.2146      -.1641      -.0879
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .816     P= .        P= .023     P= .025     P= .088     P= .363

DIM        -.2274       .2182      1.0000       .1560       .1688       .5136
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .017     P= .023     P= .        P= .105     P= .079     P= .000

LENGTH     -.5473      -.2146       .1560      1.0000       .8224       .5690
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .000     P= .025     P= .105     P= .        P= .000     P= .000

WIDTH      -.5785      -.1641       .1688       .8224      1.0000       .5255
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .000     P= .088     P= .079     P= .000     P= .        P= .000

DEPTH      -.4548      -.0873       .5136       .5690       .5255      1.0000
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .000     P= .363     P= .000     P= .000     P= .000     P= .

THICF      -.4141      -.0394       .3885       .2324       .3143       .4272
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .000     P= .681     P= .000     P= .015     P= .001     P= .000

TC         -.1312      -.1161      -.0412      -.0672      -.0121      -.1044
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .174     P= .229     P= .671     P= .488     P= .901     P= .280

PRISM      -.0774       .2727       .2129      -.1670       .0100      -.2068
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= .421     P= .004     P= .026     P= .083     P= .918     P= .031

FILL        .7042       .1396      -.1257      -.5186      -.4844      -.4131
          ( 109)      ( 109)      ( 109)      ( 109)      ( 109)      ( 109)
          P= [illegible]     P= .148     P= .193     P= .000     P= .000     P= .000

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed
```

DATA FOR TABLE IV.F-1&2

```
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                     - -  Correlation Coefficients  - -

              THICK          TC            PRISM          FILL

SPH           -.4141        -.0312        -.0779          .7082
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .000       P= .748       P= .420        P= .000

CAV           -.0399        -.1161         .2727          .1396
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .681       P= .229       P= .004        P= .148

DIM            .3885        -.0412         .2129         -.1257
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .000       P= .671       P= .026        P= .193

LENGTH         .2324        -.0672        -.1670         -.5186
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .015       P= .488       P= .083        P= .000

WIDTH          .3143        -.0121         .0100         -.4844
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .001       P= .901       P= .918        P= .000

DEPTH          .4272        -.1044        -.2068         -.4131
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .000       P= .280       P= .031        P= .000

THICK         1.0000        -.0852         .0879         -.4025
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .          P= .379       P= .363        P= .000

TC            -.0852        1.0000         .0802         -.1803
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .379       P= .          P= .407        P= .061

PRISM          .0879         .0802        1.0000         -.0043
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .363       P= .407       P= .           P= .965

FILL          -.4025        -.1803        -.0043         1.0000
             ( 109)        ( 109)        ( 109)         ( 109)
             P= .000       P= .061       P= .965        P= .

 (Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed
```

DATA FOR TABLE IV F-3

```
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           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      FILL


Variable(s) Entered on Step Number
   1..    FILL


Multiple R           .70819
R Square             .50153
Adjusted R Square    .49687
Standard Error    106.61073

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1       1223603.88586    1223603.88586
Residual           107       1216145.76549      11365.84826

F =     107.65619       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta         T  Sig T

FILL           7.511700     .723967    .708187    10.376  .0000
 Constant    331.922505   13.646574               24.323  .0000


End Block Number   1   All requested variables entered.
```

DATA FOR TABLE IV.F-3

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                                Page 5

            * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      WIDTH


Variable s  Entered on Step Number
   1..    WIDTH


Multiple R           .57852
R Square             .33469
Adjusted R Square    .32847
Standard Error    123.16651

Analysis of Variance
                      DF      Sum of Squares      Mean Square
Regression             1        816560.74474     816560.74474
Residual             107       1623188.90664      15169.98978

F =       53.82739       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

WIDTH       -161.295568   21.984714   -.578524     -7.337  .0000
(Constant)   574.144509   23.403165                24.533  .0000


End Block Number   1   All requested variables entered.
```

DATA FOR TABLE IV.F-3

```
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            * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   CPH

Block Number  1.  Method:  Enter      DEPTH


Variable s  Entered on Step Number
   1..     DEPTH


Multiple R           .45478
R Square             .20682
Adjusted R Square    .19941
Standard Error    134.48236

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        504600.61517     504600.61517
Residual           107       1935149.03621      18085.50501

F =       27.90083       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B         SE B       Beta          T  Sig T

DEPTH       -193.834141   36.696252   -.454780     -5.282  .0000
(Constant)   550.479672   26.881206                20.478  .0000


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            * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   CPH

Block Number  1.  Method:  Enter      LENGTH


Variable s  Entered on Step Number
   1..     LENGTH


Multiple R           .54732
R Square             .29955
Adjusted R Square    .29301
Standard Error    126.37694

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        730837.63854     730837.63854
Residual           107       1708912.01283      15971.14031

F =       45.75989       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B         SE B       Beta          T  Sig T

LENGTH      -133.928175   19.798371   -.547316     -6.765  .0000
(Constant)   584.548264   26.398444                22.143  .0000
```

DATA FOR TABLE IV.F-3

```
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          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      THICK


Variable(s) Entered on Step Number
   1..    THICK


Multiple R           .41407
R Square             .17145
Adjusted R Square    .16371
Standard Error    137.44635

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        418300.43428     418300.43428
Residual           107       2021449.21710      18892.04876

F =      22.14161       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

THICK      -1090.721195  231.797701  -.414068     -4.705  .0000
(Constant)   501.173013   20.725328               24.182  .0000


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          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      TC


Variable(s) Entered on Step Number
   1..    TC


Multiple R           .03117
R Square             .00097
Adjusted R Square   -.00837
Standard Error    150.92795

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1          2370.21885       2370.21885
Residual           107       2437379.43253      22779.24703

F =        .10405       Signif F =  .7477

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

TC           -10.857215   33.638020  -.031169      -.323  .7477
(Constant)   444.497163  122.137040                3.639  .0004
```

DATA FOR TABLE IV.F-3

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                              Page 9

          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      PRISM


Variable(s) Entered on Step Number
   1..    PRISM


Multiple R           .07795
R Square             .00608
Adjusted R Square   -.00321
Standard Error    150.54191

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1         14823.01166      14823.01166
Residual           107       2424926.63971      22662.86579

F =        .65407       Signif F =  .4205

------------------ Variables in the Equation ------------------

Variable              B         SE B        Beta          T  Sig T

PRISM         -2.119665     2.620936    -.077946      -.809  .4205
(Constant)   444.971033    27.689613                 16.070  .0000



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          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      DIM


Variable(s) Entered on Step Number
   1..    DIM


Multiple R           .22740
R Square             .05171
Adjusted R Square    .04285
Standard Error    147.04524

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        126163.11880     126163.11880
Residual           107       2313586.53257      21622.30404

F =       5.83486       Signif F =  .0174

------------------ Variables in the Equation ------------------

Variable              B         SE B        Beta          T  Sig T

DIM           -1.168384      .483696    -.227402     -2.416  .0174
(Constant)   480.520968    26.656349                 18.027  .0000
```

DATA FOR TABLE IV.F-3

```
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                                                                    Page 11

              * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Enter      CAV


Variable(s) Entered on Step Number
   1..    CAV


Multiple R            .02250
R Square              .00051
Adjusted R Square   -.00883
Standard Error    150.96309

Analysis of Variance
                     DF      Sum of Squares        Mean Square
Regression            1          1235.64702         1235.64702
Residual            107       2438514.00435        22789.85051

F =        .05422        Signif F =  .8163

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

CAV             .979410    4.206182    .022505       .233  .8163
(Constant)   421.162825   24.795895                16.985  .0000

End Block Number   1   All requested variables entered.
```

DATA FOR TABLE IV.F-4

```
                **** M U L T I P L E   R E G R E S S I O N ****


Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SFH

Block Number  1.  Method:  Forward       Criterion   PIN  .2000
   CAV       DEPTH     DIM       FILL      LENGTH    PRISM     TC        THICK
   WIDTH


Variable(s) Entered on Step Number
   1..    FILL


Multiple R             .70819
R Square               .50153
Adjusted R Square      .49687
Standard Error      106.61073

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            1       1223603.88588    1223603.88588
Residual            107       1216145.76549      11365.84828

F =     107.65619       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

FILL           7.511700     .723967    .708187     10.376  .0000
 Constant    331.922505   13.646574                24.323  .0000


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler          T  Sig T

CAV        -.077846 -.109180    .980523     -1.131  .2607
DEPTH      -.195609 -.252311    .829348     -2.685  .0084
DIM        -.140617 -.197588    .984204     -2.075  .0404
LENGTH     -.246312 -.298299    .731094     -3.219  .0017
PRISM      -.074929 -.106126    .999982     -1.099  .2743
TC          .099739  .138954    .967502      1.445  .1515
```

DATA FOR TABLE IV.F-4

```
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                **** M U L T I P L E   R E G R E S S I O N ****

Equation Number 1    Dependent Variable..   DFH


Variable(s) Entered on Step Number
   2..    WIDTH


Multiple R           .75761
R Square             .57397
Adjusted R Square    .56593
Standard Error     99.02356

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           2      1400349.20876     700174.60438
Residual           106      1039400.44262       9805.66455

F =      71.40511       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

FILL          5.930671     .768651    .559150      7.716  .0000
WIDTH       -85.777938   20.204106   -.307662     -4.246  .0000
(Constant)  430.552211   26.464234                16.269  .0000


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler          T  Sig T

CAV        -.114480 -.165067    .755844     -1.715  .0893
DEPTH      -.084905 -.114573    .637700     -1.181  .2402
DIM        -.108561 -.163726    .753507     -1.701  .0920
LENGTH     -.014205 -.012014    .304730      -.123  .9023
PRISM      -.072490 -.111155    .765276     -1.145  .2548
TC          .069047  .103356    .730691      1.065  .2894
THICK      -.112660 -.156241    .695853     -1.621  .1080
```

DATA FOR TABLE IV.F-4

```
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          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   SPH


Variable(s) Entered on Step Number
   3..    CAV


Multiple R           .76523
R Square             .58558
Adjusted R Square    .57374
Standard Error     98.12932

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           3       1428666.54881     476222.18294
Residual           105       1011083.10256       9629.36288

F =      49.45521       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta         T  Sig T

CAV           -4.764591    2.778422   -.109480    -1.715  .0893
FILL           6.022013     .763562    .567742     7.887  .0000
WIDTH        -89.626141   20.147023   -.321465    -4.449  .0000
(Constant)   455.768137   30.066312               15.159  .0000

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler        T  Sig T

DEPTH      -.088217 -.113905    .631384   -1.169  .2450
DIN        -.086091 -.127205    .737308   -1.308  .1938
LENGTH     -.040118 -.034113    .249633    -.348  .7285
PRISM      -.046036 -.068673    .754530    -.702  .4843
TC          .057845  .087281    .723174     .894  .3736
THICK      -.108607 -.152621    .691732   -1.575  .1183
```

DATA FOR TABLE IV,F-4

```
[illegible] SPSS for MS WINDOWS Release [illegible]                    Page 15

              * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   SPH

Variable(s) Entered on Step Number
   4..    THICK


Multiple R           .77151
R Square             .59523
Adjusted R Square    .57966
Standard Error     97.44484

Analysis of Variance
                   DF      Sum of Squares      Mean Square
Regression          4      1452217.97846     363054.49462
Residual          104       987531.67292       9495.49685

F =      38.23439       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta         T  Sig T

CAV           -4.611638    2.760750  -.105966    -1.670  .0978
FILL           5.642418     .795624   .531955     7.092  .0000
THICK       -286.069172  181.656798  -.108607    -1.575  .1183
WIDTH        -84.781580   20.241598  -.304089    -4.188  .0001
(Constant)   475.084255   32.277671              14.719  .0000


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

DEPTH      -.058894 -.075142   .624412      -.765  .4462
DIM        -.055912 -.077863   .691314      -.793  .4296
LENGTH     -.064052 -.054659   .234747      -.556  .5797
PRISM      -.037362 -.056179   .691684      -.571  .5692
TC          .042933  .064724   .650344       .658  .5118


End Block Number   1   PIN =    .200 Limits reached.
```

DATA FOR TABLE IV.F-5

```
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        * * * *   M U L T I P L E   R E G R E S S I O N   * * * *


Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Forward       Criterion   PIN  .2000        HEATTRAN


Variable(s) Entered on Step Number
   1..    HEATTRAN


Multiple R              .44288
R Square                .19614
Adjusted R Square       .18863
Standard Error       135.38523

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            1        478529.41305     478529.41305
Residual            107       1961220.23833      18329.16111

F =       26.10755       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

HEATTRAN    -684.117045  133.889767   -.442876     -5.110  .0000
 Constant    486.960537   17.640444                27.605  .0000


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        * * * *   M U L T I P L E   R E G R E S S I O N   * * * *


Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Forward       Criterion   PIN  .2000        FLATNESS


Variable(s) Entered on Step Number
   1..    FLATNESS


Multiple R              .34804
R Square                .12113
Adjusted R Square       .11292
Standard Error       141.56069

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            1        295530.75480     295530.75480
Residual            107       2144218.89657      20039.42894

F =       14.74746       Signif F =  .0002


------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

FLATNESS    -103.561373   26.967403   -.348040     -3.840  .0002
 Constant    481.980625   19.936485                24.176  .0000
```

DATA FOR TABLE IV F-5

```
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                   * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Forward      Criterion   PIN  .0000       LOVERT


Variable(s) Entered on Step Number
   1..    LOVERT


Multiple R           .32773
R Square             .10740
Adjusted R Square    .09906
Standard Error    142.66192

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        262040.33262     262040.33262
Residual           107       2177709.31875      20352.42354

F =      12.87514       Signif F =  .0005


------------------ Variables in the Equation ------------------

Variable              B          SE B       Beta          T  Sig T

LOVERT         2.559112      .713203    .327726      3.588  .0005
 (Constant)  352.499828    24.589323                14.335  .0000
```

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                                Page 23

                   * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Forward      Criterion   PIN  .0000       NONFILL


Variable(s) Entered on Step Number
   1..    NONFILL


Multiple R           .71056
R Square             .50490
Adjusted R Square    .50027
Standard Error    106.24983

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1       1231823.90794    1231823.90794
Residual           107       1207925.74344      11289.02564

F =     109.11694       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B          SE B       Beta          T  Sig T

NONFILL      515.14[illegible]    49.310201    .710560     10.446  .0000
 (Constant) -17[illegible]    58.877929                -[illegible]  .0034
```

DATA FOR TABLE IV.F-5

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                                          Page 24

              * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Forward      Criterion   PIN  .0500        VOLUME


Variable(s) Entered on Step Number
   1..    VOLUME


Multiple R           .53381
R Square             .28495
Adjusted R Square    .27827
Standard Error    127.68742

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            1        695213.42012     695213.42012
Residual            107       1744536.23126      16304.07693

F =      42.64046       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta         T  Sig T

VOLUME        -7.133541    1.092439   -.533811    -6.530  .0000
 Constant    488.662983   15.559499               31.406  .0000
```

DATA FOR TABLE IV.F-7

```
[illegible] SPSS for MS WINDOWS Release [illegible]                     Page [illegible]

       * * * *   M U L T I P L E   R E G R E S S I O N   * * * *


Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   [illegible]

Block Number  1.  Method:  Forward      Criterion   PIN  [illegible]
   TAV      DEPTH     DIM      FILL      FLATNESS HEATTRAN LENGTH    LOVERT
   NONFILL  PRISM     TI       THICK     VOLUME   WIDTH


Variable(s) Entered on Step Number
   1..    NONFILL


Multiple R           [illegible]
R Square             [illegible]
Adjusted R Square    [illegible]
Standard Error     10[illegible]

Analysis of Variance
                      DF      Sum of Squares      Mean Square
Regression             1      1231823.90794    1231823.90794
Residual             107      1207925.74344      11289.02564

F =      109.11694       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

NONFILL     [illegible]  [illegible]  [illegible]  10.44[illegible]  [illegible]
 (Constant) [illegible]  [illegible]               -3.[illegible]  [illegible]


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

TAV      [illegible] [illegible]  .981596    -1.097  .27[illegible]
DEPTH    [illegible] [illegible]  .424243    -1.662  .09[illegible]
DIM      [illegible] [illegible]  .477466    -1.832  .0697
FILL     [illegible] [illegible]  [illegible] [illegible]  .452[illegible]
FLATNESS [illegible] [illegible]  .885410    -1.[illegible]  .09[illegible]
HEATTRAN [illegible] [illegible]  .883244    -3.268  .0015
LENGTH   [illegible] [illegible]  .733416    -3.231  .0016
LOVERT    .144734 [illegible]  .925647     2.079  .0401
PRISM    [illegible] [illegible]  .999938    -1.064  .2896
TI        .1[illegible]441  .13[illegible]669  .968311     1.431  .1554
THICK    [illegible] [illegible]  .838941    -2.1[illegible]  .0374
VOLUME   [illegible] [illegible]  .878394    -4.[illegible]  [illegible]
WIDTH    [illegible] [illegible]  .747607    -4.266  [illegible]
```

DATA FOR TABLE IV.F-7

```
17 Jun 97 SPSS for MS WINDOWS Release 6.1                                    Page 20

           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   CPH


Variable(s) Entered on Step Number
   2..     VOLUME


Multiple R           .77261
R Square             .59693
Adjusted R Square    .58932
Standard Error     96.31844

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           2       1456351.82514     728175.91257
Residual           106        983397.82623       9277.33798

F =       78.48975       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B          SE B       Beta          T  Sig T

NONFILL      432.503650   47.749590    .596635      9.058  .0000
VOLUME        -4.330458     .880259   -.324050     -4.920  .0000
(Constant)   -44.668106   60.039621                 -.744  .4585

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler          T  Sig T

CAV         -.096294 -.149930    .866878    -1.554  .1232
DEPTH       -.065962 -.085791    .683903     -.882  .3796
DIM         -.059025 -.089612    .832570     -.922  .3587
FILL        -.243474 -.033536    .007634     -.344  .7314
FLATNESS    -.003180 -.004382    .757654     -.045  .9643
HEATTRAN    -.115196 -.156074    .734199    -1.619  .1084
LENGTH      -.057991 -.063314    .460452     -.650  .5171
LUVERT       .189839  .285149    .797435     3.048  .0029
PRISM        .022032  .033054    .795182      .339  .7354
TD           .043614  .066463    .829592      .683  .4964
THICK       -.089334 -.126128    .783045    -1.303  .1955
WIDTH       -.126474 -.124084    .387983    -1.281  .2029
```

DATA FOR TABLE IV.F-7

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                                   Page 27

              * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   Dfm


Variable s  Entered on Step Number
   3..     LOVERT


Multiple R           .79354
R Square             .62970
Adjusted R Square    .61912
Standard Error     92.75867

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           3     1536311.62260     512103.87420
Residual           105      903438.02877       8604.17170

F =       59.51809       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B          SE B       Beta          T  Sig T

LOVERT         1.482393       .486275    .189839      3.048  .0029
NONFILL      388.391696     48.207586    .535783      8.057  .0000
VOLUME        -4.675871       .855260   -.349897     -5.467  .0000
 Constant    -32.239273     57.963925                 -.556  .5793


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

DAY         -.065617 -.104870   .778441     -1.075  .2847
DEPTH       -.027011 -.036094   .661163      -.368  .7133
DIM          .024852  .035671   .746746       .364  .7166
FILL        -.240745 -.034566   .037634      -.353  .7250
FLATNESS    -.164860 -.198755   .538218     -2.068  .0411
HEATTRAN    -.083347 -.116268   .708627     -1.194  .2353
LENGTH      -.215091 -.219868   .386930     -2.298  .0235
PRISM        .108726  .157734   .744578      1.629  .1063
TC           .024842  .039292   .747506       .401  .6892
THICK        .049718  .058594   .514323       .599  .5508
WIDTH       -.206983 -.205831   .366190     -2.145  .0343
```

DATA FOR TABLE IV.F-7

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                                          Page 28

          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   SPH

Variable s  Entered on Step Number
   4..     LENGTH


Multiple R            .80474
R Square              .64760
Adjusted R Square     .63405
Standard Error      90.92284

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            4       1579985.53061     394996.38265
Residual            104        859764.12076       8266.96270

F =       47.78011       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

LENGTH       -52.632784   22.899094   -.215091     -2.298  .0235
LOVERT         2.021010     .531140    .258816      3.805  .0002
NONFILL      321.310088   55.539882    .443244      5.785  .0000
VOLUME        -3.257106    1.041067   -.243731     -3.129  .0023
 Constant     81.088070   75.227573                 1.078  .2836

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler          T  Sig T

CAV         -.079283 -.129312   .383495     -1.323  .1886
DEPTH        .049799  .062076   .320357       .631  .5293
DIM          .052545  .076176   .375645       .775  .4399
FILL        -.255312 -.037575   .007633      -.382  .7035
FLATNESS    -.071332 -.062076   .191865      -.631  .5293
HEATTRAN    -.019878 -.025723   .316867      -.261  .7945
PRISM        .058371  .079889   .327717       .813  .4179
TC           .001952  .003122   .376390       .032  .9748
THICK        .093632  .110528   .369428      1.129  .2617
WIDTH       -.118605 -.098449   .242801     -1.004  .3177
```

DATA FOR TABLE IV F - 7

```
[illegible] SPSS for MS WINDOWS Release 6.1                              Page [illegible]

          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   [illegible]


Variable(s) Entered on Step Number
   5..    CAV


Multiple R            .80839
R Square              .65349
Adjusted R Square     .63667
Standard Error      90.59616

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            5       1594362.16619     318872.43324
Residual            103        845367.48520       8207.64549

F =      38.85066       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B          SE B       Beta         T  Sig T

CAV           -3.450402     2.607056   -.079283    -1.323  .1886
LENGTH       -55.490819    22.918756   -.226771    -2.421  .0172
LOVERT         1.935394      .533170    .247852     3.630  .0004
NONFILL      327.444637    55.534155    .451707     5.896  .0000
VOLUME        -3.224674     1.037548   -.241603    -3.112  .0024
 (Constant)  [illegible]  [illegible]               1.266  .2082


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

DEPTH    [illegible] [illegible]  [illegible]   .630  .5303
DIM      [illegible]  .111396     .388731      1.121  .2648
FILL     -.021541 [illegible]     [illegible]  -.323  .7473
FLATNESS [illegible] [illegible]  .141964      -.633  .5303
HEATTRAN -.024453 -.031867        .315476      -.322  .7480
PRISM    [illegible]  .117393     .327667      1.194  .2353
TC       [illegible] -.011266     .371712      -.114  .9096
THICK     .085446     .101196     .367316      1.029  .3057
WIDTH    -.114835 [illegible]     .242830     -1.006  .3169


End Block Number  1   PIN =   .050 Limits reached.
```

DATA FOR TABLE IV F-849

```
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Number of valid observations (listwise) =        81.00

                                                         Valid
Variable        Mean    Std Dev    Minimum    Maximum        N  Label

SPH           432.48     150.53        160        800       81
THICK            .07        .06       .010       .400       81
LENGTH          1.05        .46       .274      2.240       81
WIDTH            .84        .39       .250      1.914       81
DEPTH            .72        .33       .204      1.811       81
TC              6.13        .75       4.50       9.60       81
FILL           12.75      14.01          0         33       81
PRISM           9.12       5.68       1.20      25.00       81




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Number of valid observations (listwise) =        28.00

                                                         Valid
Variable        Mean    Std Dev    Minimum    Maximum        N  Label

SPH           416.64     150.71        225        830       28
THICK            .05        .03       .015       .130       28
LENGTH          1.47        .83       .300      3.543       28
WIDTH           1.16        .80       .160      2.575       28
DEPTH            .42        .32       .184      1.533       28
TC              6.13        .57       5.30       8.10       28
FILL           11.74      14.86          0         33       28
PRISM           9.71       5.15       1.60      19.60       28
```

DATA FOR TABLE IV F-14

```
[illegible] Jan 97 SPSS for MS WINDOWS Release [illegible]                      Page 40

           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   [illegible]


Variable(s) Entered on Step Number
   5..    WIDTH


Multiple R            .81143
R Square              .65841
Adjusted R Square     .63564
Standard Error      [illegible]

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            5      1193488.[illegible]     238697.[illegible]
Residual             75       [illegible]         8255.[illegible]

F =      28.91261       Signif F = [illegible]


------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta          T  Sig T

HEATTRAN    -731.639699  227.481383  -.442141    -3.216  .0019
LOVERT         2.204841     .697933   .244426     3.159  .0023
NONFILL      361.922366  [illegible]  [illegible]     6.080  .0000
VOLUME        -3.608928    1.447874  [illegible]    -2.493  .0149
WIDTH        134.563432  [illegible]  [illegible]     1.915  .0593
 (Constant)  -54.859[illegible]  84.1[illegible]              -.652  [illegible]


------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T

DEPTH         .047916  [illegible]  [illegible]       .158  .87[illegible]
DIM          -.018113 -.024[illegible]  [illegible]      -.212  .8324
FILL        -.159869 -.173[illegible]  [illegible]     -1.515  .1341
FLATNESS     -.097404 -.127[illegible]  [illegible]     -1.107  .2717
LENGTH       -.176445 -.121[illegible]  [illegible]     -1.054  .2953
PRISM         .062127  .0775[illegible]  [illegible]       .669  .5054
TI           -.062138 -.045774  [illegible]      -.424  .4[illegible]
THICK         .082967  [illegible]  [illegible]       .870  .387[illegible]
```

DATA FOR TABLE IV.F-10

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                              Page 39

          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   SPH

Variable s  Entered on Step Number
   4..     VOLUME


Multiple R            .80107
R Square              .64172
Adjusted R Square     .62286
Standard Error      92.44149

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            4       1163219.56571     290804.89143
Residual             76        649452.65651       8545.42969

F =       34.03146       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable                B          SE B          Beta          T  Sig T

HEATTRAN      -373.810580  131.953529    -.246336     -2.833  .0059
LOVERT           1.973019     .699303     .219085      2.821  .0061
NONFILL        345.005750   59.892605     .467813      5.760  .0000
VOLUME          -2.168854    1.258712    -.147679     -1.723  .0889
 (Constant)     33.988058   71.474857                    .476  .6358

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler          T  Sig T

DEPTH        .119464  .146244   .380068       1.281  .2042
DIM          .028752  .028439   .584874        .246  .8061
FILL        -.081119 -.123748   .337443      -1.080  .2836
FLATNESS    -.017122 -.024176   .558801       -.209  .8354
LENGTH       .044159  .037519   .258394        .325  .7460
PRISM        .017865  .022416   .455108        .194  .8466
TC          -.029613 -.045617   .578295       -.395  .6937
THICK        .113774  .137155   .520671       1.199  .2343
WIDTH        .344822  .215977   .140427       1.915  .0593
```

DATA FOR TABLE IV F-10

```
17 Jun 97 SPSS for MS WINDOWS Release 6.1                          Page 38

        * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   [illegible]

Variable(s) Entered on Step Number
   3..     LOVERT

Multiple R            .7922[illegible]
R Square              .627[illegible]
Adjusted R Square     .6[illegible]
Standard Error      93.615[illegible]

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            3      1128848.32138      376282.77379
Residual             77       674823.90065        8763.94676

F =      43.2[illegible]62       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B          SE B        Beta          T  Sig T

HEATTRAN    -494.701733  113.175314   -.326[illegible]     -4.371  .0000
LOVERT         2.156480     .69993[illegible]    .23945[illegible]      3.081  .0029
NONFILL      349.533552   60.5[illegible]5129    .4734[illegible]      5.768  .0000
 Constant     18.929561   71.9[illegible]                    .263  .792[illegible]

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T

DEPTH         .202307  [illegible]  [illegible]   [illegible]  .4[illegible]
DIM          -.022085  [illegible]  [illegible]   [illegible]  [illegible]
FILL         -.893430  [illegible]  [illegible]   -1.1[illegible]  .2[illegible]
FLATNESS     -.062068  [illegible]  .6[illegible]   [illegible]  .4[illegible]
LENGTH       -.047416  [illegible]  [illegible]   [illegible]  [illegible]
PRISM        -.057827  [illegible]  [illegible]   [illegible]  .4[illegible]
TI           -.019853  [illegible]  .665[illegible]   [illegible]  [illegible]
THICK         .078082  [illegible]  [illegible]   [illegible]  .4[illegible]
VOLUME       -.147679  [illegible]  [illegible]   -1.[illegible]  [illegible]
WIDTH         .111639  [illegible]  [illegible]   [illegible]  .4[illegible]
```

DATA FOR TABLE IV.F-10

```
27 Jun 97 SPSS for MS WINDOWS Release 6.1                                Page 37

          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   FM

Variable(s) Entered on Step Number
   2..    HEATTRAN


Multiple R              .76277
R Square                .58182
Adjusted R Square       .57111
Standard Error        98.58067

Analysis of Variance
                      DF      Sum of Squares      Mean Square
Regression             2      1054656.58734      527328.29367
Residual              78       758015.63489        9718.14917

F =       54.26221       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B         SE B        Beta          T  Sig T

HEATTRAN    -497.736345  119.172909   -.328002     -4.177  .0001
NONFILL      427.885037   57.917314    .550194      7.388  .0000
 Constant    -19.639172   74.494512                 -.264  .7928

------------- Variables not in the Equation -------------

Variable      Beta In   Partial  Min Toler          T  Sig T

DEPTH         .135038   .061443    .085003       .535  .5940
DIM          -.101951  -.144440    .758955     -1.285  .2027
FILL         -.447144  -.062607    .008202      -.551  .5836
FLATNESS      .016388   .024131    .825614       .212  .8328
LENGTH        .049431   .043713    .327020       .384  .7021
LOVERT        .233456   .331284    .716165      3.081  .0029
PRISM        -.138541  -.207771    .818247     -1.864  .0662
TO           -.012408  -.018457    .761462      -.162  .8717
THICK        -.076351  -.103971    .760621      -.908  .3665
VOLUME       -.184497  -.231257    .626876     -2.096  .0403
WIDTH        -.001752  -.001220    .202704      -.011  .9915
```

DATA FOR TABLE IV.F-10

```
* * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   DPH

Block Number  1.  Method:  Forward       Criterion   PIN  .1000
   DEPTH     DIM       FILL      FLATNESS HEATTRAN LENGTH    LOVERT    NONFILL
   PRISM     TC        THICK     VOLUME   WIDTH


Variable(s) Entered on Step Number
   1..    NONFILL


Multiple R           .69879
R Square             .48830
Adjusted R Square    .48183
Standard Error    108.35586

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        885133.86453     885133.86453
Residual            79        927538.35769      11740.99187

F =       75.38834       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B          SE B        Beta          T  Sig T

NONFILL       515.346[illegible]   59.353577    .698787      8.683  .0000
 Constant    -174.808344   70.971593                  -2.463  .0159

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

DEPTH       -.307258 -.386638   .810243    -3.703  .0004
DIM         -.199786 -.274677   .967228    -2.523  .0137
FILL        -.135881 -.017275   .008271     -.153  .8791
FLATNESS    -.023465 -.031481   .920977     -.278  .7816
HEATTRAN    -.328012 -.427512   .869272    -4.177  .0001
LENGTH      -.243037 -.301102   .765412    -2.789  .0066
LOVERT       .242413  .303194   .800462     2.810  .0063
PRISM       -.056287 -.078654   .999177     -.697  .4880
TC           .097688  .134940   .976362     1.203  .2327
THICK       -.159464 -.201394   .816170    -1.816  .0732
VOLUME      -.302237 -.403286   .911054    -3.892  .0002
WIDTH       -.294240 -.370985   .813434    -3.528  .0007
```

DATA FOR TABLE IV.F-11

```
[illegible] SPSS [illegible] WINDOWS Release [illegible]                       Page [illegible]

        * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   SPH

Block Number  1.  Method:  Forward      Criterion   PIN  .1000
   DEPTH     DIM       FILL      FLATNESS LENGTH   LOVEPT    NONFILL  TC
   THICK     VOLUME    WIDTH


Variable(s) Entered on Step Number
   1..     FLATNESS


Multiple R           .76214
R Square             .58085
Adjusted R Square    .56473
Standard Error     99.42722

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1        356194.02390     356194.02390
Residual            26        257030.08324       9885.77243

F =      36.03098       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B         SE B       Beta          T  Sig T

FLATNESS    -200.767075   33.446811   -.762138     -6.003  .0000
(Constant)   471.794110   32.835944                14.444  .0000


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

DEPTH        .174714  .201213   .514152      1.021  .3170
DIM         -.044433 -.077126   .997401      -.386  .7024
FILL         .297712  .400189   .425122      2.183  .0387
LENGTH       .446514  .200303   .077536      1.021  .3170
LOVEPT       .425444  .612444   .470708      3.889  .0007
NONFILL      .401215  .417336   .435475      2.284  .0347
TC           .063346  .095260   .946371       .478  .6363
THICK       -.316235 -.499122   .923619     -2.880  .0081
VOLUME      -.178521 -.182199   .436601      -.927  .3629
WIDTH       -.317071 -.279337   .324367     -1.452  .1544
```

DATA FOR TABLE IV.F-11

```
** Run of SPSS for MS WINDOWS Release 6.1                                Page 37

           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   IPH


Variable(s) Entered on Step Number
   2..     LOVERT


Multiple R           .85957
R Square             .73886
Adjusted R Square    .71797
Standard Error     80.03395

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           2        453088.26671     226544.13335
Residual            25        160135.84045       6405.43362

F =      35.36749       Signif F =  .0000

------------------ Variables in the Equation ------------------

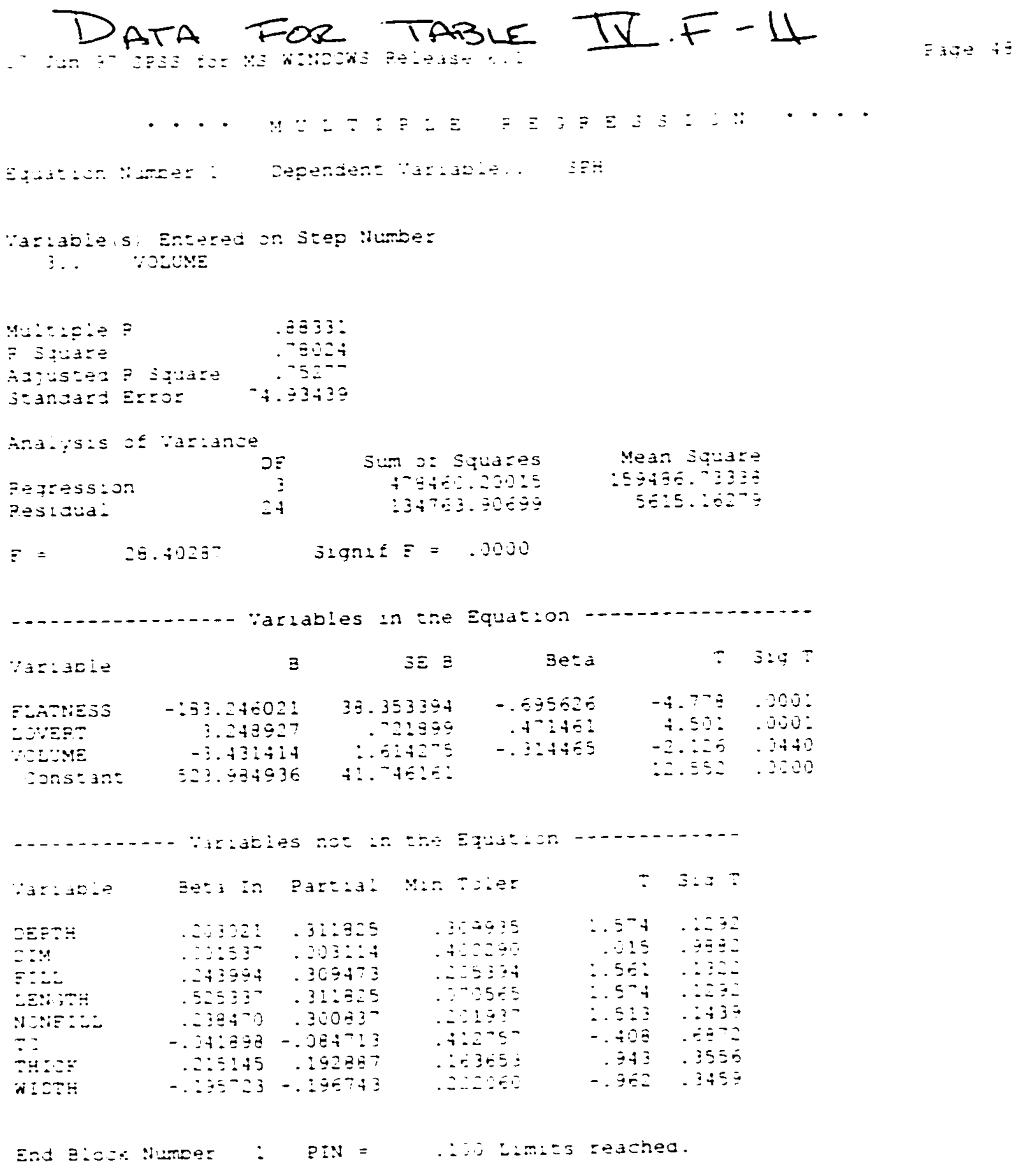
Variable              B        SE B       Beta          T  Sig T

FLATNESS    -241.117649  28.852768  -.915314     -8.357  .0000
LOVERT         2.935601    .754783   .425994      3.889  .0007
(Constant)   567.087075  38.974246               14.550  .0000

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler        T  Sig T

DEPTH         .197545  .278342   .476298     1.421  .1685
DIM           .045036  .085604   .823646      .421  .6776
FILL          .169510  .222882   .314937     1.120  .2734
LENGTH        .511167  .278392   .076086     1.421  .1685
N REFILL      .178824  .219591   .312371     1.101  .2814
PI           -.016583 -.030468   .837869     -.152  .8804
THICK         .145306  .151683   .167128      .757  .4565
VOLUME       -.314465 -.398045   .418398    -2.126  .0441
WIDTH        -.334578 -.372787   .312011    -1.968  .0607
```



DATA FOR TABLE IV.F-11

```
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          * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   SPH


Variable(s) Entered on Step Number
   3..     VOLUME


Multiple R           .88331
R Square             .78024
Adjusted R Square    .75277
Standard Error     74.93439

Analysis of Variance
                     DF      Sum of Squares      Mean Square
Regression            3        478460.20015     159486.73338
Residual             24        134763.90699       5615.16279

F =      28.40287       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B          SE B       Beta         T  Sig T

FLATNESS    -183.246021   38.353394  -.695626    -4.778  .0001
LOVERT         3.248927     .721899   .471461     4.501  .0001
VOLUME        -3.431414    1.614275  -.314465    -2.126  .0440
 Constant    523.984936   41.746161              12.552  .0000


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

DEPTH        .203021  .311825   .304935      1.574  .1292
DIM          .001537  .003114   .400290       .015  .9882
FILL         .243994  .309473   .205394      1.561  .1322
LENGTH       .525337  .311825   .070565      1.574  .1292
NONFILL      .238470  .300837   .201937      1.513  .1439
TI          -.041898 -.084713   .412757      -.408  .6872
THICK        .215145  .192887   .163653       .943  .3556
WIDTH       -.195723 -.196743   .212060      -.962  .3459


End Block Number   1   PIN =      .100 Limits reached.
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DATA FOR TABLE IV.F

```
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Number of valid observations (listwise) =        109.00

                                                            Valid
Variable        Mean    Std Dev    Minimum    Maximum           N  Label

SPH           425.85     150.30        160        830         109
THICK            .07        .06       .011       .400         109
LENGTH          1.18        .61       .274      3.543         109
WIDTH            .92        .54       .160      2.575         109
DEPTH            .64        .35       .089      1.811         109
TC              6.18        .70       4.50       9.60         109
FILL           12.50      14.17          0         33         109
PRISM           9.02       5.53       1.00      25.00         109
```

CostQuick©

An Injection Molded Plastic Part Estimating Package

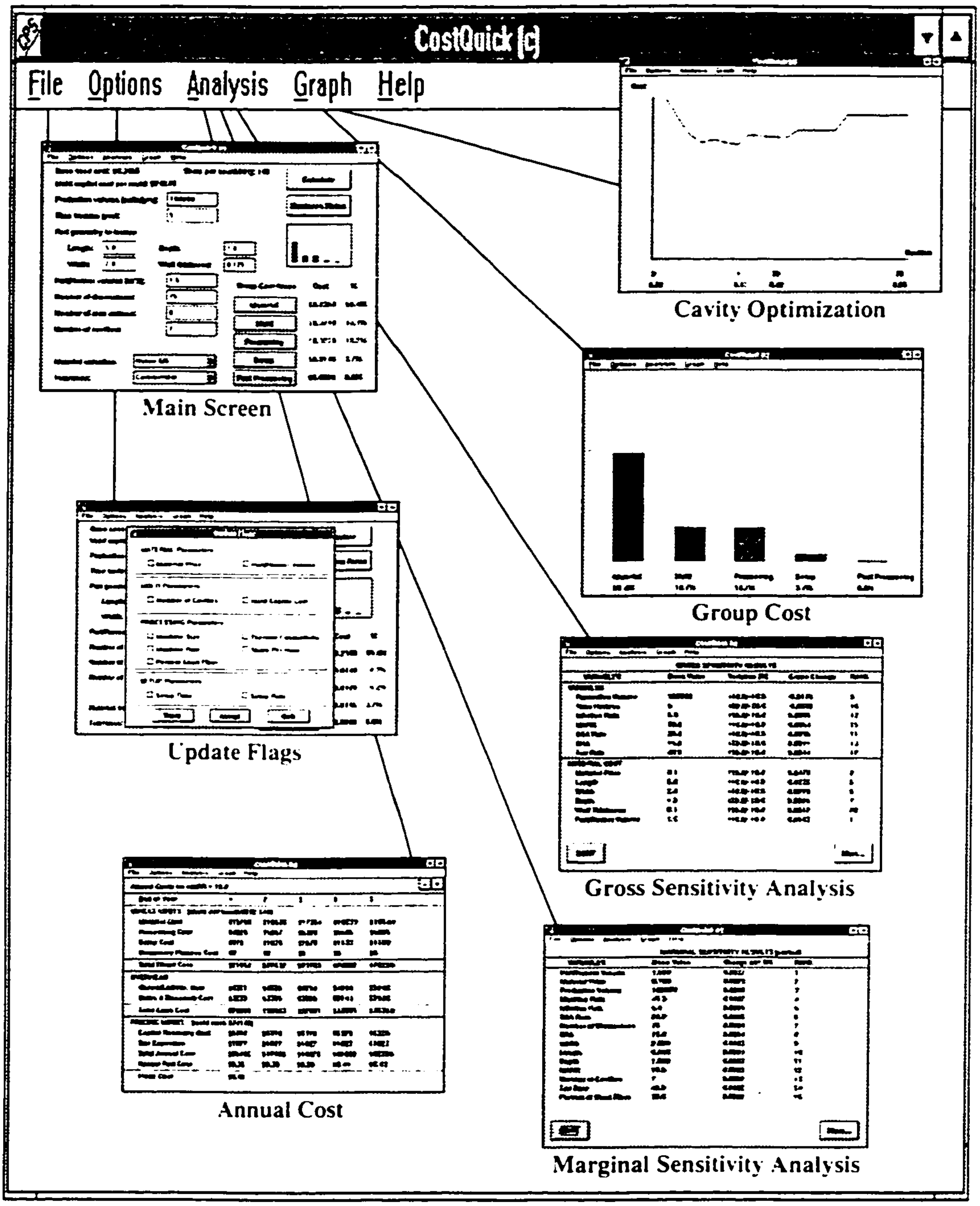
USER'S GUIDE

Designers

Dr. Donald N. Merino

Donald W. Merino

CostQuick© - An Injection Molded Plastic Parts Cost Estimator



CONTENTS

SECTION 1: Background

SECTION 2: Using CostQuick

WELCOME

Welcome to CostQuick™, a plastics part cost estimating package that enables engineers to determine the cost of their designs in the earliest stages. This allows for better and cheaper products and the prospect of continual improvement. The advantage of having this easy to use costing package lies in its ability to show the impact of changes in design on the cost which would be incurred in making the product, over the entire cycle of production.

This section of the *CostQuick User's Manual*© gives a guide to the documentation, providing you with information about the various features present in the package. It also gives you information about the installation procedures and the software that you will need to run it efficiently.

ABOUT THIS PACKAGE

CostQuick was created by Dr. Donald N. Merino and Donald W. Merino of Stevens Institute of Technology. It is based on extensive research conducted in several mold shops in the New Jersey and Minnesota areas, considered to be the best mold shops by a major conglomerate. CostQuick was developed with three goals in mind. The package allows engineers to get a good estimate of the costs of their designs, it enables them to "tweak" their designs for cost-effectiveness, and it provides a quick and accurate proforma cost analysis for designed projects before implementation. The package is easy to use and accurate enough to provide the design engineer with a good estimate as to the relative costs that would be incurred. The package uses Engineering Economics methodology to determine full-price costing, i.e. it takes into account tax rates and MARR, thus, generating a comprehensive cost estimate allowing for the time value of money and the return on investment.

INSTALLATION PROCEDURES

CostQuick is set up to run on Microsoft Windows and this package is, therefore, essential. If you do not have Windows, please refer to the Microsoft Corporation for help in its purchase and installation.

Once the Windows package has been installed, put the disk of CostQuick in the "A:" drive and enter "A:install". This would automatically copy the relevant files into your "c:/costquick" directory which would also be generated. In addition, an icon would be set up under the "Tools" window of the Windows "Main" menu. To start CostQuick, double click with the mouse button on the icon titled "CostQuick" or run "c:/costquick/cq" from the main menu of Windows. This will put you directly into the main menu of CostQuick.

SECTION 1: BACKGROUND

This section provides an introduction to the theoretical basis and assumptions, as well as a guide to the relative accuracy of the models upon which CostQuick is based. It also provides justification for the assumptions used in CostQuick and their impact on the model.

1.1 INTRODUCTION

CostQuick is a package which gives design engineers the ability to estimate the cost of their designs and to make changes or "tweak" the design for the optimum balance between the design variables and the long term or "full-price" cost. Designed projects require an accurate and quick proforma cost analysis before their implementation can take place. These analyses are performed by the easy to use and quick models that have been implemented in CostQuick.

The need for an accurate plastics part cost estimator has become more acute in recent years as the development of the plastics industry has proceeded at ever increasing rates. As in any industry, part cost is a major concern in the plastics industry. The cost of a plastic part is the sum of several costs associated with the part including:

- Material
- Mold
- Processing
- Setup
- Post-processing

Generally, the costs of a plastic part are mainly a combination of the material, processing and mold costs. Of these, the material and processing costs can be estimated fairly accurately, but, the mold costs show a wide variation between the estimates and the actual costs incurred by the mold makers. In a study conducted by Donald W. Merino, the variation between the price quoted and the actual cost, on an average, was over 60% as opposed to the assertion of 20% made by all the shops. Therefore, a model that could accurately estimate the mold cost was developed. Additionally, a sensitivity analysis which gave an accurate view of the relative impacts of the various costs associated with the part was developed and incorporated into CostQuick. Thus, CostQuick enables an engineer to accurate predict the effect that a small change in any of the design variables would have on the overall cost of the part.

There are various elements of mold costs which must be factored into any generic mold costing package in order for it to be accurate within the bounds of the variables established. These elements are set up in a group technology structure in order to facilitate the input of data and ease the analysis of their impact on the overall cost. The elements included in the model are:

- Length
- Width

- Depth
- Part/Runner Volume
- Number of Dimensions
- Maximum Wall Thickness
- Number of Side Actions
- Tightest Tolerance
- Material
- Number of Cavities
- Capacity

These elements represent the various part and mold features which impact on the cost. The selection of these elements from a far wider group originally studied proceeded on the basis of regression analysis and extensive research of mold shops around the US. This group technology structure is versatile enough to give the cost of the mold, cycle time and the material costs for a wide range of candidate parts. An explanation of all these elements is given in the next few sections.

1.1.1 Length, Width and Depth

These three are the dimensional elements used to determine the cost of the moldbase, mold material and machining time. These three variables define the "prism", which is the *smallest rectangular box* that encloses a part.

Once the size of the prism has been determined, its longest side becomes the length variable. The width is the distance between two points that are the furthest apart as measured in a direction perpendicular to the length. The depth is the distance between the top plane of the prism and the point which is furthest from it, measured in a direction perpendicular to the top plane. The Length, therefore, is greater than the Width, which is greater than the Depth, in general.

1.1.2 Part/Runner Volume

The part/runner volume is the actual volume of the part. In most cases, this was found to be about 15% of the prism volume. This factor correlates to the mold machining time, part cycle time and the part material cost.

The correlation between the mold machining time and the volume of the part occurs through the amount of material that has to be milled out. The larger the part/runner volume, the greater the mold machining time required to produce the mold since more of the material has to be milled out.

The part cycle time relates to the part/runner volume through the cooling time required for the part. The smaller the part/runner volume, the greater the ratio of the surface area available for cooling, transforming into a reduction of the cooling time.

Part material cost is the cost of the total amount of material required for a part and so, depends directly on the volume of the part. The smaller the part volume, the smaller the part material cost. Part material cost can be found by a simple multiplication of the cost of the material per unit volume and the volume of the part.

1.1.3 Number of Dimensions

The number of dimensions is a measure of the part complexity. Generally, the part complexity is determined via the number of certain features present in the part such as ribs, bosses and gussets. There are several classes of parts, however, that do not have these features, for example, O-rings. In order to facilitate these classes of parts an alternative methodology is required. The number of dimensions required to completely specify the part geometry is a very general, straight forward and accurate method of determining the degree of complexity of the geometry. The greater the number of dimensions, the greater the part complexity. The greater the part complexity, the greater the cost of the mold required to produce the part.

1.1.4 Maximum Wall Thickness

The maximum wall thickness has a considerable impact on the cooling time of the part and thus, the cycle time. Thicker walls require longer cooling times and the cooling time for multi-walled parts are usually constrained by the thickest wall. Therefore, the maximum wall thickness becomes an important criteria in determining the cycle time.

1.1.5 Number of Side-Actions

The side-action variable is a step function from 0 to 4 and measures the number of side-actions required. Side-actions increase the cost of the die and also have an impact on the cycle time. A mold with a side-action is more complex and, therefore, costs more. Side-actions are needed whenever an undercut occurs in the part.

1.1.6 Tolerance

The tolerance specified for a part is directly related to the molding difficulty. Generally, the tighter the tolerance, the more precise is the molding required and, therefore, the higher the cost and cooling time, especially if the die is used to shrink fit the part.

1.1.7 Material Cost

A material code is used to determine the material to be used for the part. The material costs and processing costs are dependent on the material used and the type of material is, therefore, a major criterion. Material cost is generally a major proportion of the total cost, especially in high volume production runs where it can frequently be 60-70% of the overall cost.

1.1.8 Number of Cavities

The number of cavities affects the mold cost directly. As the number of cavities increases, the mold cost increases proportionately. However, as the number of parts to be made increases, the mold cost becomes a less important factor, as opposed to the processing cost, with respect to the overall cost. The processing cost would decrease on a per part basis if a multi-cavity mold is used. Thus, an increase in the number of cavities might ultimately decrease the overall part cost.

1.1.9 Capacity

Capacity refers to the number of shots per hour that can be accommodated. This depends almost completely on the cycle time of the part. The number of shots that can be accommodated are calculated by dividing one hour by the cycle time of the part. This is the maximum number of shots that can be produced no matter what the size of the machine. The minimum size of the machine that has to be used in order to produce the required number of parts is also related to this capacity. Based on the number of shots that can be produced per hour, the total number of hours that are worked per year, and the production volume required, the number of cavities needed in the mold can be calculated. The total projected surface area of all the cavities determines the size of the machine required. This relationship is based on the work done by Dym, and his formulae have been used in CostQuick.

1.2 THEORETICAL BASIS

This section provides the economic and statistical underpinnings of the model used in CostQuick and a brief description of the development of the algorithms for mold costing and cycle time.

1.2.1 Mold Cost

In order to develop the model, considerable research was conducted and the data gathered was analyzed using a Modified Group Technology System (MGTS) to determine the correlation between the features proposed and the cost of the injection mold. Data on 110 parts was gathered from molding shops and analyzed through the use of a number of statistical techniques, eventually leading to a multiple regression analysis, in order to develop an equation that accurately related the variables. A correlation coefficient of 0.9 was the targeted value.

The proposed variables in the MGTS were

- Dimensions
- Cavities
- Percent Prism
- Side Actions
- Depth
- Length
- Tolerance
- Width

These variables were correlated to the mold cost and the correlation coefficient determined. The three variables with the highest correlation to the cost were cross correlated to other variables in order to develop composite variables which would give still higher correlation coefficients. The low correlation variables were thus amalgamated into composite functions.

A regression and stepwise multiple regression was performed in order to develop an initial equation and numerous transformations were performed on the variables based on the results. These transformed variables were now put through the process described above and the resulting equation developed. The equation, when tested, gave a Coefficient of Determination of 0.823 which transforms to a correlation coefficient of greater than 0.9. The final equation that was developed was:

$$\begin{aligned}\text{Mold Cost (1992 Dollars)} = &- 4993\\ &+ 1135*\sqrt{(\text{Cavity} * \text{Dimension})}\\ &+ 12266*\text{Side Action}\\ &+ 54*\sqrt{(\text{Width}*\text{Dimension})} * \text{Percent Prism}\\ &+ 1358*\sqrt{(\text{Length} * \text{Depth})}\end{aligned}$$

The above equation, although general in nature, would be most accurate within the parameters of the data collected about the parts. The relevant ranges of the variables, therefore, need to be defined and are given in table 1.

Variable	***High Value***	***Low Value***	***Mean Value***	***Std. Dev.***
Mold Cost	$57,402	$2,025	$14,508	$11,322
Cavities	16	1	5	3
Length	3.54"	0.27"	1.18"	0.64"
Width	2.57"	0.16"	0.91"	0.52"
Depth	1.81"	0.09"	0.65"	0.36"
Dimensions	117	5	46	29
Tightest Tolerance	0.01"	0.000394"	0.0035"	0.0017"
Side Actions	1	0	0.03	0.16

Table 1: Relevant Ranges of Variables for Mold Cost Estimation

1.2.2 Cycle-Time

A Cycle-time algorithm was developed using the data collected from the molding vendors on 110 parts. The process of generating an equation which would give a correlation coefficient of over 0.9 was similar to the one described in the Mold Cost determination (Section **1.2.1**). A Modified Group Technology System (MGTS) was proposed and the variables defined in it were analyzed using several statistical tools in order to generate the required equation. The variables proposed in the MGTS were:

- Percentage of Fiber Fill
- Width
- Length
- Depth

- Wall Thickness
- Percent Prism
- Thermal Conductivity

The first step in the process of generating an equation was the creation of a correlation matrix between these variables and the cycle time. The three variables with the highest correlation to the cycle time were then cross correlated with other variables to establish any dependencies that might occur. A regression analysis was now performed to determine a linear relationship between these variables and the cycle time. A stepwise multiple regression was now performed to determine the formula based on the linear model. The variables were transformed, i.e., new variables which were combinations of these variables were generated for a better fit. The new variables were then regressed against the cycle time. The transformations that were generated were derived from a one dimensional heat conduction equation. A stepwise regression was performed on the transformed variables in order to generate the required equations.

Two formulae were generated using the above approach. The first was for small dense parts upon which the wall thickness had little or no effect as far as cooling and thereby the cycle time was concerned. The formula developed was:

$$\begin{aligned}\text{Cycle Time (Seconds)} = {} & + 4.69 \\ & + 2.11 * \text{Width} \\ & + 0.08 * \text{Percent of Fiber Fill} \\ & + 3.6 * \sqrt{(\text{Length}*\text{Width}*\text{Depth})/((1\text{-Fill})*\text{Thermal Conductivity})}\end{aligned}$$

The second formula was generated for thinner parts whose cycle time is driven by wall thickness. The equation generated was:

$$\begin{aligned}\text{Cycle Time (Seconds)} = {} & + 8.22 \\ & + 0.15 * \text{Percent of Fiber Fill} \\ & + 152.9 * \sqrt[6]{(\text{Wall Thickness}/((1\text{-Fill})*\text{Thermal Conductivity})} \\ & \qquad * \text{Percent of Prism}\end{aligned}$$

Both of these formulae gave a correlation coefficient (R) of greater than 0.9. As in the cost estimation of molds, the cycle time estimation equations, although general in nature, would be more accurate within the parameters of the variables for the data collected about the parts. These ranges for the various variables, therefore, need to be kept in mind when using the package to estimate the costs.

The relevant ranges of the variables are given in table 2:

Variable	***High Value***	***Low Value***	***Mean Value***	***Std. Dev.***

Cycle Time	22.5 sec.	4.5 sec.	9.84 sec.	3.96 sec.
Wall Thickness	0.4"	0.01"	0.068"	0.06"
Length	3.54"	0.27"	1.19"	0.65"
Width	2.57"	0.16"	0.91"	0.52"
Depth	1.81"	0.09"	0.65"	0.36"
Thermal Conductivity	7.00	4.5	5.94	0.68
%Short Fiber Fill	33%	0%	15.4%	15.64%
Percent Prism	25%	1.2%	8.93%	5.46%

<u>Table 2</u>: Relevant Ranges of Variables for Cycle Time Estimation

1.3 BASIC ASSUMPTIONS

This section provides a succinct list of assumptions used in the creation of CostQuick. The models incorporated in CostQuick have an underlying basis which should be carefully examined to enable an effective use of the program. The assumptions used are justified in the following paragraphs.

1.3.1 *One Machine One Mold*

It is assumed by CostQuick that the production volume as entered by the user is for one machine using a single mold. be it of one or more cavities. for one year. To facilitate this. CostQuick checks whether the production volume requested by the user is feasible for one machine up to the maximum machine tonnage present. If the production volume required is greater than the production capacity of a machine, CostQuick subdivides the production volume and performs the check again. It then informs the user as to the number of molds and. therefore. the number of machines that would be required for the production volume. CostQuick then calculates the cost per part based on the material cost of one part. process cost of one type of machine and the capital cost of multiple molds.

1.3.2 *Tonnage and Labor Rates*

The tonnage of a machine that is required to generate the parts is calculated by CostQuick on the basis of work done by Dym. Essentially. Dym's work resulted in a step function of an increase in the tonnage required based on the surface area of the part and the number of cavities that have to be filled. The tonnage increase is in levels of 50 tons each.

The labor rates depend on the tonnage of the machine and are saved in a database. The default rates used by CostQuick are based on the 1992 Society of Plastic Engineers mold makers survey. These can be changed as and when the results of new surveys are published or tailored to your own mold shop.

1.3.3 *Relevant Range*

CostQuick is accurate primarily in the relevant ranges of the variables as presented in tables 1 and 2. Extrapolation of these results outside the relevant range is possible but the accuracy of such cost analyses cannot be predicted with any great degree of certainty. They would, however, provide a good first approximation of the costs involved and the sensitivity analysis would certainly provide a good idea of the factors that drive the costs.

1.3.4 *Dollar Base*

1992 was selected as the dollar base for the package and so, all the costs shown by CostQuick are in terms of the 1992 dollar. As the labor rates are revised, CostQuick provides the values in terms of current dollars.

1.3.5 *One Year Multiples*

The Time Horizon is set to be in multiples of one year. This is primarily to facilitate the Annual Cost structure that would be incurred and is calculated by CostQuick.

1.4 ACCURACY

The accuracy of CostQuick within the relevant parameters as specified above, has been tested extensively, the results falling well within acceptable uncertainty ranges, ±20%, for several classes of parts. Thus, CostQuick is able to provide an excellent first approximation of the costs involved, sufficient for a feasibility analysis of projects.

SECTION 2: USING COSTQUICK

This section provides a comprehensive overview of the CostQuick Plastic Part Estimating System. It also provides explanations of the results, where necessary, as well as the method of analyzing them.

2.1 GETTING STARTED

To get started on CostQuick, select "Main" from the MS-Windows menu. Double click with the mouse on the icon labeled "CostQuick". Alternatively, run the file "c:/CostQuick/cq" from the "File" option of MS-Windows. Both of these would start CostQuick and put you in the main menu of CostQuick. The Main Screen would appear as shown in Figure 2.1.

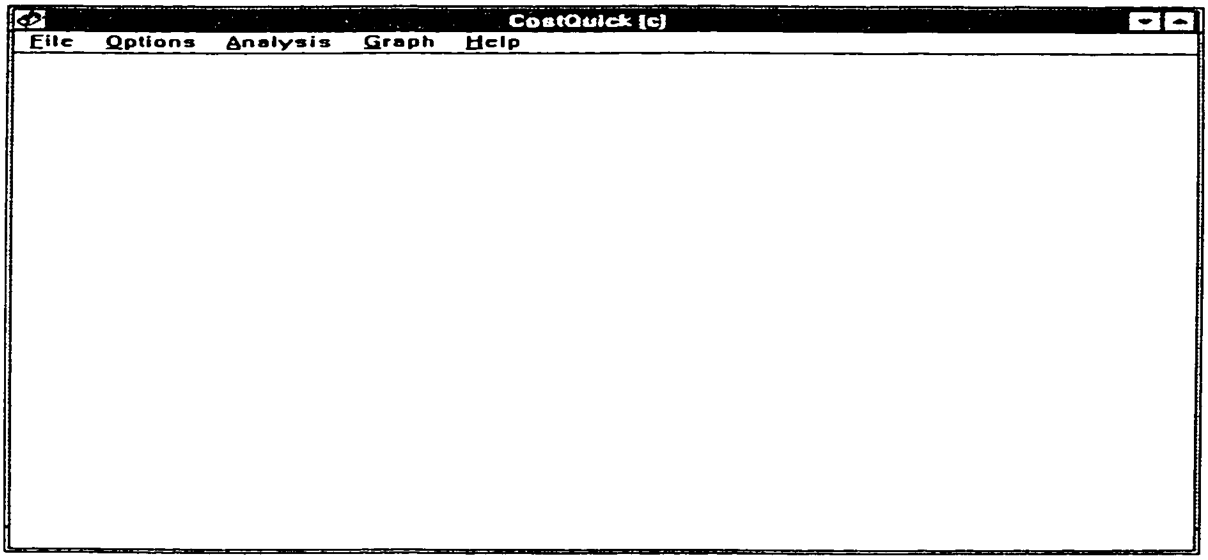


Figure 2.1: Main Screen

2.2 FILE

Under the "File" command, at the top of the Main menu, are seven options that can be used. These constitute the entry/exit protocol of CostQuick. These seven commands are explained below. Any of these commands can be used at any point of the analysis without affecting the analysis and, thus, these commands are global in nature.

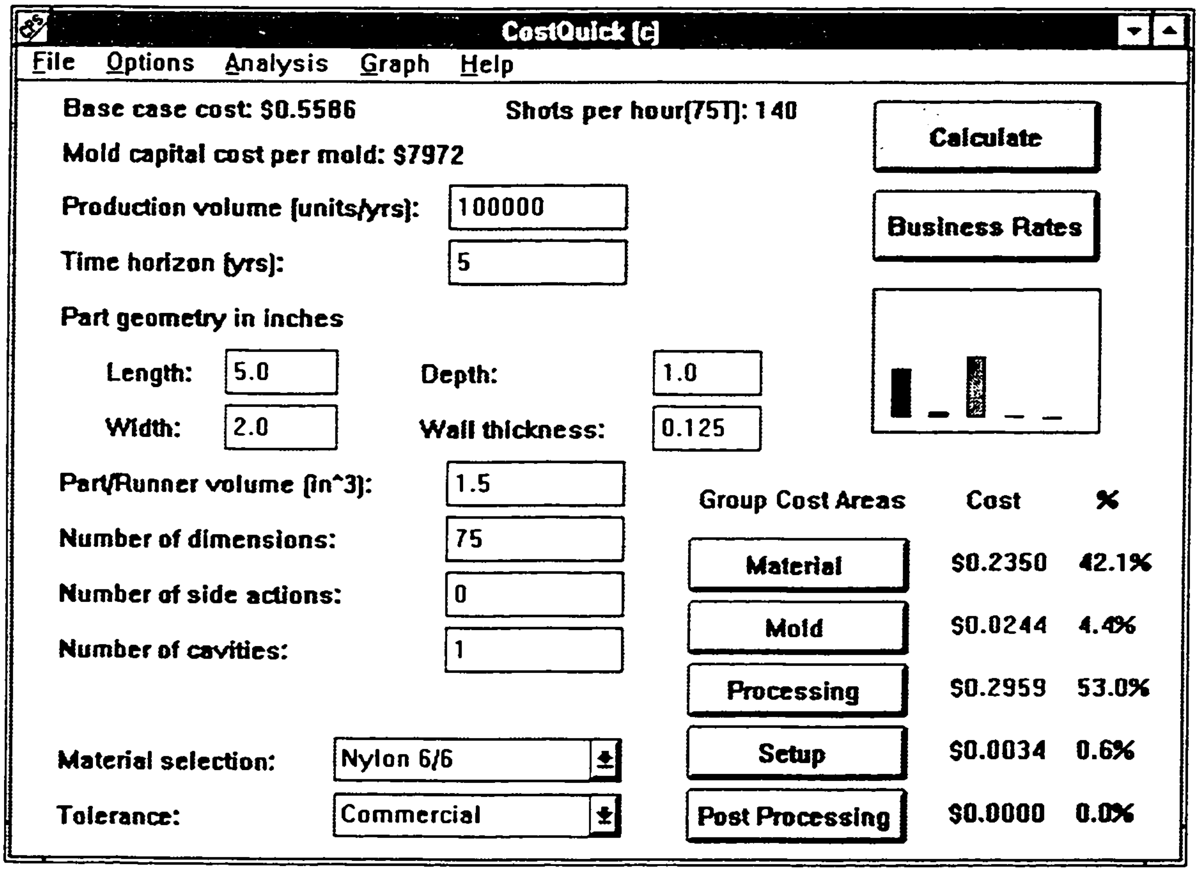
2.2.1 *Load Project*

The ***load project*** command allows the entry of a previously saved CostQuick program. This enables the continuation of modifications as and when they occur. The use of this command will automatically upload the relevant program into CostQuick and put the user into the main screen of the program. The default extension of the programs allowed to be loaded in CostQuick is ".cq".

However, any other extension specified by the user can also be loaded provided the file format is compatible with the CostQuick program.

2.2.2 *Main Screen*

This command enables the user to start a new project in CostQuick or to get to the Main Screen from any other screen in CostQuick. In the case of a new project, all the variables are set at their default values and the user is put into the main screen of the program, shown in Figure 2.2.2. A calculation using the default values can be performed by clicking the "calculate" button on the top right corner of the screen. This provides a means of checking that the program has been loaded correctly. The correct solution for the default values is given in Appendix 2.



Base case cost: $0.5586

Shots per hour(75T): 140

Mold capital cost per mold: $7972

Production volume (units/yrs): 100000

Time horizon (yrs): 5

Part geometry in inches

Length: 5.0

Depth: 1.0

Width: 2.0

Wall thickness: 0.125

Part/Runner volume (in^3): 1.5

Number of dimensions: 75

Number of side actions: 0

Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

Group Cost Areas	Cost	%
Material	$0.2350	42.1%
Mold	$0.0244	4.4%
Processing	$0.2959	53.0%
Setup	$0.0034	0.6%
Post Processing	$0.0000	0.0%

Figure 2.2.2: Main Screen

2.2.3 *Save*

The *save* option allows the saving of any CostQuick analysis undertaken by the user. The program will use the extension ".cq" as a default when saving the projects, but will allow any other extension specified by the user. If the analysis has not been saved before the user terminates the session, the program will alert the user to this situation and enable the user to save the analysis.

2.2.4 *Save As*

This option allows the user to save the analysis under a different file name if so desired by the user. The default extension used by the program is ".cq", but the use of any other extension specified by the user is allowed.

2.2.5 *Print*

The ***print*** command allows the user to print out any particular screen of the CostQuick program. The command will print out the screen that the user is on at the time the ***print*** command is used. The output of the ***print*** command is sent directly to the printer that is specified in the "printer setup".

2.2.6 *Exit*

The exit protocol of the CostQuick package is facilitated by the ***exit*** command. This command can be used at any point in the analysis, but if the program has not been saved immediately prior to this command, the user will be warned and given the option of saving the analysis. Thereafter, the user is put back into the Windows menu structure.

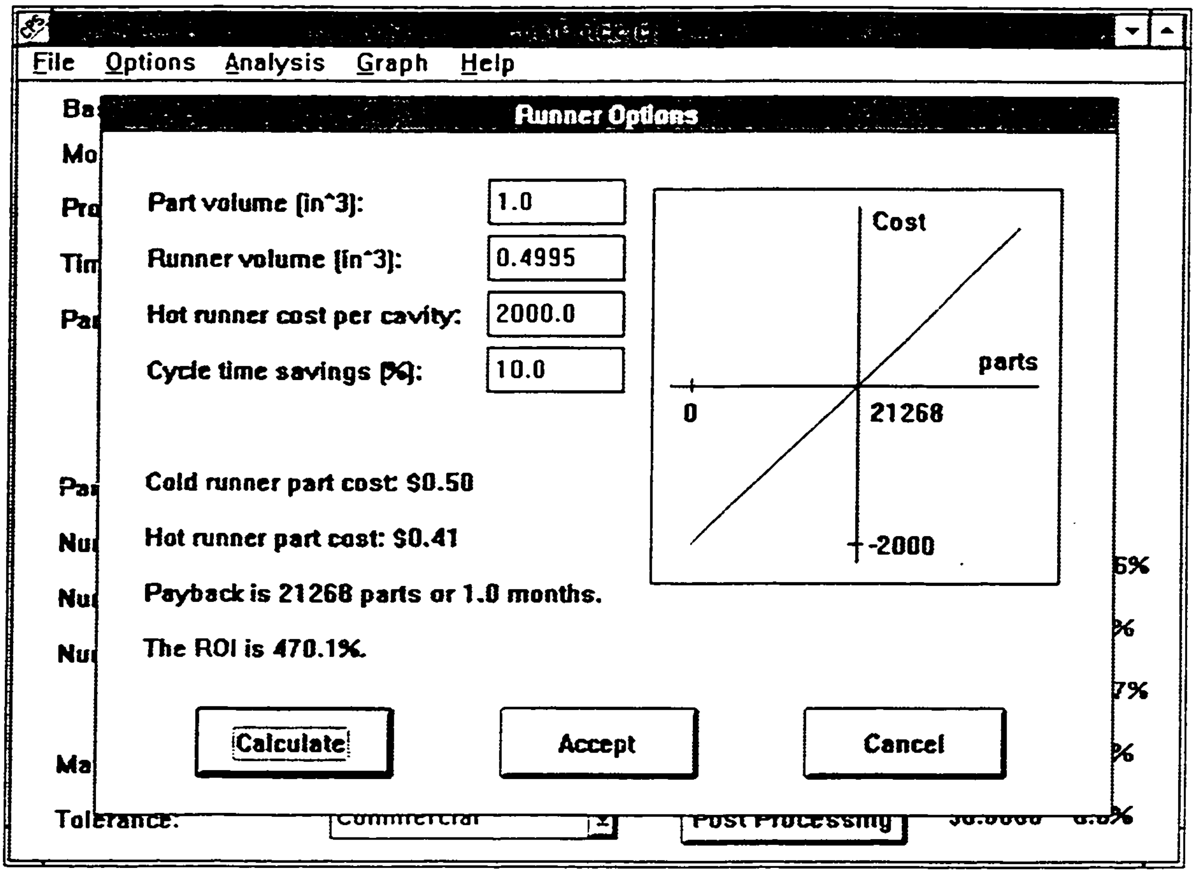
2.3 OPTIONS

The "Options" menu enables the specification of the type of analysis required, units which are to be used and the variables that need to be calculated by CostQuick or, alternatively, manually input by the user. The "Options" menu consists of four sub-menus for these purposes. The meanings and usage of the four sub-menus are explained below.

2.3.1 *Hot Runner©*

The type of runner that is used can be specified in this option. The trade-offs between the hot and the cold runner systems can, thus, be explored via the use of this option. In general, there are three aspects which impact on the choice between a hot and a cold runner system. Molds with hot runner systems are more expensive than ones with the cold runners, but, the volume of the material required is smaller in hot runner systems. Depending on the part production volume it might become more cost efficient to have a hot runner mold than a cold runner mold. The trade-off between the two occurs in the capital cost of the part. In high production volume runs, the preponderance of the cost shifts towards the material costs, necessitating the reduction in this aspect of the overall cost, as opposed to mold cost. Thus, a hot runner system would become preferable to a cold runner system.

If the ***Hot Runner*** option is used, a screen with the various factors that affect the cost of a hot runner system is brought up by CostQuick (Fig. 2.3.1).



Part volume [in^3]: 1.0
Runner volume [in^3]: 0.4995
Hot runner cost per cavity: 2000.0
Cycle time savings [%]: 10.0

Cold runner part cost: $0.50
Hot runner part cost: $0.41
Payback is 21268 parts or 1.0 months.
The ROI is 470.1%.

Figure 2.3.1: Hot Runner Screen

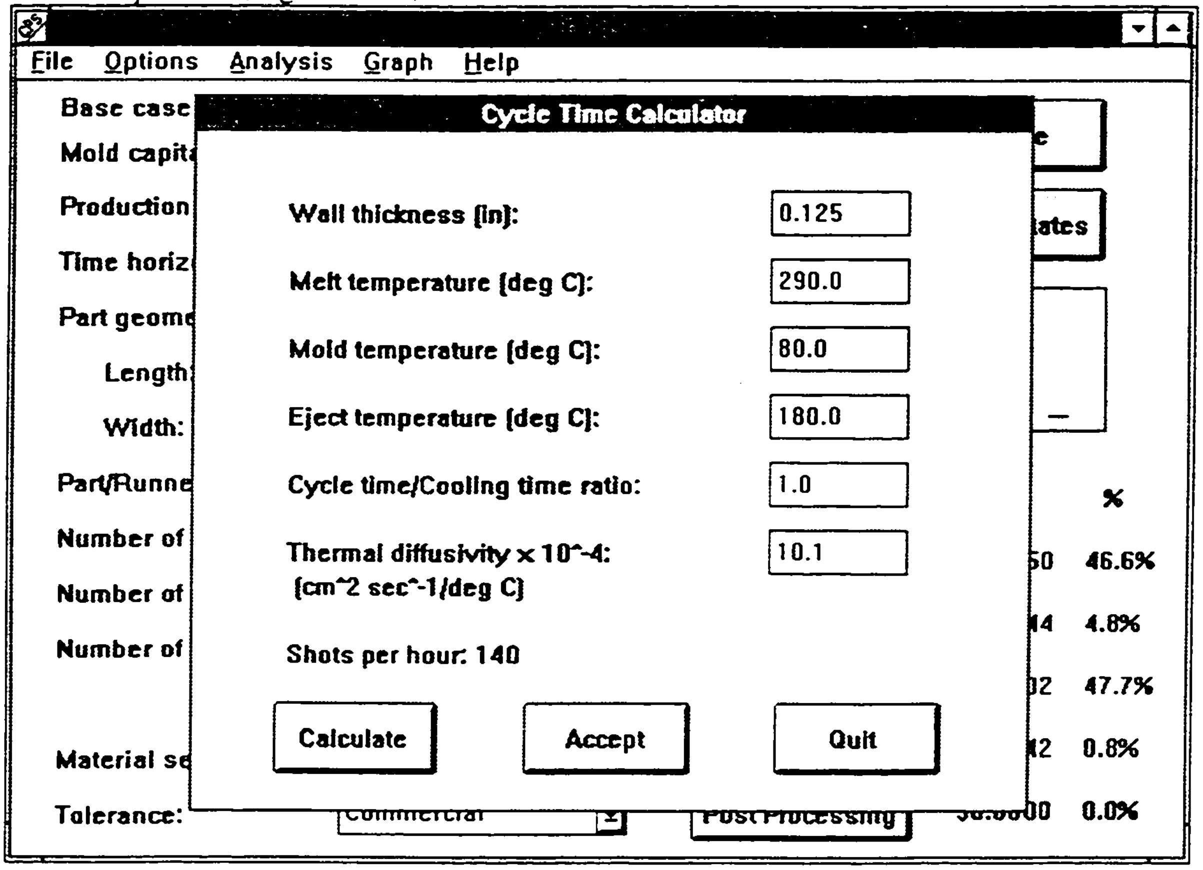
The Hot Runner Screen shows the inputs required for CostQuick to calculate the cost of a hot runner mold. The Part volume and the Runner volume are calculated by CostQuick on the bases of a 66.6% to 33.3% breakdown of the Part Runner volume input in the Main Screen. Since these values are calculated, they are highlighted in blue. If these values are input manually, the values will not be highlighted. The cost of the hot runner per cavity in a mold has to be input next. This directly affects the mold cost. The expected cycle time savings that would occur due to the use of a hot runner has to be input in order to enable CostQuick to determine the trade-off between the increased cost of the hot runner mold and the savings that accrue due to a reduced cycle time.

The graph on the right of the input variables is the break even graph. It shows, graphically, the number of parts that have to be produced to pay back the additional investment of the Hot Runner mold. The Hot Runner mold saves on the material required, and this saving has to make up for the increased cost of the mold. This trade off is shown in the graph.

The use of the ***Hot Runner*** option enables the exploration of the relative benefits to be gained through the use of the hot and cold runner systems and a comparison of the costs involved. If the ***Hot Runner*** option is not tagged the cold runner system is used. If the hot runner option is not to be used, the "Cancel" button should be used in order to exit the hot runner screen. This will cause the cold runner system to be used.

2.3.2 *Cycle Time*

This option enables the user to select calculation of the cycle-time either based on the one-dimensional heat transfer equation or regression analysis. Use of the option brings up a screen presenting the variables which are needed for the calculation of the cycle time based on the *One Dimensional Heat Transfer© Equation* (Figure 2.3.2).



Wall thickness (in): 0.125

Melt temperature (deg C): 290.0

Mold temperature (deg C): 80.0

Eject temperature (deg C): 180.0

Cycle time/Cooling time ratio: 1.0

Thermal diffusivity x 10^-4: (cm^2 sec^-1/deg C) 10.1

Shots per hour: 140

Figure 2.3.2: Cycle Time Calculator

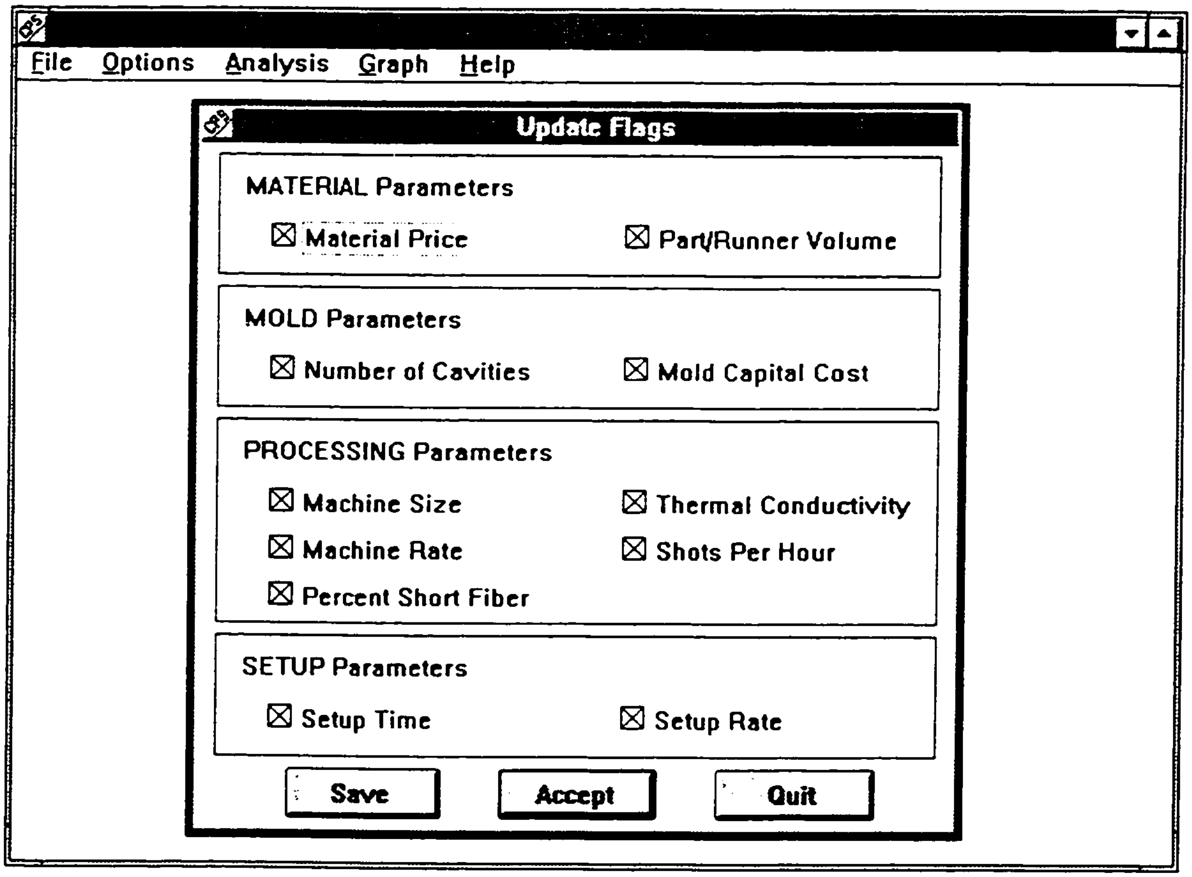
The Cycle Time Calculator requests a number of inputs in order to calculate the cycle time using the One Dimensional Heat Transfer Equation. The Wall Thickness is the maximum wall thickness of the part and is the same as the value which is entered on the Main Screen. The Melt Temperature is the temperature slightly above the melting temperature of the material. This is the temperature that has to be achieved in allow a free flow of the material. The Mold Temperature is the temperature that the mold is to be maintained at and is always lower than the Melt Temperature. The Ejection Temperature is the temperature that the part has to cool to before it can be ejected from the mold. This temperature is lower than the Melt Temperature but higher than the Mold Temperature. The Cycle Time Cooling Time Ratio is the ratio of the Cycle Time to the Cooling Time. The default value in CostQuick is 1.2 but this value is generally between 1.2 and 1.5. The Thermal Diffusivity is material dependent and CostQuick pulls this value from a database. Using all these values CostQuick calculates the Cycle Time for a Hot Runner Mold.

If this option is not to be used, the "Cancel" button at the bottom left hand corner must be used. If the "Accept" button is used, the Shots Per Hour Flag in the Update Flag Menu is automatically switched off.

2.3.3 *Update Flags©*

This option allows the selection of the variables which the user wants CostQuick to calculate. If the user wishes to enter a value of the variable listed manually and does not wish this value to be affected by other calculations that CostQuick makes, then the user should click on the relevant button to *remove* the check against it. Else CostQuick will calculate and update the value. The values that are calculated by CostQuick are highlighted in blue through all the screens. Those that CostQuick does not calculate are not colored.

There are three options listed at the bottom of the Update Flags screen. These are the save, accept and the quit options as shown in Figure 2.3.3.



MATERIAL Parameters

☒ Material Price
☒ Part/Runner Volume

MOLD Parameters

☒ Number of Cavities
☒ Mold Capital Cost

PROCESSING Parameters

☒ Machine Size
☒ Thermal Conductivity
☒ Machine Rate
☒ Shots Per Hour
☒ Percent Short Fiber

SETUP Parameters

☒ Setup Time
☒ Setup Rate

Figure 2.3.3: The Update Flags Screen

The *save* option saves the parameters that the user wishes CostQuick to calculate on a permanent basis. As a default, all the variables shown on the Update Flag screen are calculated and marked, as shown. If the user wishes to change the values for the current session only, the ***accept*** option can be used. The ***quit*** option enables the user to leave the screen without making any changes.

2.3.4 *Metric Units*

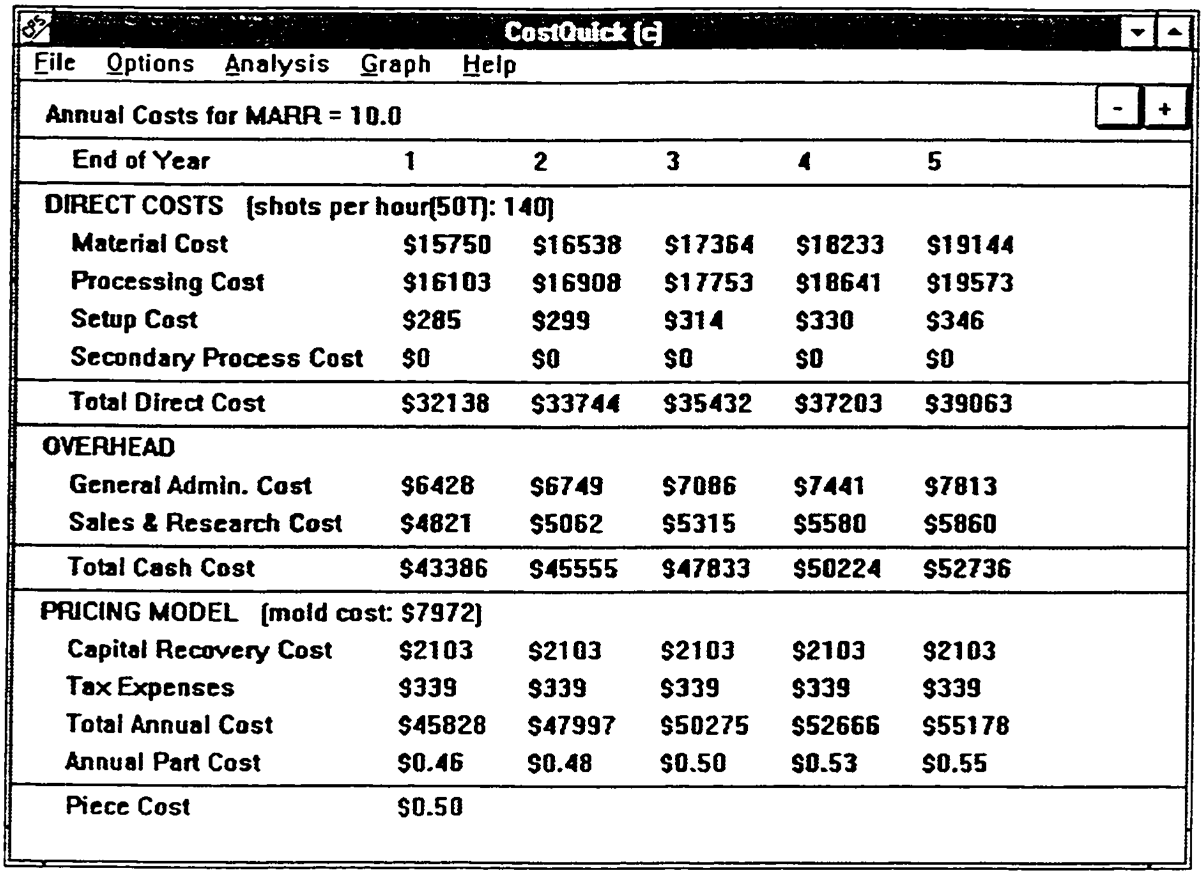
The units that the user wishes to use can be specified by the ***Metric units*** option. If this option is checked, Metric Units are being used. Else, British Units are used. The default units are the British units which enable the use of pounds, inches and seconds. The Metric units would allow the use of kilograms, centimeters and seconds.

2.4 ANALYSIS

The "Analysis" menu allows the examination of the annual cost, the marginal sensitivity analysis and the gross sensitivity analysis of the project based on the values input by the user. These are the major outputs of the CostQuick package along with the optimal number of cavities and the relative breakdown of costs into the mold, material, processing, setup and post-processing costs.

2.4.1 *ANNUAL COST*

The ***Annual Cost*** analysis provides a breakdown of the projected costs which would be incurred from year to year over the period of the time horizon specified, taking into account the projected inflation, the MARR and the projected Tax rate. The "Annual Cost" screen is presented in Figure 2.4.1.



Annual Costs for MARR = 10.0

End of Year	1	2	3	4	5
DIRECT COSTS [shots per hour(50T): 140]					
Material Cost	$15750	$16538	$17364	$18233	$19144
Processing Cost	$16103	$16908	$17753	$18641	$19573
Setup Cost	$285	$299	$314	$330	$346
Secondary Process Cost	$0	$0	$0	$0	$0
Total Direct Cost	$32138	$33744	$35432	$37203	$39063
OVERHEAD					
General Admin. Cost	$6428	$6749	$7086	$7441	$7813
Sales & Research Cost	$4821	$5062	$5315	$5580	$5860
Total Cash Cost	$43386	$45555	$47833	$50224	$52736
PRICING MODEL [mold cost: $7972]					
Capital Recovery Cost	$2103	$2103	$2103	$2103	$2103
Tax Expenses	$339	$339	$339	$339	$339
Total Annual Cost	$45828	$47997	$50275	$52666	$55178
Annual Part Cost	$0.46	$0.48	$0.50	$0.53	$0.55
Piece Cost	$0.50				

Figure 2.4.1: The "Annual Cost" screen

The total annual cost of a part is the sum of various costs which together ensure its production. These include Direct, Overhead, Capital Recovery and Tax expenses, all of which are explained below.

2.4.1.1 MARR

The first line of the "Annual Cost" screen shows the Minimum Acceptable Rate of Return (MARR) value chosen by the user. The default value for this is 10% and the MARR represents an inflation adjusted value. The MARR can be edited through the Business Rates menu (Sec. 3.2.4) accessed through the Main Screen (Sec. 2.2.2) shown in Figure 2.2.2. The Main Screen can be opened using the FILE-MAIN SCREEN command.

2.4.1.2 Direct Cost

The next section represents the Direct Costs which would be incurred during the time horizon of the project. These rates take into account the inflation rate specified through the Business Rates menu (Sec. 3.2.3). All the costs represent the total annual costs of the variables. An explanation of the Material cost, Processing cost, Setup cost and the Secondary Processing cost is provided below. Mold costs are not considered as Direct costs and are treated instead in the Capital Recovery costs (Sec. 2.4.1.4)

- Material cost represents the total annual cost of the plastic material required for the designated annual production volume of the part. It is a function of the unit material cost, the production volume and the part volume, adjusted for the inflation.
- Processing cost is the total annual cost of processing the part and is dependent on the machine rate, the annual production volume and the cycle time. The machine rate is dependent on the tonnage of the machine being used. A further explanation of this can be found under the section headed Processing Group Cost Area (Sec. 3.5).
- Setup cost is the cost of setting up the machine for the production of the part. It is dependent on the tonnage of the machine being used, adjusted for inflation. It is assumed by CostQuick that there is only one setup performed per year per machine. Further information about the Machine Tonnage is provided in Sec. 3.5.
- Secondary Processing cost is the cost of any finishing required once the part has been molded. It is dependent on the labor rate as specified by the user. As a default, it is assumed by CostQuick that no further processing is required on the part. Further information about the labor rate is provided in Sec. 3.6.

The Total Direct cost is the sum of the above four costs. The Direct cost is not dependent on the MARR.

2.4.1.3 Overhead

The section following the Direct cost is one relating to the Overhead costs associated with the production. The costs considered here include the General Administrative cost and the Sales and Research cost incurred by the business.

- General Administrative costs are the costs associated with the administration of the product line and the general production of the part (Sec. 3.2.5). These costs are dependent on the MARR as well as the rate of inflation and, thus, increase more rapidly than the Direct costs. This facet is reflected in the third section. Information about MARR and the inflation rate can be found under Business Rates (Sec. 3.2).
- The Sales and Research cost reflects the overhead due to the twin factors of the sales division cost and the research cost associated with the product (see Sec. 3.2.6).

2.4.1.4 Pricing Model

The pricing model includes the Capital Recovery cost and the Tax Expense incurred by the business. These expenses are constant over the planning horizon but have to be adjusted for the inflation (Sec. 3.2)

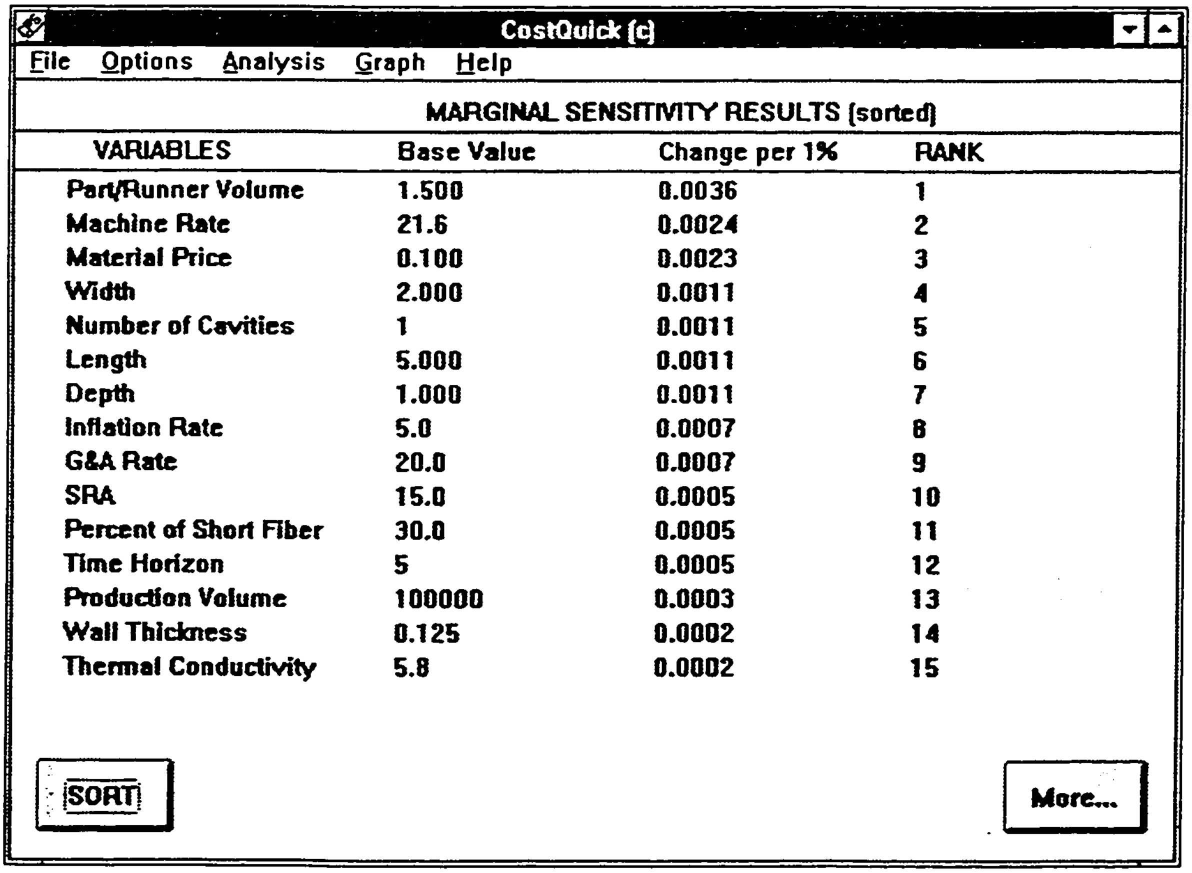
- Capital Recovery cost is the cost of the capital expenditure, primarily the mold cost, which must be recuperated every year to cover the capital cost.
- Tax expense is the projected cost of the taxes to be paid by the business on the project in question. Information about Tax Rates can be found in Sec 3.2.7.

The Total Annual cost is the sum of the Total Direct cost, the Total Cash cost, the Capital Recovery cost and the Tax Expense. The Annual Part cost is the cost of the single part and is calculated by dividing the Total Annual cost by the Annual Production Volume (Sec. 3.1.1).

The Piece Cost is the *average* of the Annual Part costs over the time horizon and represents the approximate cost of the piece over the production life cycle of the part.

2.4.2 MARGINAL SENSITIVITY ANALYSIS©

A Marginal Sensitivity Analysis reflects the relative impact of a change in the base value of a variable on the cost of the part. Specifically, the Marginal Sensitivity of a variable is the effect that a one percent change in the base value of the variable has on the cost of the part. As an example, consider the variable "material price". It has a base value, as shown in Figure 2.4.2, of $0.1/cubic inch. A change of one percent, i.e. $0.001, in its value (for the $0.1 base cost) would translate into a $0.0023 change in the cost of the part.



MARGINAL SENSITIVITY RESULTS (sorted)

VARIABLES	Base Value	Change per 1%	RANK
Part/Runner Volume	1.500	0.0036	1
Machine Rate	21.6	0.0024	2
Material Price	0.100	0.0023	3
Width	2.000	0.0011	4
Number of Cavities	1	0.0011	5
Length	5.000	0.0011	6
Depth	1.000	0.0011	7
Inflation Rate	5.0	0.0007	8
G&A Rate	20.0	0.0007	9
SRA	15.0	0.0005	10
Percent of Short Fiber	30.0	0.0005	11
Time Horizon	5	0.0005	12
Production Volume	100000	0.0003	13
Wall Thickness	0.125	0.0002	14
Thermal Conductivity	5.8	0.0002	15

Figure 2.4.2: Sorted Marginal Sensitivity Analysis

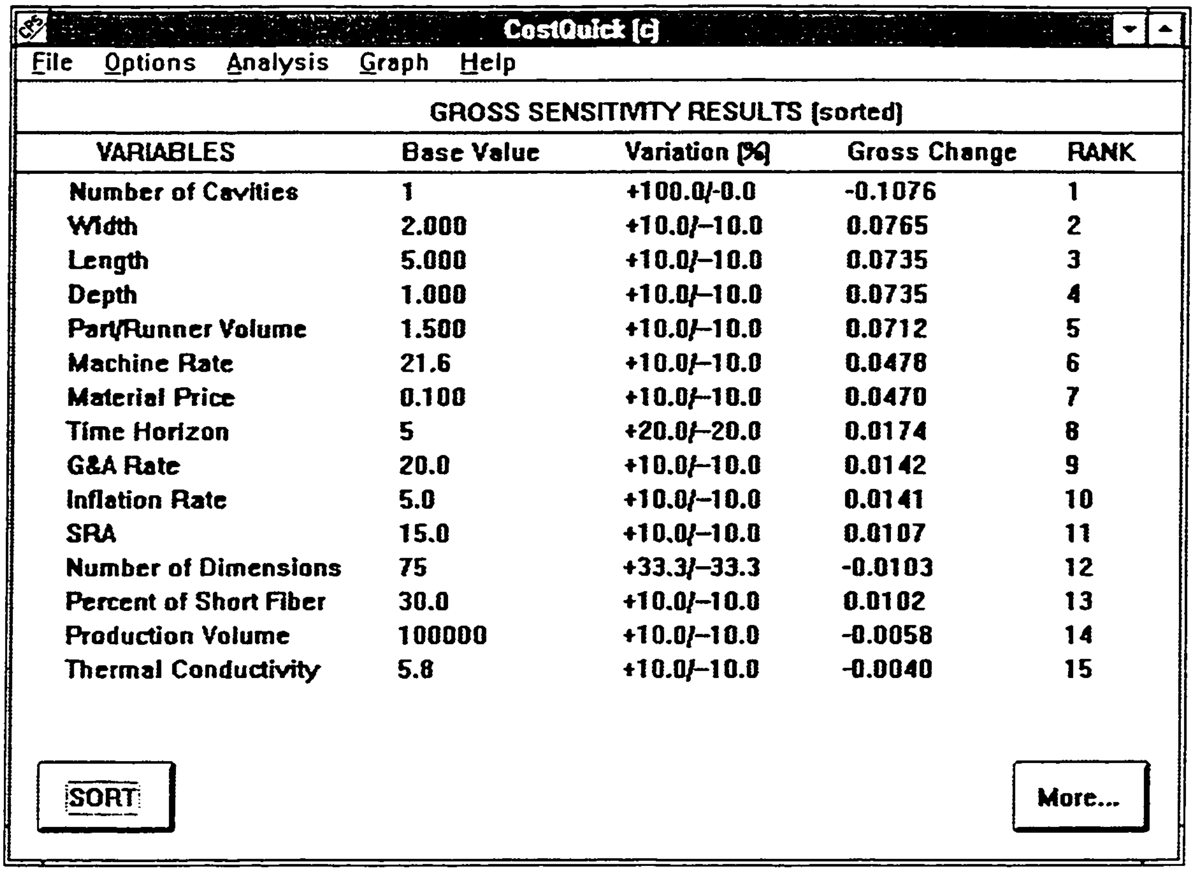
The Sorted Marginal Sensitivity Analysis screen (Figure 2.4.2) shows the variables ranked according to the impact that a change of 1% in them would have on the cost of the part. Column 1 gives a list of the variables which might have an impact on the cost. Column 2 shows the base value of the variable as specified by the user or calculated by CostQuick. Column 3 shows the impact, in dollars, of a change of one percent in the base value of the variable on the cost of the part. Column 4 gives the rank of the variable as far as its impact is concerned.

The "Sort" button on the bottom left hand corner of the screen enables the display of the variables according to the type of variables, i.e., Processing, Setup, Post-processing, Business, Mold or Material, or according to the rank of the variables. The variable which has the greatest impact is highlighted. The "More" button on the bottom right hand corner of the screen enables the scrolling of the variables in case of a spill-over of the variables onto the next page.

2.4.3 GROSS SENSITIVITY ANALYSIS©

The Gross Sensitivity Analysis represents the impact of the change in a variable's value coupled with the uncertainty associated with the assigned value. As an example, consider the variable "Number of Cavities". The base value of this, i.e., the number of cavities, is "1", as shown in Figure 2.4.3. However, since the number of cavities could increase to "2", the uncertainty associated with this value is +100%. The prescription of these limits is treated under the "Variable Selection" section of this manual (Sec. 3). The change in the part cost which would ensue due to the increase in the number of cavities from one to two is a reduction in price of $1.076, as reflected in the gross sensitivity analysis screen (Figure 2.4.3).

As in the Marginal Sensitivity Analysis, the sorted Gross Sensitivity Analysis screen presents the variables in decreasing order of importance. The unsorted Gross Sensitivity Analysis screen presents the variables according to their type, i.e., Processing, Setup, Post-Processing, Business, Mold or Material. The variable with the greatest impact is highlighted. The "More" button enables the scrolling of the variables in case of a spill-over of the variables onto the next page.



GROSS SENSITIVITY RESULTS (sorted)

VARIABLES	Base Value	Variation (%)	Gross Change	RANK
Number of Cavities	1	+100.0/-0.0	-0.1076	1
Width	2.000	+10.0/-10.0	0.0765	2
Length	5.000	+10.0/-10.0	0.0735	3
Depth	1.000	+10.0/-10.0	0.0735	4
Part/Runner Volume	1.500	+10.0/-10.0	0.0712	5
Machine Rate	21.6	+10.0/-10.0	0.0478	6
Material Price	0.100	+10.0/-10.0	0.0470	7
Time Horizon	5	+20.0/-20.0	0.0174	8
G&A Rate	20.0	+10.0/-10.0	0.0142	9
Inflation Rate	5.0	+10.0/-10.0	0.0141	10
SRA	15.0	+10.0/-10.0	0.0107	11
Number of Dimensions	75	+33.3/-33.3	-0.0103	12
Percent of Short Fiber	30.0	+10.0/-10.0	0.0102	13
Production Volume	100000	+10.0/-10.0	-0.0058	14
Thermal Conductivity	5.8	+10.0/-10.0	-0.0040	15

Figure 2.4.3: Sorted Gross Sensitivity Analysis

The sorted Gross Sensitivity Analysis screen (Figure 2.4.3) shows the variables ranked according to the impact that a change according to the maximum uncertainty in them would have on the cost of the part. Information on the uncertainty percent can be found in Sec. 3.2. Column 1 gives a list of the variables which might have an impact on the cost. Column 2 shows the base value of the variable as specified by the user or calculated by CostQuick. Column 3 shows the uncertainty present in the estimation of the value of the variable. Column 4 shows the impact, in dollars, of a change according to the uncertainty present in the base value of the variable on the cost of the part. Column 5 gives the rank of the variable as far as its impact is concerned.

2.5 GRAPH

The "Graph" menu allows a visual presentation of the Cavity Optimization with respect to cost and the breakup of the cost of the part in terms of the component costs.

2.5.1 CAVITY OPTIMIZATION©

A major feature of CostQuick is the Cavity Optimization feature. CostQuick can calculate the optimum number of cavities required in the mold for the least overall cost. CostQuick calculates the cost of a part based on the number of cavities. The number of cavities determines the mold cost, the machine size and, therefore, the machine rate and based on these calculations, estimates of the cost of the part are made. Taking these values, CostQuick calculates the marginal and gross sensitivities as well as the relative importance of the different cost components. A graph of the number of cavities verses the cost is presented under the "Cavity Optimization" option under the "Graph" menu and appears as shown in Figure 2.5.1. The cost of the part is plotted on the left hand side vertical scale and the number of cavities is on the bottom horizontal scale. The optimum number of cavities for the lowest total part cost is highlighted.

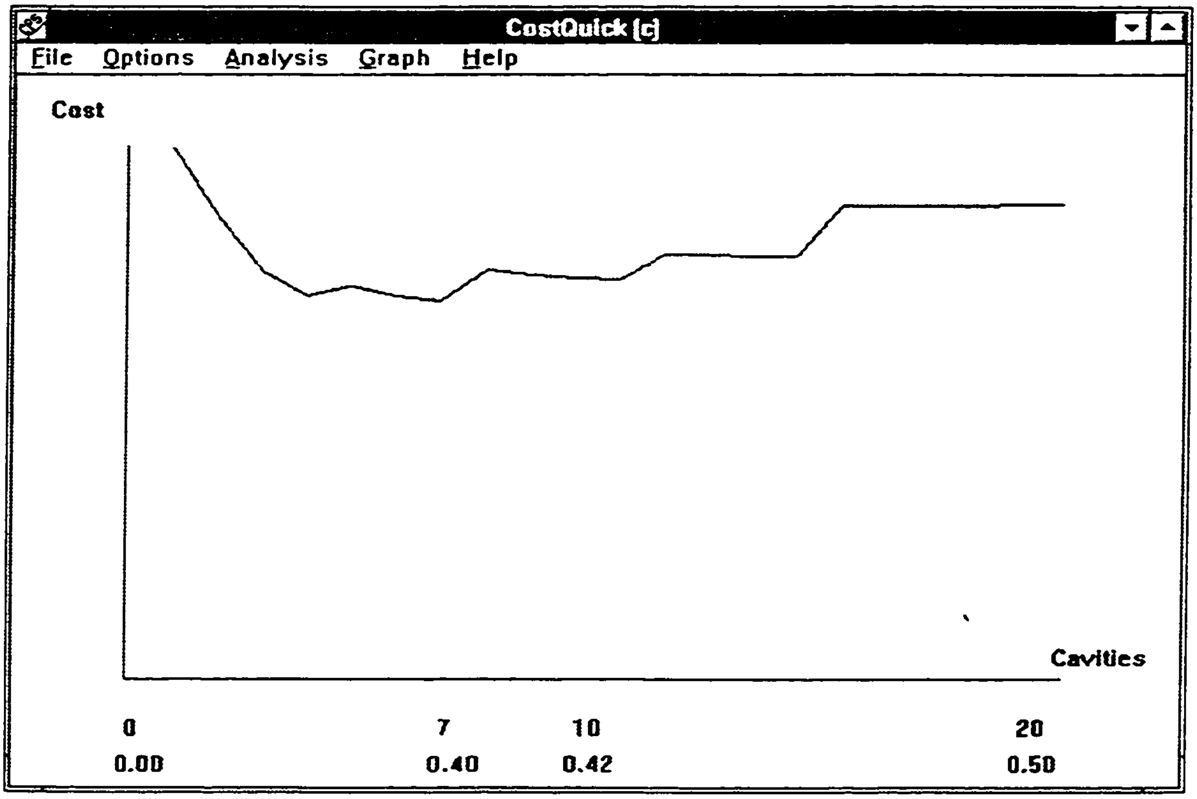


Figure 2.5.1: Cavity Optimization

Once this option is used, if the "Cavity Optimization" option in the "Update Flags" menu (Sec. 2.3.3) is checked, the number of cavities and other assorted variables in the main menu would be automatically updated.

2.5.2 GROUP COST

The "Group Cost" option allows the user to graphically visualize the various components of the total cost of the part. The various costs are color coded and the height of the bars is proportional to the values of the different costs. The relative percentages appear below the bars, as shown in Figure 2.5.2. Information about the various types of costs can be found in the Annual Cost section (Sec. 2.4.1). A scaled group cost breakdown also appears on the Main Screen (Figure 2.2.2).

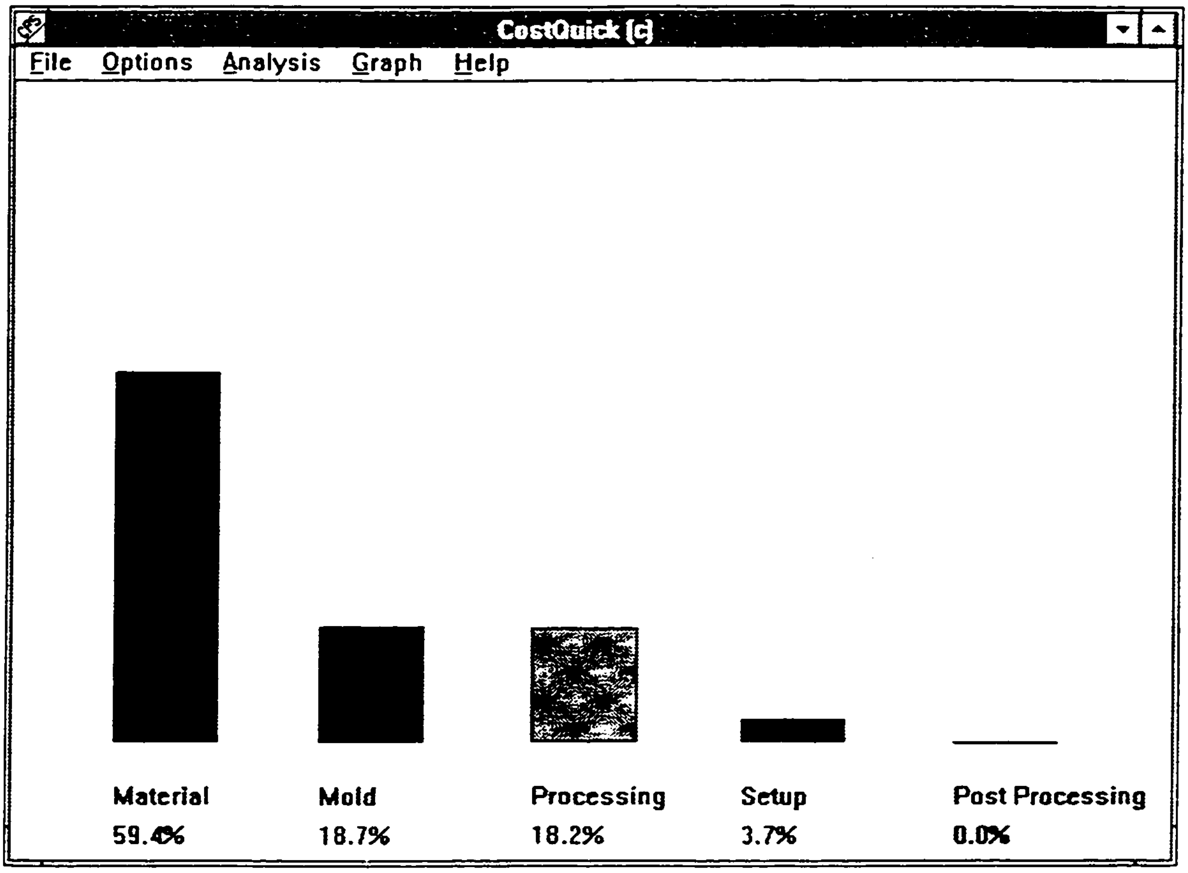


Figure 2.5.2: The Group Cost Screen

2.6 HELP

CostQuick features an on-line "help" system for the support of the user. The "help" option allows the user to get assistance on any aspect or command of CostQuick. "Help" can be invoked at any point in the program and will provide the explanation of any option in CostQuick as well as the relevant background theoretical basis if so desired by the user.

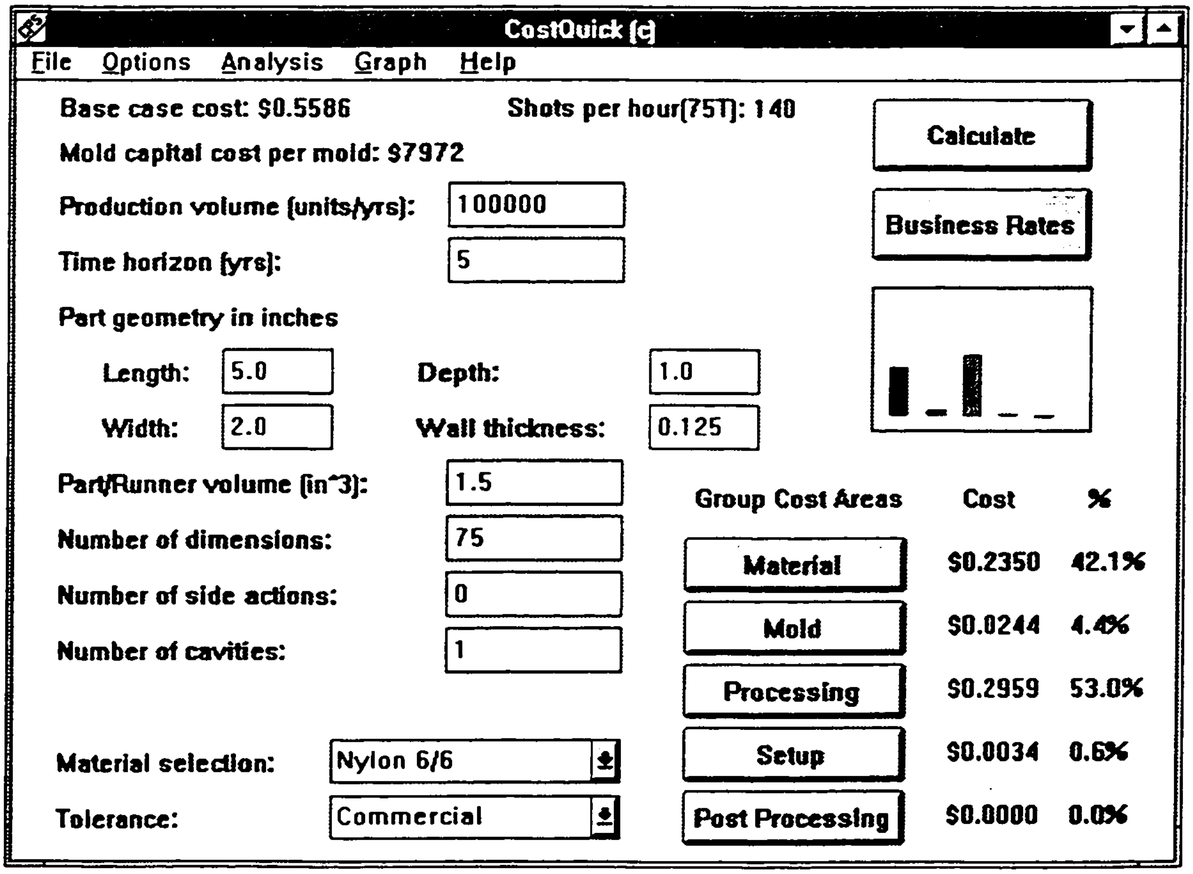
SECTION 3: VARIABLE SELECTION AND INPUT

There are a number of variables which can be input into CostQuick or calculated by it. This section provides a comprehensive guide to the process of inputting data into CostQuick, as well as the effects that these variables may have on other variables. The explanation provided presents a guide on a screen by screen basis beginning with the Main Screen. The Main Screen can be accessed from any screen in CostQuick through the FILE-MAIN SCREEN commands.

IMPORTANT NOTE: The ***Calculate*** button on the top right hand corner of the screen *must* be pressed after any changes have been made to enable CostQuick to recompute the values of the variables. CostQuick *does not* recompute unless the ***Calculate*** button is pressed.

3.1 MAIN INPUT SCREEN^{c} VARIABLES

The Main Screen provides access to several variables as shown in Figure 3.1.



Base case cost: $0.5586

Shots per hour(75T): 140

Mold capital cost per mold: $7972

Production volume (units/yrs): 100000

Time horizon (yrs): 5

Part geometry in inches

Length: 5.0

Depth: 1.0

Width: 2.0

Wall thickness: 0.125

Part/Runner volume (in^3): 1.5

Number of dimensions: 75

Number of side actions: 0

Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

Group Cost Areas	Cost	%
Material	$0.2350	42.1%
Mold	$0.0244	4.4%
Processing	$0.2959	53.0%
Setup	$0.0034	0.6%
Post Processing	$0.0000	0.0%

Figure 3.1: Main Screen Variables

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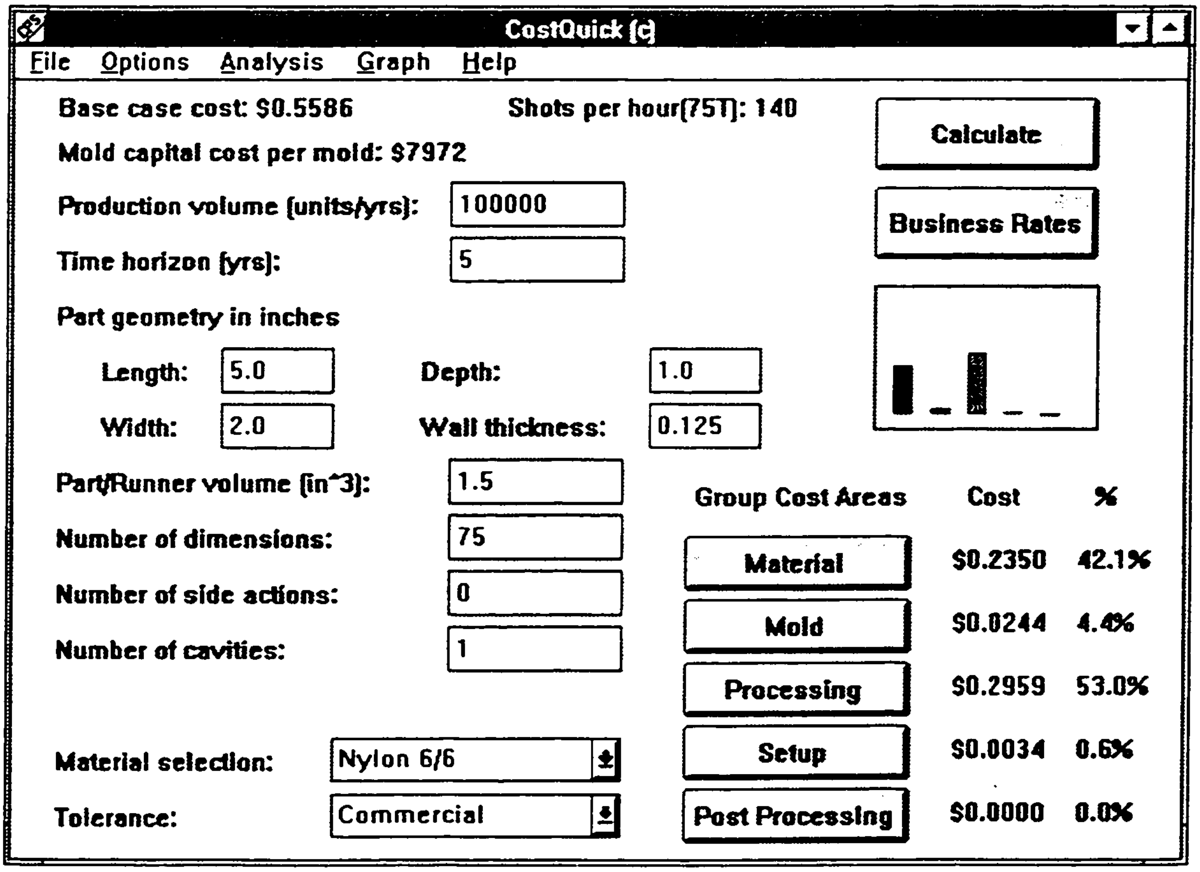

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Processing	$0.2959	53.0%
Setup	$0.0034	0.6%
Post Processing	$0.0000	0.0%

Figure 3.1: Main Screen Variables

The Main Screen of CostQuick provides an overall view of the package. The first line of the screen presents the final Base case cost, or the overall part cost, in deep blue taking into account all the factors that are present in CostQuick. Other major results, also highlighted in blue are the number of shots per hour, with the tonnage of the machine in brackets, and the mold cost per mold. If more than one machine is required, CostQuick shows the number of molds by the multiplication value in front of the dollar value of the single mold.

The ***Calculate*** button on the top right side of the screen has to be clicked after a variable is entered in order for CostQuick to calculate the Part Cost. The major variables that can be entered through the Main Screen are explained below.

A major aspect of the Main Screen is the part cost breakdown which is shown in the graphical screen and corresponds to the Group Cost Areas cost and percentage breakdowns shown in the bottom right area of the Main Screen. The colors in the graphical display correspond to the colored costs shown in the Group Cost Areas. The graphical display is the same as in the ***Group Cost*** option under the ***Graph*** option (Sec. 2.5.2).

IMPORTANT NOTE: If a variable is calculated by CostQuick, it is highlighted in blue on the main screen. Else, it remains white. The selection of the variables that you want CostQuick to calculate can be made through the ***Update Flags*** option under the ***Options*** menu (Sec. 2.3.3).

3.1.1 Production Volume

Production Volume is the number of parts that are to be produced in a year. Production Volumes between 1 and 99,999,999 can be accommodated by CostQuick. The Production Volume has a major impact on the cost of a part since it affects the Mold Cost per part, a major factor in the overall cost of the part. It does not have an effect on the Material cost since that is considered as an independent variable by CostQuick, and is presumed to be input by the user. However, the Total Material cost is the cost of the total amount of material that is needed, and is, therefore, directly related to the Production Volume.

3.1.2 Time Horizon

Time Horizon is the number of years that the part is expected to be produced in the quantities determined by the Production Volume. Time Horizon has an effect on the overall cost of the part through its impact on the mold costs. The mold cost is amortized over the time horizon and, thus, the longer the time horizon the lower the mold cost.

3.1.3 Part Geometry Variables

Part Geometry variables include the length, width, depth and the wall thickness variables. These are the primary variables for any mold pricing and material pricing of a part. They impact on the material price per part as well as the number of cavities in the mold and, therefore, the machine size and the machine rate. They also have an impact on the cycle time of the part.

The length, width and depth of a part relate to the smallest sized prism, i.e. rectangular box, which can enclose the part completely. The wall thickness for injection molded parts, except for few exceptions, cannot be greater than 0.125 inches. This is due to the limitations in the cooling differential between the internal and external surfaces which develops if the part is any thicker, and results in the warping of the part.

3.1.4 Part/Runner Volume

Part/Runner volume constitutes the actual volume of the part. CostQuick estimates this variable as 15% of the prism volume (Length*Width*Depth) (See Sec. 1.1.2). If the actual volume is known, it can be entered here. However, the Part/Runner switch in the Update Flags menu (Sec. 2.3.3) must be switched off in order to prevent a recalculation by CostQuick.

3.1.5 Number of Dimensions

The number of dimensions that are required to completely specify the part provide a guide to the complexity of the part (Sec. 1.1.3). The number typically comes from a detailed part drawing but can be estimated fairly easily early in the design cycle. The more complex a part, the greater the number of dimensions required to specify it. This provides a good estimate as to the cost of the mold that would be needed.

3.1.6 Number of Side Actions

This variable is a step function in CostQuick and ranges from 0 to 4. Side actions increase the mold cost as well as the cycle time for the part, and, therefore, affect the cost of the part substantially (Sec. 1.1.5). The default value in CostQuick is 0.

3.1.7 Number of Cavities

CostQuick calculates the number of cavities required in the mold based on the production volume and the cycle time of the part. The cost of the mold increases as the number of cavities increase. This increase in capital cost can be offset by the material cost of the plastic and an average reduction in the cycle time per part if the production volume is increased beyond a certain level. The processing cost per part is thereby reduced. A critical point is therefore calculated by CostQuick in each case of increase of the number of cavities. The number of cavities also affects the tonnage of the machine directly. As the number of cavities increase, a larger tonnage injection molding machine is required to provide the pressure to force the material into all the cavities. This increases the machine rate and, thus, contributes to an increase in price.

3.1.8 Material Selection

CostQuick has built in default values for certain materials. The prices of these materials have been taken from the Society of Plastic Engineers manual for 1992. The default values can be changed by the user.

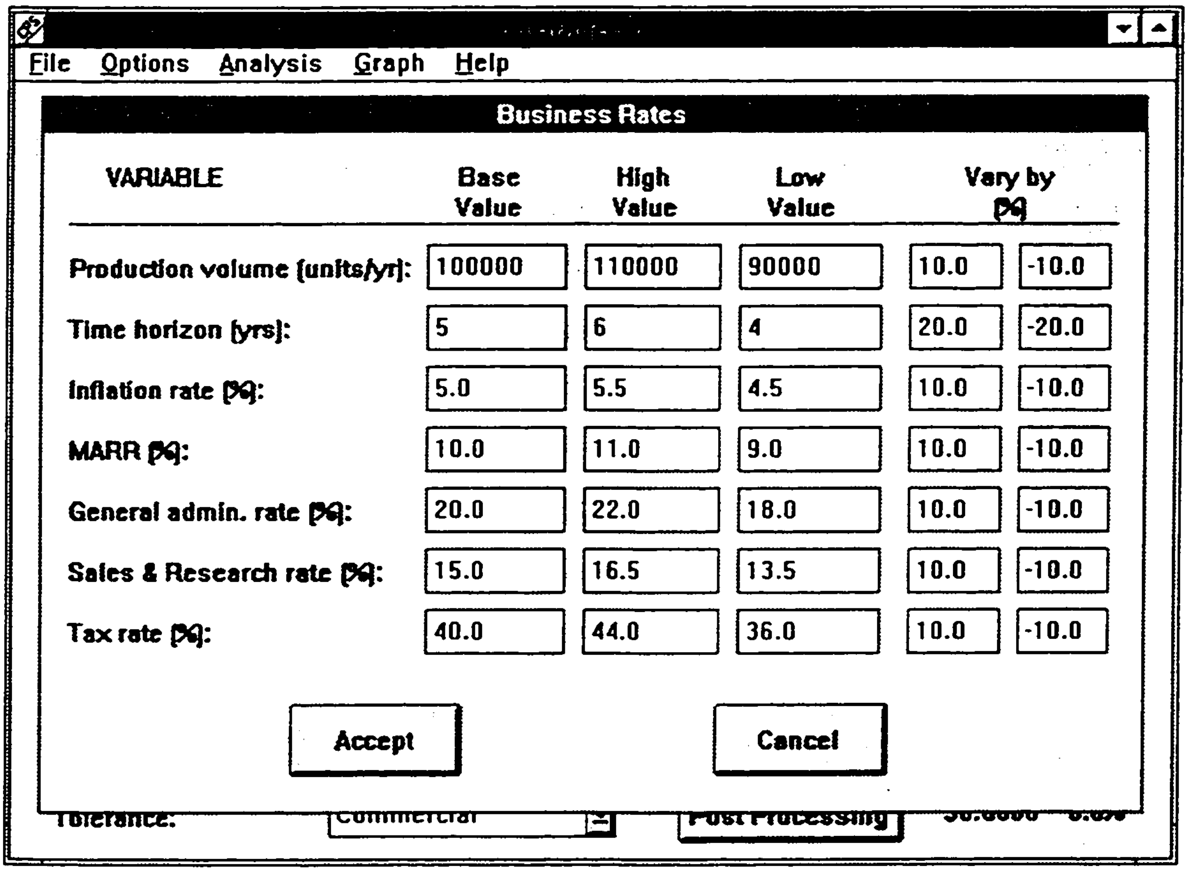
Additionally, the values for the material selection can be manually input through the Material Group Cost Areas menu (Sec. 3.3).

3.1.9 Tolerance

The Tolerance variable allows three basic types of tolerances to be selected by the user. These are the Commercial, Tight and Fine tolerances (Sec. 3.4.4).

3.2 BUSINESS RATES

At the top right of the main screen under the "CALCULATE" button is the Business Rates button. Upon clicking this button with the mouse, the Business Rates menu will pop-up, as shown in Figure 3.2.



Business Rates

VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
Production volume (units/yr):	100000	110000	90000	10.0	-10.0
Time horizon (yrs):	5	6	4	20.0	-20.0
Inflation rate (%):	5.0	5.5	4.5	10.0	-10.0
MARR (%):	10.0	11.0	9.0	10.0	-10.0
General admin. rate (%):	20.0	22.0	18.0	10.0	-10.0
Sales & Research rate (%):	15.0	16.5	13.5	10.0	-10.0
Tax rate (%):	40.0	44.0	36.0	10.0	-10.0

Figure 3.2: Business Rates Menu

The first column in the menu screen shows the different Business Rate variables which are explained in the next few paragraphs. The first line provides a list of the various values that can be input and/or are calculated by CostQuick. The "Base Value" is the nominal value of the variable. The next two variables, "High Value" and "Low Value", are calculated by CostQuick according to the "Vary By (%)" variable. This allows CostQuick to calculate the Gross Sensitivity of the cost upon these variables. The "Vary By (%)" variable represents the inherent uncertainty in the estimation of these variables, many of which are future dependent and so are not amenable to exact prediction. The High and Low value can be input directly in which case the "Vary by %" column would calculate the percentage change automatically.

3.2.1 Production Volume

The Production Volume is the number of parts to be produced on one injection molding machine using one mold in one year. This value can be varied using the "Vary By" variables to enable the calculation of the affect of this variation on the cost (see Gross Sensitivity Analysis). The base value of the Production Volume can lie between 1 and 99,999,999. Production Volume can have a considerable impact on the cost of a part. In general, as the Production Volume increases the cost decreases. However, Production Volume is also dependent upon external considerations, such as the ability of the Sales Division to sell the product etc., which must be carefully accounted for before the value is input into CostQuick.

3.2.2 Time Horizon

The Time Horizon represents, in years, the span of time that the part is expected to be produced. With the rapidly changing marketplace of today, production runs of longer than 4-5 years are not expected. The default value in CostQuick is 5 years, but longer Time Horizons can be accomodated. Time Horizon impacts on the cost mainly through the amortization of the capital costs over the time period entered. In general, the greater the time horizon, the lower the cost. Time Horizon also sets up the time limit over which the annual cost of the part is calculated (see "Annual Cost" for more information) by CostQuick.

3.2.3 Inflation Rate

Inflation Rate is the expected national inflation rate. This is highly subjective as it depends on the perceptions of the population and the actions of the Treasury Department in controlling the interest rates. The default value in CostQuick is 5% with an allowed variation of ±10%.

3.2.4 MARR

MARR is the "Minimum Acceptable Rate of Return" that the user must have in order to go through with the project. It is the sum of the projected inflation rate and the interest rate that is currently available, multiplied by some factor that reflects the risk undertaken in the project. MARR is, therefore, a highly subjective value that can vary by a considerable amount. CostQuick is conservative in its default and sets the value as 10% with a variance of ±10%. However, it should, in general, be determined by the corporation.

3.2.5 General Administrative Rate

The General Administrative Rate is the administrative overhead percentage based on the Variable costs. The variable cost is the sum of material, processing, setup and post-processing costs. It does not include the Fixed cost, i.e. the mold cost. The General Administrative Rate is, therefore, a percentage of the sum of the four variable costs. CostQuick assumes a rate of 20% with a variance of 10% as the default value. However, it should, in general, be determined by the corporation.

3.2.6 Sales and Research Rate

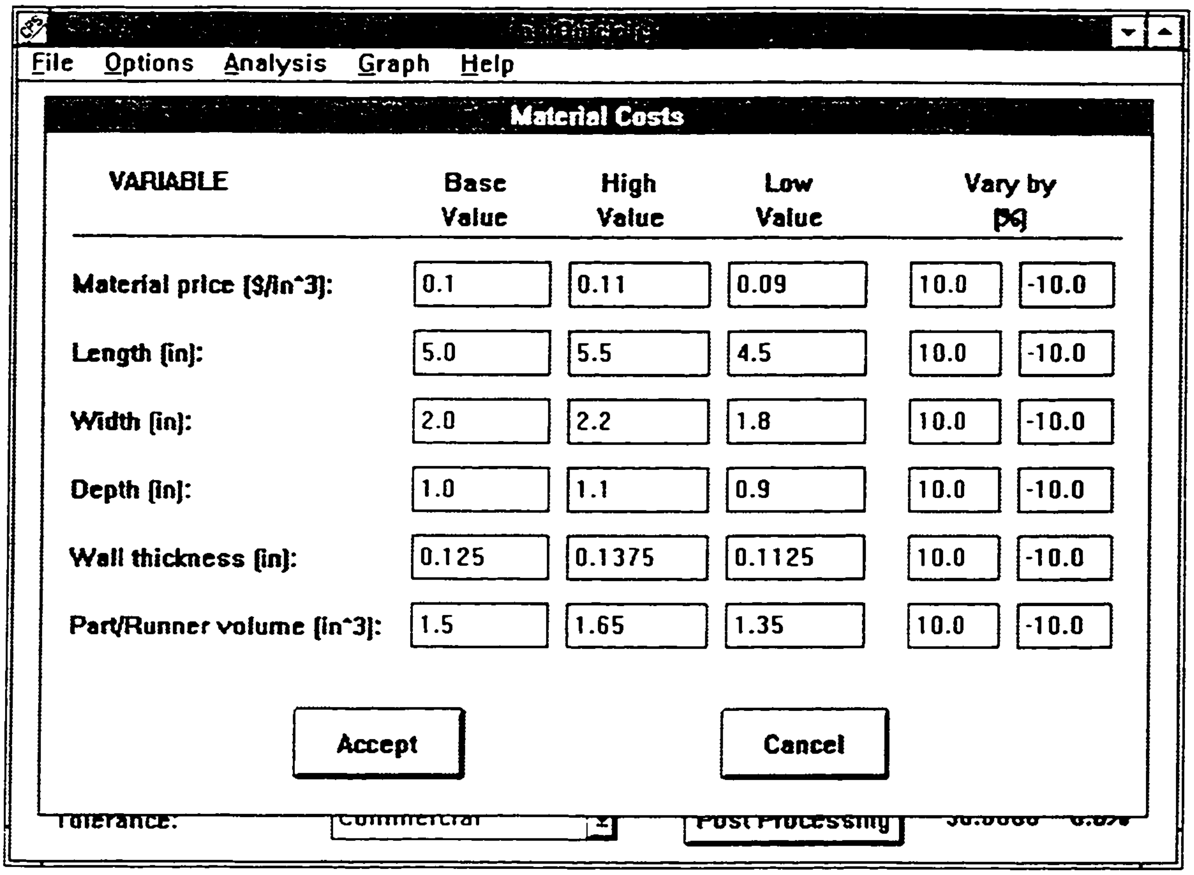
The Sales and Research Rate is based on the Direct Cost (Sec. 1.4.1.2). The variable cost is the sum of material, processing, setup and post-processing costs. It does not include the Fixed cost, i.e. the mold cost. The Sales and Research Rate is, therefore, a percentage of the sum of the four variable costs. CostQuick assumes a base rate of 15% with a ±10% variance as the default value. However, it should, in general, be determined by the corporation.

3.2.7 Tax Rate

The Tax Rate is based on the profit of the corporation by the IRS. The corporation should have an estimate of its tax rate.

3.3 MATERIAL GROUP COST AREA

The "Material" button under the "Group Cost Areas" allows the user to access the "Material Costs" variables menu in CostQuick, the outlay of which is shown in Figure 3.3.



VARIABLE	Base Value	High Value	Low Value	Vary by [%]	
Material price [$/in^3]:	0.1	0.11	0.09	10.0	-10.0
Length [in]:	5.0	5.5	4.5	10.0	-10.0
Width [in]:	2.0	2.2	1.8	10.0	-10.0
Depth [in]:	1.0	1.1	0.9	10.0	-10.0
Wall thickness [in]:	0.125	0.1375	0.1125	10.0	-10.0
Part/Runner volume [in^3]:	1.5	1.65	1.35	10.0	-10.0

Figure 3.3: Material Cost Menu

3.3.1 Material Price

Material Price is the cost of the plastic material *per unit volume*. The values for several materials are already stored under the "Material Selection" variable accessed through the Main Screen (Sec. 3.1.8). If the user wishes to input specific prices, however, these can be accessed through this menu. A variation in the price of the materials is possible and CostQuick assumes a variation of ±10%. This enables a Gross Sensitivity analysis (see "Gross Sensitivity Analysis"-Sec. 2.4.3 for further information) of the Material price with respect to the Overall part cost.

3.3.2 Auxiliary Variables

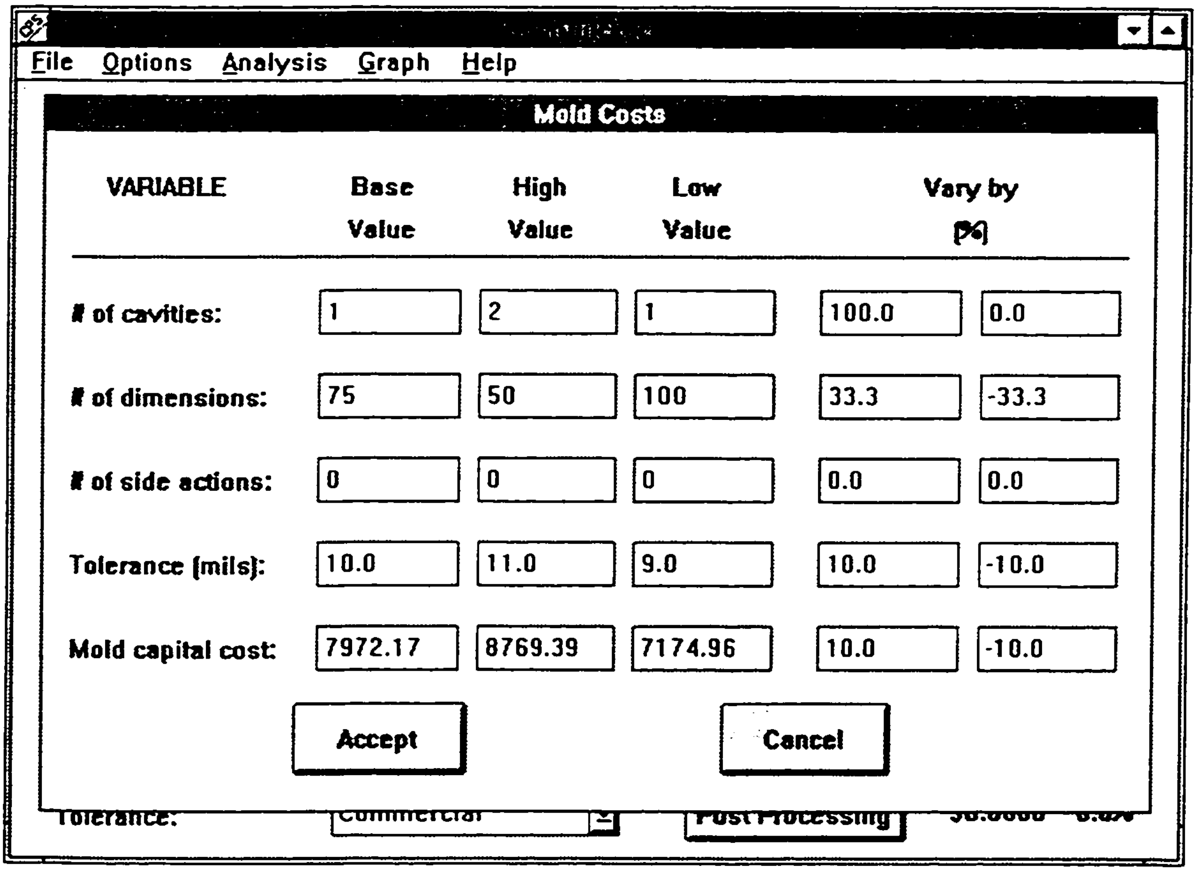
The "Length", "Width", "Depth", "Wall Thickness" and "Part Runner Volume" base rates are the same variables as can be accessed through the Main Screen (see "Main Screen Variables"). In the Material Cost menu, however, their variances can, also, be set. CostQuick assumes a variance of ±10%. This enables a Gross Sensitivity analysis (see "Gross Sensitivity Analysis" for further information) of the variables in question to occur.

IMPORTANT NOTE: The ***Accept*** button at the bottom of the menu should be clicked in order to accept the changes made. CostQuick automatically updates all affected variables and takes the user back to the Main Screen.

IMPORTANT NOTE: Once the changes have been made, and accepted through the use of the ***Accept*** button, and CostQuick is showing the MAIN MENU, the ***Calculate*** button on the upper right hand corner must be clicked for CostQuick to calculate the effect the changes made would have on the other variables and ultimately the part cost.

3.4 MOLD GROUP COST AREA

The "MOLD" button under the "Group Cost Areas" allows access to the Mold Variables through the Mold Cost Screen shown in Figure 3.4. The variables that can be accessed are explained in the next few sections.



VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
# of cavities:	1	2	1	100.0	0.0
# of dimensions:	75	50	100	33.3	-33.3
# of side actions:	0	0	0	0.0	0.0
Tolerance (mils):	10.0	11.0	9.0	10.0	-10.0
Mold capital cost:	7972.17	8769.39	7174.96	10.0	-10.0

Figure 3.4: Mold Cost Menu

3.4.1 Number of Cavities

If the number of cavities have already been decided upon, they can be input in this menu. However, CostQuick does have a Cavity Optimization feature which would automatically calculate the number of cavities required for the lowest part cost (see "Cavity Optimization" under the "Graph" menu). If the Cavity Optimization feature is not used, CostQuick will calculate the part cost according to the number of cavities input in this menu. The default value of 1 cavity is assumed by CostQuick along with a +100% variance. The base rate of the number of cavities is the same as the "Number of Cavities" variable which can be input through the "Main Screen" (Sec. 3.1.7).

3.4.2 Number of Dimensions

The number of dimensions required to completely specify the part geometrically can be input here. There exists a very high correlation between the complexity, and therefore the cost, and the number of dimensions required to specify the part. The default number of dimensions assumed by CostQuick is 75 with a variance of ±33.3%. The base rate of the number of dimensions is the same as the "Number of Dimensions" variable which can be input under the "Main Screen" (Sec. 3.4.2).

3.4.3 Number of Side Actions

The number of side actions is a step function from 0 to 4 which accounts for the side actions required in the mold to create the part. An increase in the number of side actions increases the mold cost and, therefore, the cost of the part. A default value of 0 is assumed by CostQuick for the number of side actions. The base rate of the number of side actions is the same as the "Number of Side actions" variable which can be input under the "Main Screen" (Sec. 3.1.6).

3.4.4 Tolerance

If a specific value of tolerance has to be used, it can be input here. The unit for the tolerance is Milli Inches or Mils. Else the default tolerances of Commercial, Tight and Fine can be used through the "Main Screen" variables. Tolerance affects the machine rate, the tighter the tolerance the higher the machine rate. The machine rate corresponding to the different tolerances can be edited through the machine table.

"Commercial" tolerance is set in CostQuick as 5 mils., "Tight" tolerance at 3 mils., and "Fine" tolerance at 1 mil. A variation of ±10% is assumed by CostQuick.

3.4.5 Mold Capital Cost

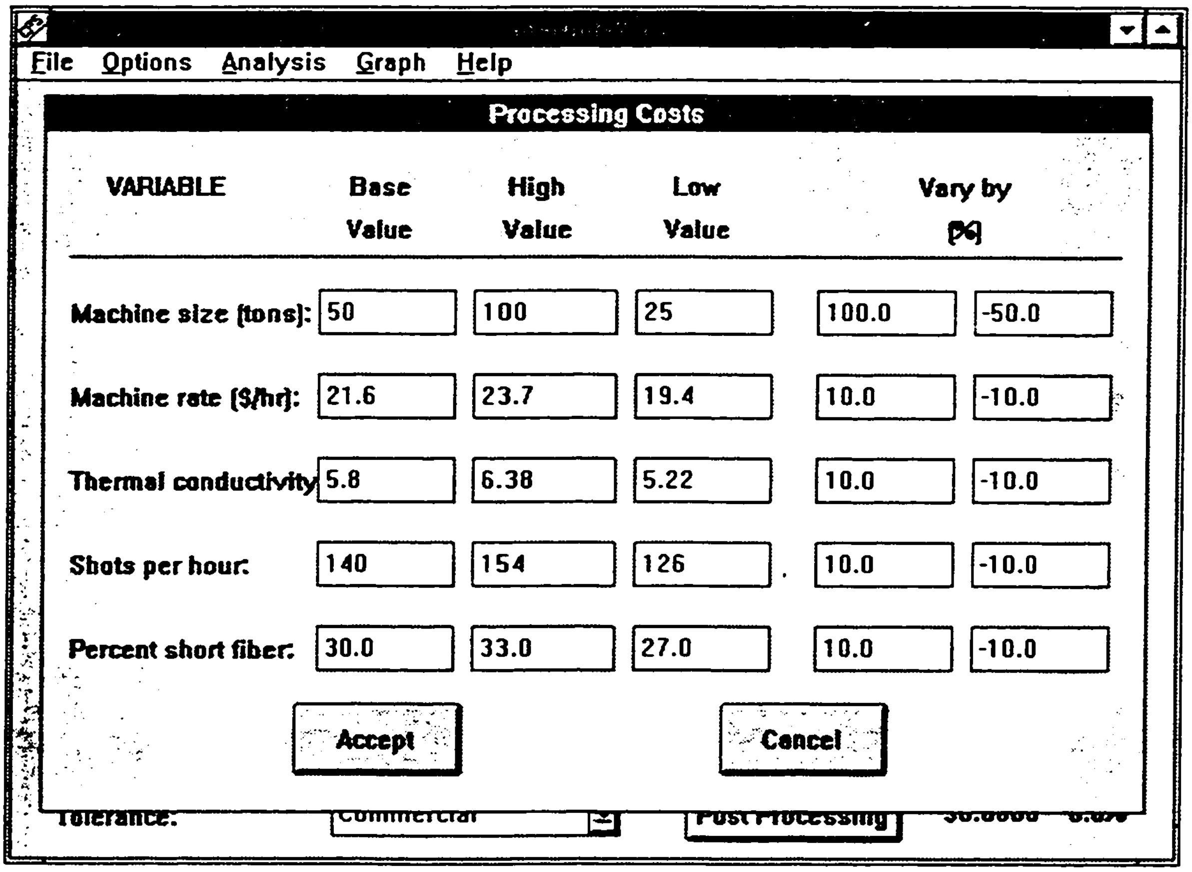
The Mold Capital Cost, if already known, can be entered here. CostQuick automatically calculates the Mold Capital Cost based on the above variables. However, if this aspect of CostQuick is not to be used, the Mold Cost switch in the "Update Flags" menu should be switched off. This would ensure that the value entered here is used by CostQuick and not calculated. A variation of ±10% is assumed by CostQuick and this variation may be desirable once the quotes have been received from the mold shops.

IMPORTANT NOTE: The ***Accept*** button at the bottom of the menu should be clicked in order to accept the changes made. CostQuick automatically updates all affected variables and takes the user back to the Main Screen.

IMPORTANT NOTE: Once the changes have been made, and accepted through the use of the ***Accept*** button, and CostQuick is showing the MAIN MENU, the ***Calculate*** button on the upper right hand corner must be clicked for CostQuick to calculate the effect the changes made would have on the other variables and ultimately the part cost.

3.5 PROCESSING GROUP COST AREA

When the "Processing" button under the Group Cost Areas is clicked, the Processing Cost screen is entered into by CostQuick. This screen is shown in Figure 3.5.



VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
Machine size (tons):	50	100	25	100.0	-50.0
Machine rate ($/hr):	21.6	23.7	19.4	10.0	-10.0
Thermal conductivity	5.8	6.38	5.22	10.0	-10.0
Shots per hour:	140	154	126	10.0	-10.0
Percent short fiber:	30.0	33.0	27.0	10.0	-10.0

Figure 3.5: Processing Cost Menu

3.5.1 Machine Size

The machine size required is calculated by CostQuick on the basis of the number and size of the cavities in a mold. The calculation is performed using Dym's equations. The machine size and rate are taken from a database which can be modified and customized to reflect the resources of any mold shop. The default machine size and rate have been taken from the Society of Plastic Engineers publication of 1992.

If the actual machine size, in tons, to be used is known, it can be entered here. CostQuick will, however, calculate a new value unless the "Machine Size" switch under the "Update Flags" menu of the "Options" command is switched off. The variance is assumed to be from +100% to -50%.

You may want to override this value based on the machine availability.

3.5.2 Machine Rate

The machine rate is a function of the machine size and is found by CostQuick in a database. This machine rate has been taken from the Society of Plastic Engineers publication of 1992.

If the exact machine rate is known, it can be entered here. CostQuick will, however, take the database value unless the "Machine Rate" switch under the "Update Flags" menu of the "Options" command is switched off. CostQuick assumes a variance of 10%.

3.5.3 Thermal Conductivity

The thermal conductivity of the material needs to be input here. The normal units for this are calories/cm sec K. This is used for the cycle time determination using the one dimensional heat transfer equation. The default value in CostQuick is 5.8 cal/cm sec K, with a variance of 10%. This value is updated based on the material selected via the main screen.

3.5.4 Shots per Hour

The number of shots per hour are calculated from the cycle time of the parts. If, however, the number of shots per hour are already known, they can be input here. CostQuick will, however, calculate a new value unless the "Shots per Hour" switch under the "Update Flags" menu of the "Options" command is switched off. CostQuick assumes that the variance is 10%.

3.5.5 Percent Short Fiber

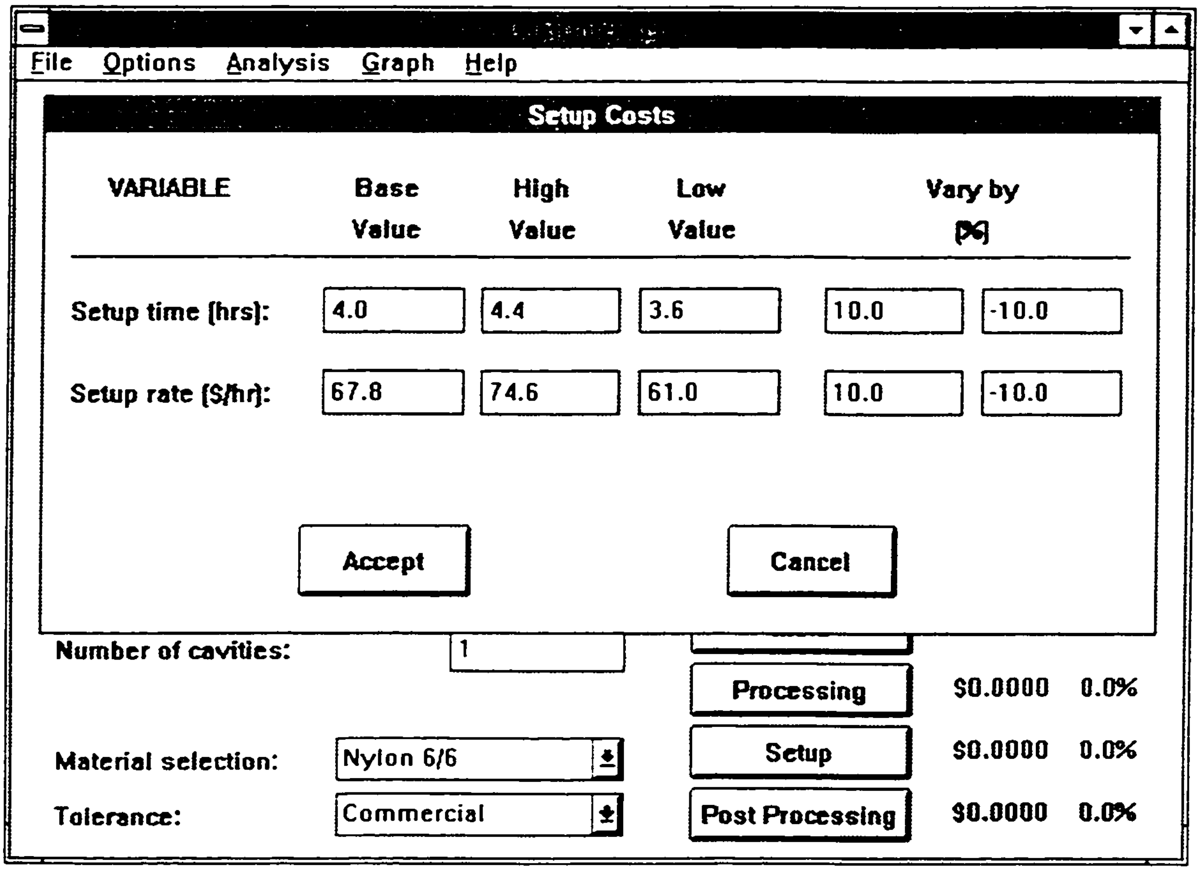
The percentage of short fibers in the material makes a considerable impact on the cycle time of the part. The larger the percentage of fibers, the greater the cycle time. The default value used by CostQuick is 30% with a variance of 10%.

IMPORTANT NOTE: The ***Accept*** button at the bottom of the menu should be clicked in order to accept the changes made. CostQuick automatically updates all affected variables and takes the user back to the Main Screen.

IMPORTANT NOTE: Once the changes have been made, and accepted through the use of the ***Accept*** button, and CostQuick is showing the MAIN MENU, the ***Calculate*** button on the upper right hand corner must be clicked for CostQuick to calculate the effect the changes made would have on the other variables and ultimately the part cost.

3.6 SETUP GROUP COST AREA

The various setup cost variables can be accessed and edited through clicking the "Setup" switch under the "Group Cost Areas". The resulting screen is shown in Figure 3.6.



VARIABLE	Base Value	High Value	Low Value	Vary by [%]	
Setup time [hrs]:	4.0	4.4	3.6	10.0	-10.0
Setup rate [$/hr]:	67.8	74.6	61.0	10.0	-10.0

Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

Processing	$0.0000	0.0%
Setup	$0.0000	0.0%
Post Processing	$0.0000	0.0%

Figure 3.6: Setup Cost Menu

3.6.1 Setup Time

The time required, in hours, to setup the machine for the performance of an operation can be input here. Since the setup time depends on the machine size, CostQuick extracts it from the database. The database can be modified to reflect the resources of the mold shop. The default values have been taken from the Society of Plastic Engineers publication of 1992.

If the setup time is known, it can be entered here. CostQuick will, however, take the database value unless the "Setup Time" switch under the "Update Flags" menu of the "Options" command is switched off. CostQuick assumes a variance of 10%.

3.6.2 Setup Rate

The cost per hour to setup a machine for the performance of an operation can be input here. Since the setup rate depends on the machine size, CostQuick extracts it from the database. The database can be modified to reflect the resources of the mold shop. The default values have been taken from the Society of Plastic Engineers publication of 1992.

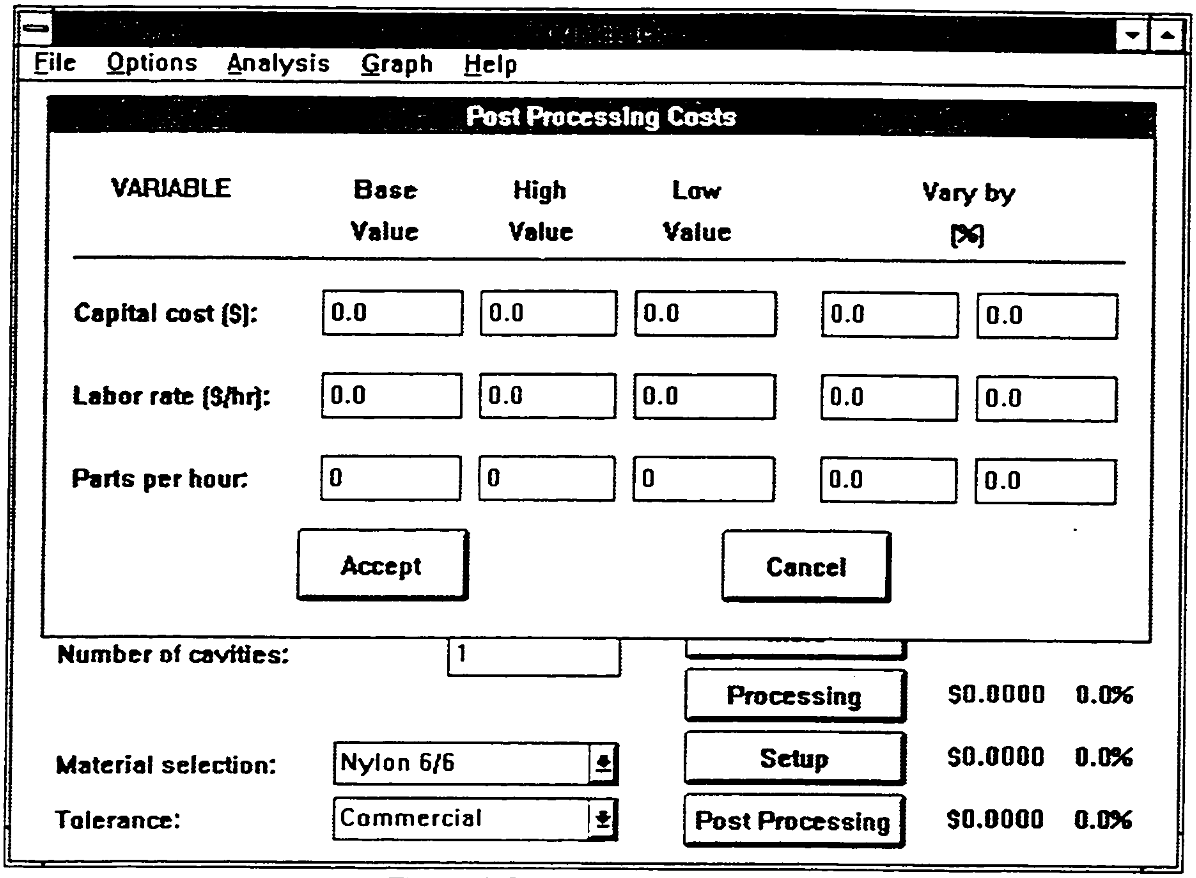
If the setup rate is known, it can be entered here. CostQuick will, however, take the database value unless the "Setup Rate" switch under the "Update Flags" menu of the "Options" command is switched off. CostQuick assumes a variance of 10%.

IMPORTANT NOTE: The ***Accept*** button at the bottom of the menu should be clicked in order to accept the changes made. CostQuick automatically updates all affected variables and takes the user back to the Main Screen.

IMPORTANT NOTE: Once the changes have been made, and accepted through the use of the ***Accept*** button, and CostQuick is showing the MAIN MENU, the ***Calculate*** button on the upper right hand corner must be clicked for CostQuick to calculate the effect the changes made would have on the other variables and ultimately the part cost.

3.7 POST PROCESSING GROUP COST AREA

The various post-processing cost variables can be entered via the "Post-Processing" option under the "Group Cost Area". The resulting screen is shown in Figure 3.7.



Post Processing Costs

VARIABLE	Base Value	High Value	Low Value	Vary by [%]	
Capital cost ($):	0.0	0.0	0.0	0.0	0.0
Labor rate ($/hr):	0.0	0.0	0.0	0.0	0.0
Parts per hour:	0	0	0	0.0	0.0

Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

Processing $0.0000 0.0%

Setup $0.0000 0.0%

Post Processing $0.0000 0.0%

Figure 3.7: Post Processing Cost Menu

The "Base Value" represents the nominal value of the variable. The "high" and "low" values represent the uncertainty present in the estimation of the nominal value of the variable in question. The "Vary By %" represents the uncertainty in the nominal value on a percentage basis. The "High" and "Low" values and the "Vary by %" values are two methods of estimating the uncertainty and are directly related.

3.7.1 Post Process Capital Cost

Once a part has been produced through the injection molding process, it might need some further processing to become a finished part. The capital costs associated with this further processing can be entered here. Capital costs refer to the cost of the machinery, jigs and dies that need to be purchased in order to convert the molded part into the finished product.

3.7.2 Labor Rate

The labor rate, in terms of dollars per hour, that has to be incurred for any post processing required on the part can be entered here. The labor rate divided by the number of parts processed per hour represents the variable cost of post processing per part and is added to the part variable cost.

3.7.3 Parts Per Hour

The number of parts that have to be post-processed per hour can be entered here. The number of parts per hour affects the variable cost of post processing a part directly. The variable cost associated with post processing of a part is calculated by dividing the labor rate per hour by the number of parts post processed.

IMPORTANT NOTE: The ***Accept*** button at the bottom of the menu should be clicked in order to accept the changes made. CostQuick automatically updates all affected variables and takes the user back to the Main Screen.

IMPORTANT NOTE: Once the changes have been made, and accepted through the use of the ***Accept*** button, and CostQuick is showing the MAIN MENU, the ***Calculate*** button on the upper right hand corner must be clicked for CostQuick to calculate the effect the changes made would have on the other variables and ultimately the part cost.

Appendix A (Sample Exercise)

INSTALLING COSTQUICK

Put the disk containing CostQuick into the floppy drive on your computer. Type "install" and hit enter. A directory called "CostQuick" will be created in the "c:" drive and an icon for CostQuick will be set up in the windows "main" menu.

RUNNING COSTQUICK

To start CostQuick, go to the windows "MAIN" menu and double click on the icon titled "CostQuick" with the mouse. If you do not have a mouse, enter "cntrl+f" and then "run" the file "c:/CostQuick/CostQuick". This will put you in the CostQuick main menu (Figure 2.2.2).

SAMPLE EXERCISE

Open a new project by selecting "File" and "Main Screen". This will put you into the Main Screen of CostQuick. The Base case cost at this point should be $0.00.

The first step when using CostQuick should be the selection of the type of analysis that you desire. To select this go to the "Options" menu by clicking on the Options command on the top command line of CostQuick. This will expand the options menu giving you four choices:

- Hot Runner
- Cycle Time
- Update Flags
- Metric Units

Hot Runner: The type of runner system that is required in the mold for the part and the material being used can be selected with this option. If the *Hot Runner* option is tagged, a hot runner system is the one being used. If it is not tagged the cold runner system will be assumed.

Select the cold runner option, i.e. *untag* the *Hot Runner* option.

Cycle Time: Two choices can be used in CostQuick to calculate the cycle time required for the part in the injection molding process. The first choice is the calculation performed on the basis of an equation generated by means of a regression analysis of several parts. The second choice is a calculation performed using an equation generated through a first order linear heat transfer differential equation. When you open the Cycle Time menu, CostQuick assumes that the differential equation is going to be used, and therefore requests the values for the various factors which are required for the calculation in a table format. However, it is not necessary to use the differential equation. If you Cancel without Accepting the values. CostQuick assumes that an equation developed through the regression analysis is going to be used.

Select the regression option, i.e. use the *Cancel* button to exit the Cycle Time menu.

Update Flags: The variables that you want CostQuick to calculate can be selected here. These variables have been divided according to the type of cost that they affect directly. By clicking on the boxes to the right of the options indicated you can select or unselect them, requiring them to be calculated or not calculated respectively. *The default selection for these variables is tagged, i.e., **all of them will be calculated** by CostQuick.*

Leave all the choices *tagged* for now.

Metric units: A choice of the British or Metric units is available in CostQuick. If the *Metric unit* option is tagged, CostQuick will prompt you for values in th metric system. If it is not tagged British units will be used.

Select the British units, i.e. *untag* the *Metric units* option.

Once the Options have been specified other variables can be input into CostQuick.

Inputting Variables

The variables that you wish to input in CostQuick can be selected by clicking on the relevant boxes with the mouse.

Main Screen Variables

Click on the box showing the *Production volume* (units/yr.) and enter a value of 200000. The default value is 100000 units/yr. Next click on the value for *Time horizon* (yr.) and enter the number of years that you expect the part to be in production for as 4.

The part geometry variables can be selected by clicking on the relevant boxes. Once you have decided the maximum *length, width, depth* and *wall thickness* of the part, you can enter them in the relevant boxes. For the purpose of this exercise, however, enter the values of 10, 7, 5 and 0.125 for the length, width, depth and wall thickness.

Next click on the *Part/Runner volume* box. This is the actual volume of your part in cubic inches or cubic centimeters, depending on whether you are using the British or Metric units. The value should change to 52.5 as soon as you click in the *Part/Runner volume* box.

The number of dimensions required to completely specify the part should be entered in the *Number of dimensions* box. As an example, a simple rectangular box can be completely specified by 3 dimensions (length, width, depth), while a cylinder will require just 2 (radius, depth or height). A rectangular box with a cylindrical hole will require 7 (in addition to the five basic dimensions-3 for the rectangular box, 2 for the cylindrical hole-an additional 2 dimensions will be required to position the cylindrical hole in the rectangular box). Enter 75 for the number of dimensions.

The Number of side actions that have to be put in the moldbase to accommodate any undercuts can be entered upon clicking the box to right of the *Number of side actions* option. The default value is 0. Leave the value as 0 for the exercise.

If the number of cavities that the mold should have are known, they can be entered by clicking on the *Number of cavities* box. You have the option of entering this number manually or letting CostQuick calculate the optimum number of cavities for the least cost for you. If you wish to enter the number of cavities manually, make sure that the *Number of cavities* option in the *Update Flags* menu is not selected. Else, CostQuick will calculate the base cost for the optimum number of cavities when you do a *Cavity Optimization*. The default value is 1. For now leave the value as 1.

You can select the type of material that the part is to be made of by clicking on the *Material selection* box. If you click on the arrow next to the *Material selection* option, a list of predefined materials table will pop up. If the selection that you want is not present, you can enter the various features of the material that you wish manually through the *Material* option under *Group Cost Areas*. Select *Nylon 6/6* from the list of materials.

Three levels of tolerances can be specified in CostQuick through the *Tolerance* box. When you click on the arrow next to the *Tolerance* box the three options will pop up. The commercial tolerance is 5 mils, fine is 3 mils and tight is 1 mil. If you wish to specify your own tolerance, you can do so through the *Mold* option under *Group Cost Areas*. Select *Commercial* from the *tolerance* list.

IMPORTANT NOTE: Once you have entered the values for all the variables, you must click on the *Calculate* button for CostQuick to accept the changes.

Business Rates

Once the variables on the main screen have been input and the calculate button has been pressed, click on the *Business Rates* button positioned just below the "Calculate" button on the top right hand corner of the main screen.
This will get you into the screen where you can enter the business rates and their ranges, as specified or required by your corporation.

NOTE: The *Base Value* of a variable corresponds to its expected value. The *High Value* and *Low Value* are the limits of the uncertainty that is present in the specification of the *Base Value*.

NOTE: You can either specify the *High Value* and *Low Value* for the range of the variable in question, or you can use the *Vary by (%)* option to let CostQuick calculate the values according to the variation range percentages that you specify. Since both the methods are just different ways of specifying the same variation, the two of them cannot be used simultaneously.

NOTE: When you change a particular value, CostQuick will not immediately change the corresponding Base, High, Low, Positive or Negative Vary By (%) values unless you click to change another value on the screen or the Accept button is clicked. For example, if you change the Base value of the Inflation Rate, the corresponding High and Low values will not change unless you click some other button such as the Base value of MARR, or click the Accept button.

The *Production volume*, which is the number of parts that you expect to produce in a year, can be entered by clicking on the *Base Value* box for *Production volume*. This base value is the same as the value that you can enter in the *Production volume* box on the *Main Screen*. Any uncertainty that may be present in this value can be entered in the High and Low value boxes. Since you have already specified 200000 as the production volume in the main screen, the base value will show 200000. A +/- 10% variation should show the High Value to be 220000 and the Low Value to be 180000.

The *Time Horizon* was already selected as 4 years on the main screen and so its Base Value should be 4. A variation of +/- 25% would give the High Value as 5 and the Low Value as 3. The *Time Horizon* has to be in whole numbers.

Next, click on the *Base Value* for the *Inflation rate*. Enter the value of 3.5 for the base value. The High and Low values will change according to the variation of +/- 10%. Note, however, that the values do not change immediately. They will change when you click on the *Base value* of the *MARR* button next.

Change the value of the *Base value* of the *MARR* to 12%. Notice that the *High* and *Low* values for the *Inflation Rate* have now changed to reflect the +/- 10% variation percentage. The *High* and *Low* values of the *MARR* should not change immediately but when you click on the *Base Value* of the *General administrative rate*, the *High* and *Low Values* for the *MARR* will change to 13.2 and 10.8 respectively.

Click on the *Base Value* for *General administrative rate*. Notice the changes that occur in the High and Low Values in the MARR. The *Base Value* for the *General administrative rate* has a default of 20.0. For this exercise, assume that the rate is 20.0.

For the purpose of this exercise, leave the *Sales and research rate* and the *Tax rate* at 15.0 and 40.0 respectively.

After completing all the changes, click the *Accept* button at the bottom of the screen. This will close the Business Rates menu and put you back into the main screen of CostQuick. Notice that the *Base case cost* is 8.5547. Now click the *Calculate* button on the main screen. The value should change to 8.2382.

Material Group Cost Area

Click on the *Material* button under the Group Cost Areas. This will put you in the Material Cost screen.

NOTE: The *Base Value* of a variable corresponds to its expected value. The *High Value* and *Low Value* are the limits of the uncertainty that is present in the specification of the *Base Value.*

NOTE: You can either specify the *High Value* and *Low Value* for the range of the variable in question, or you can use the *Vary by (%)* option to let CostQuick calculate the values according to the variation range percentages that you specify. Since both the methods are just different ways of specifying the same variation, the two of them cannot be used simultaneously.

NOTE: When you change a particular value, CostQuick will not immediately change the corresponding Base, High, Low, Positive or Negative Vary By (%) values unless you click to change another value on the screen or the *Accept* button is clicked. For example, if you change the *Base value* of the *Material Price*, the corresponding High and Low values will not change unless you click some other button such as the *Base value* of the *Length*, or click the *Accept* button.

All the values in the Material Costs screen have already been specified according to the inputs on the main screen. Notice that the *Base Values* of the *Length, Width, Depth, Wall Thickness* and *Part/Runner volume* are the same as the ones on the main screen. The *Material price* is dependent on the Material that was selected through the main screen. Since you have already selected Nylon, a *Base value* of 0.1 should be showing. Change the *Base Value* of the *Material price* to 0.2. Next click on the *Base Value* of the *Length*. Notice that the High and Low Values of the Material Price have changed to 0.22 and 0.18 respectively. Leave the other variable values as they are and click the Accept button.

Note that the *Base case cost* has not changed and still is 8.2382. Now click the *Calculate* button on the top right hand side of the main screen. The *Base case cost* should change to 15.9679. Go back into the Material cost menu by clicking on the *Material* button under the *Group Cost Areas*. Change the Base Value for the Material Price once again to 0.1. Change the Base Values of the Length, Width and Depth to 8.0, 6.0 and 4.0 respectively. Click the Accept button to get to the main screen. Notice that the values for Length, Width and Depth have changed accordingly and the value for the Part/Runner volume has also changed to 28.8. Click the *Calculate* button. The Base case cost should now be $4.7451. Notice also that the breakdown of the total cost, as shown to the right of the Material button under the Group Cost Areas is now showing 4.2403 and 89.4%. This means that the Material cost is $4.2403, representing 89.4% of the Base case or total cost of $4.7451.

Mold Group Cost Area

The Mold cost is now $0.0242 representing approximately 0.5% of the overall cost of $4.7451. This is shown under the Cost and % headings to the right of the Mold button under the Group Cost Areas. Click on the *Mold* button under the *Group Cost Areas* to enter the *Mold Cost* menu.

NOTE: The *Base Value* of a variable corresponds to its expected value. The *High Value* and *Low Value* are the limits of the uncertainty that is present in the specification of the *Base Value*.

NOTE: You can either specify the *High Value* and *Low Value* for the range of the variable in question, or you can use the *Vary by (%)* option to let CostQuick calculate the values according to the variation range percentages that you specify. Since both the methods are just different ways of specifying the same variation, the two of them cannot be used simultaneously.

NOTE: When you change a particular value, CostQuick will not immediately change the corresponding Base, High, Low, Positive or Negative Vary By (%) values unless you click to change another value on the screen or the *Accept* button is clicked. For example, if you change the *Base value* of the *Number of cavities*, the corresponding High and Low values will not change unless you click some other button such as the *Base value* of the *Number of dimensions*, or click the *Accept* button.

The *Base Values* of all the variables except *Mold capital cost* have been defined already through the selection of these variables on the main screen. The *Base Value* of the *Mold capital cost* is calculated by CostQuick. If, however, you already know the Mold capital cost, you have the option to enter it here. If you are inputting the cost and do not wish it to change, make sure that the *Mold capital cost* button under the *Update Flags* menu is _NOT_ tagged. Else, CostQuick will calculate and, hence, change this cost.

Click on the *Base Value* box of the *Number of cavities* and change this to 3. Change the *Base Value* of the *Number of dimensions* to 50. Click on the *Base Value* button of the *Mold capital cost*.

Click the *Accept* button at the bottom of the screen to go back to the main screen. Notice that the Number of cavities and the Number of dimensions variables have changed accordingly. Now click the *Calculate* button. Notice that the cost breakdown for the Mold cost, as shown to the right of the Mold button under the Group Cost Areas, has changed to $0.0320 and 0.7%. This means that the Mold cost of $0.0320 per part is 0.7% of the Base case or total cost, which now is $4.5471.

Processing Group Cost Area

The Processing cost at this point is $0.2544 representing approximately 5.6% of the overall cost of $4.5471. This is shown under the Cost and % headings to the right of the Processing button under the Group Cost Areas. Click on the *Processing* button under the *Group Cost Areas* to enter the *Processing Cost* menu.

NOTE: The *Base Value* of a variable corresponds to its expected value. The *High Value* and *Low Value* are the limits of the uncertainty that is present in the specification of the *Base Value.*

NOTE: You can either specify the *High Value* and *Low Value* for the range of the variable in question, or you can use the *Vary by (%)* option to let CostQuick calculate the values according to the variation range percentages that you specify. Since both the methods are just different ways of specifying the same variation, the two of them cannot be used simultaneously.

NOTE: When you change a particular value, CostQuick will not immediately change the corresponding Base, High, Low, Positive or Negative Vary By (%) values unless you click to change another value on the screen or the *Accept* button is clicked. For example, if you change the *Base value* of the *Machine Size*, the corresponding High and Low values will not change unless you click some other button such as the *Base value* of the *Machine rate*, or click the *Accept* button.

The Machine size is calculated by CostQuick based on the projected surface area of all the cavities in a mold. If the tonnage is already known it can be entered in the *Base Value* box of the *Machine size* option. However, if the value is being entered manually, the *Machine size* option under the *Update Flags* menu must *NOT* be tagged. Else, CostQuick will calculate the value and change it accordingly. Similarly, the Machine rate is based on the Machine size and CostQuick will take this value from the database unless it is specifically told not to. In the latter case the *Machine rate* button under the *Update Flags* menu should *NOT* be tagged. For the time being, leave the Machine size and the machine rate as is. The Machine size at this point should be 1000 tons and the Machine rate $73/hr.

CostQuick also takes the Thermal conductivity value from a database based on the Material selected. However, if a material different from the ones in the database is, this value should be entered manually. Since you have selected Nylon from the database, there is no need to change this value.

CostQuick calculates the number of shots per hour based on the cycle time and the production volume of the part, assuming a 40 hour work week. The value should be 140. For this exercise, leave the Shots per hour as is.

The percent of short fiber affects the cycle time of the part. Change the *Base Value* of the *Percent of short fiber* to 10.0. Click the *Accept* button to go to the main screen. Click the *Calculate* button. The Base case cost will change to $4.5120.

Notice the cost break down for Processing cost at the right of the Processing button under the Group Cost Areas. The cost should be $0.2193 and the percentage 4.9. Thus, Processing costs are $0.2193 representing 4.9% of the Base case cost of $4.5120.

Setup Group Cost Area

The Setup cost at this point is $0.0204 representing approximately 0.5% of the overall cost of $4.5120. This is shown under the Cost and % headings to the right of the Setup button under the Group Cost Areas. To enter the *Setup Cost* menu click on the *Setup* button under the *Group Cost Areas*.

NOTE: The *Base Value* of a variable corresponds to its expected value. The *High Value* and *Low Value* are the limits of the uncertainty that is present in the specification of the *Base Value*.

NOTE: You can either specify the *High Value* and *Low Value* for the range of the variable in question, or you can use the *Vary by (%)* option to let CostQuick calculate the values according to the variation range percentages that you specify. Since both the methods are just different ways of specifying the same variation, the two of them cannot be used simultaneously.

NOTE: When you change a particular value, CostQuick will not immediately change the corresponding Base, High, Low, Positive or Negative Vary By (%) values unless you click to change another value on the screen or the *Accept* button is clicked. For example, if you change the *Base value* of the *Setup time*, the corresponding High and Low values will not change unless you click some other button such as the *Base value* of the *Setup rate*, or click the *Accept* button.

The Setup time and Setup rate are Machine size dependent and so are extracted from a database by CostQuick. However, the values for a machine may vary from company to company. Thus, you can enter your own time and rate. If these values are being input manually the corresponding buttons under the Update Flags menu should NOT be tagged. Else, CostQuick will substitute these values with ones it extracts from the database. For the purpose of this exercise, leave the values as they are. Click the *Accept* button at the bottom of the screen to go to the main screen.

Post Processing Group Cost Area

The values for the Post Processing costs do not have a default in CostQuick. If there is some post processing required after molding, the values can be input in the Post Processing Cost menu. Click on the *Post Processing* button under the *Group Cost Areas* to enter into the Post Processing Cost menu.

NOTE: The *Base Value* of a variable corresponds to its expected value. The *High Value* and *Low Value* are the limits of the uncertainty that is present in the specification of the *Base Value*.

NOTE: You can either specify the *High Value* and *Low Value* for the range of the variable in question, or you can use the *Vary by (%)* option to let CostQuick calculate the values according to the variation range percentages that you specify.

Since both the methods are just different ways of specifying the same variation, the two of them cannot be used simultaneously.

NOTE: When you change a particular value, CostQuick will not immediately change the corresponding Base, High, Low, Positive or Negative Vary By (%) values unless you click to change another value on the screen or the *Accept* button is clicked. For example, if you change the *Base value* of the *Labor rate*, the corresponding High and Low values will not change unless you click some other button such as the *Base value* of the *Parts per hour*, or click the *Accept* button.

Enter 2000.0 for the *Base Value* of the *Post process capital cost*, 20.0 for the *Base Value* of the *Labor rate* and 100 for the *Base Value* of the *Parts per hour*. Also, set all the *Vary by (%)* values to 10.0. Click on the *Accept* button at the bottom of the screen to get into the main screen and then click *Calculate*.

Notice that the Base case cost now increases to $4.8065. The cost break down for the Post processing cost is now $0.2945 representing 6.1% of the overall cost.

Analysis

There are 3 different types of analysis that are performed by CostQuick apart from the breakdown of the total cost (Base case cost) into the component group costs. Click on the *Analysis* option on the command line of CostQuick. Upon doing so you will be presented with three options:

- Annual Costs
- Marginal Sensitivity Analysis
- Gross Sensitivity Analysis

Together, these give you a range of information upon which to decide the worth of the design.

Annual Cost

Select the *Annual cost* option under the *Analysis* command. This gives you a year by year cost breakdown for the Time Horizon that has been selected, in this case 4 years. As an illustration, go to the main screen by selecting *File - Main Screen* command from the command line of CostQuick. Change the *Time Horizon* value to 5. Click the *Calculate* button. Notice that the Base case cost changes. Go back into the Annual cost screen by selecting *Analysis - Annual Cost* from the command line. Notice that the number of years has increased from 4 to 5. The Annual cost screen is explained in greater detail in section 2.4.1.

Marginal Sensitivity Analysis

Marginal Sensitivity Analysis provides an indication of the relative effects of various factors on the total cost of the part. Primarily, Marginal Sensitivity Analysis is an analysis of the effect that a 1% change in the base value of a factor would have on the total cost of the part. The factor with the greatest effect is highlighted. Get into the Marginal Analysis screen through *the Analysis - Marginal Sensitivity* commands from the command line of CostQuick. The factors are presented according to the cost types they affect.

Notice that the *Part/Runner volume* is highlighted since it has the greatest effect on the total cost, while the *Material Price* is the second most important factor. To test this, go to the main screen by selecting the *File - Main Screen* command. Now increase the value of the *Part/ Runner volume* by 1%, i.e. change it from 28.8 to 29.088 (an increase of 1%) and click *Calculate*. The Base case cost increases from 4.887 to 4.9317, an increase of $0.0447. Change the *part/runner volume* back to 28.8 and hit *Calculate*. Now click the *Material* button under the *Group Cost Areas*. Select *Material price* and change the *Base Value* to 0.101 (an increase of 1%). Click the *Accept* button to get back to the main screen and then click the *Calculate* button. The Base case cost increases to $4.9302 an increase of $0.0432 which is slightly less than the change for the Part/Runner volume ($0.0447). In this manner, CostQuick calculates the effect of each factor and provides a good check as to the effect that a micro manipulation of the factors would have on the cost. Thus, if costs need to be reduced, only the top 4-5 factors need to be looked at for small changes.

Get to the Material cost screen by selecting the *Material* button under the *Group Cost Areas* and change the *Base Value* of the *Material price* to 0.1. Click the *Accept* button to get to the main screen and then click the *Calculate* button.

Gross Sensitivity Analysis

The effects of micro manipulation of factors on the total cost are made evident by the Marginal Sensitivity analysis. The effects of a macro manipulation, however, are more difficult. This is the reason that the Vary by (%) values are requested in CostQuick. The Vary by (%) values represent the measure of uncertainty that there is in the estimation of the Base Value of a factor. Using these uncertainty figures, a Gross Sensitivity Analysis is performed by CostQuick and the results tabulated. To get into the Gross Sensitivity Analysis, select the *Analysis - Gross Sensitivity* command from the command line of CostQuick.

Notice that the factors are again broken down according to the types of costs that they affect. Again the Part/Runner volume is ranked as the factor which affects the cost the most and so is highlighted. However, the Gross Sensitivity Analysis depends on the uncertainty in the estimate of the Base Value, as represented by the High and Low Values or the Vary By (%) values. To clarify this concept, click the *File - Main Screen* command to get to the main screen and then go to the Material screen by clicking the *Material* button under the *Group Cost Areas*. Now change the values of the *Vary By (%)* boxes for the *Part/Runner volume* to +/-5 from +/-10. Click the *Accept* button to get to the main screen and then click the *Calculate* button. Go to the Gross Sensitivity screen by selecting the *Analysis - Gross Sensitivity* command from the command line of CostQuick. Notice that the Part/Runner volume is no longer the factor which affects the total cost the most. Instead the Material Price is highlighted. This is because CostQuick calculates the effect that the maximum deviation from the Base Value of a factor would have on the total cost (Base case cost) and ranks the factors accordingly. By reducing the variation of the Base Value of the Part/Runner volume from +/-10% to +/-5%, the maximum deviation was cut in half and did not affect the total cost as much as a +/-10% deviation in the Material Price would.

To check this, get to the main screen by using the *File - Main Screen* command. Change the *Part/Runner volume* from 28.8 to 30.32 (an increase of 5%). Click the *Calculate* button. Notice that the Base case cost has increased from $4.887 to $5.1214, an increase of $0.2344. Now, change the *Part/Runner volume* back to 28.8 and click Calculate. Then get to the Material cost screen by clicking the *Material* button under the *Group Cost Areas*. Change the *Base Value* of the *Material* price from $0.1 to $0.11 (an increase of 10%, corresponding to the +10% Vary By value). Click the *Accept* button to get to the main screen and then click the *Calculate* button. Notice that the Base case cost increases from $4.8870 to $5.3186, an increase of $0.4316 which is greater than that for the 5% increase of the Part/Runner volume. In this manner, CostQuick calculates the effect that the maximum deviation of a factor would have on the Base case cost and ranks them accordingly.

Graphical Charts - Cavity Optimization and Group Cost

CostQuick has two graphical tools to enable you to easily and quickly judge the analysis results. Select the *Graph* command on the command line of CostQuick and you will be presented with 2 options:

- Cavity Optimization
- Group Cost

Group Cost graph is an enlarged and more detailed version of the graph present on the main screen. It shows, in a graphical format, the relative proportions of the various cost types contributing to the total cost. These cost types are:

- Material
- Mold
- Processing
- Setup
- Post Processing

Together they total up to the Base case cost.

The Cavity Optimization, on the other hand, presents the result of an iterative calculation performed by CostQuick.

Cavity Optimization

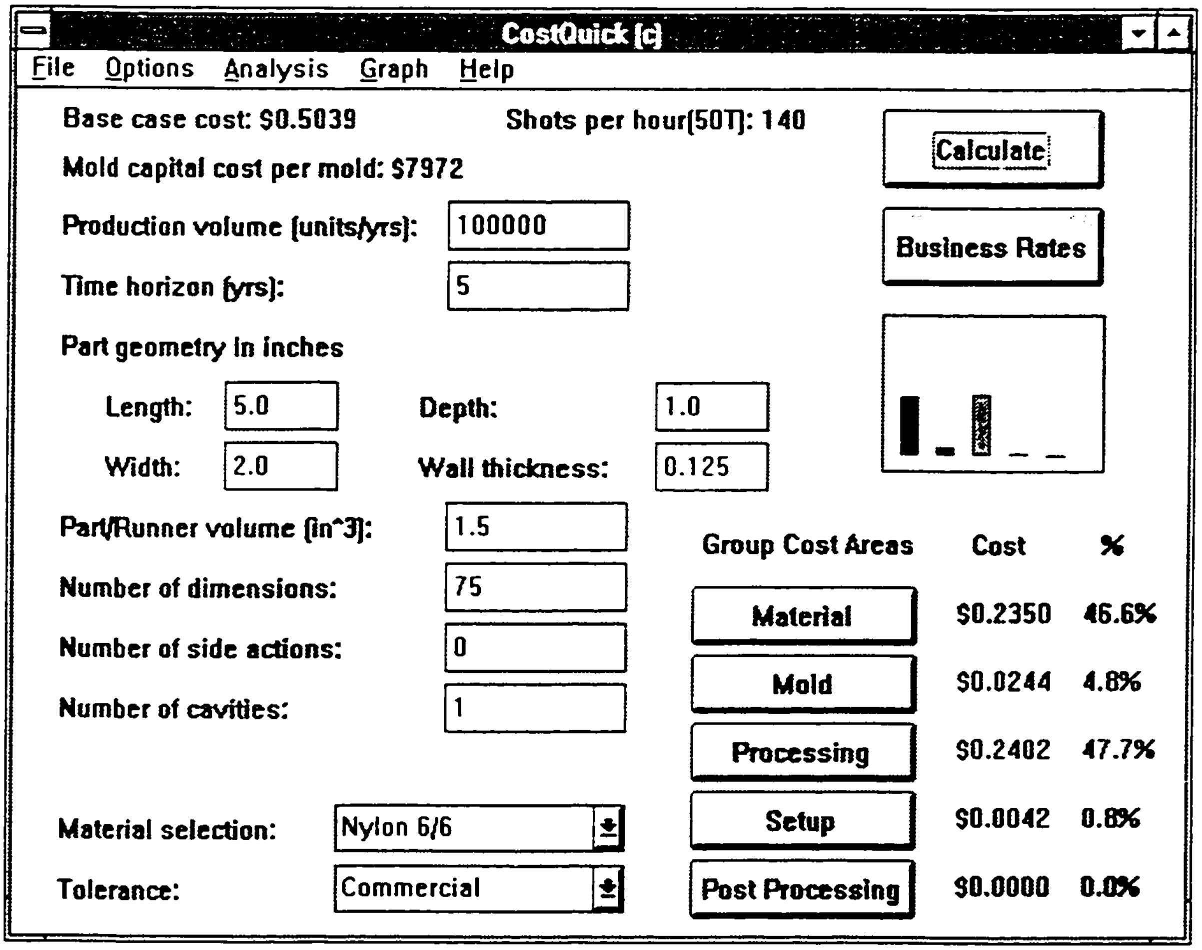
CostQuick presents a unique feature in that it actually performs a number of cavities verses total cost analysis and then presents the smallest total cost as the optimum number of cavities enabling detection of the cheapest solution over the *entire* life time (Time Horizon) of the part.

Change the *Number of cavities* on the main screen to 4 and click *Calculate*. Select the *Graph - Cavity Optimization* commands from the command line of CostQuick. Notice that the number 3 is highlighted in red along with a value of 4.86. The 3 represents the number of cavities which is the optimum number of cavities for the cheapest total cost of $4.86. The total part cost with a 2 cavity mold is $4.94 and that with a 4 cavity mold is $4.89. CostQuick automatically changes the Number of Cavities and the Base case cost on the main screen once the cavity optimization has been performed *except* when the *Number of Cavities* box in the *Update Flags* menu has *NOT* been tagged.

This concludes the Sample Exercise.

Appendix B (Default Screens)

The following screens present the various default screens of QuickCost. They can be used to check the program functionality.



Base case cost: $0.5039

Shots per hour[50T]: 140

Mold capital cost per mold: $7972

Production volume (units/yrs): 100000

Time horizon (yrs): 5

Part geometry in inches

Length: 5.0

Depth: 1.0

Width: 2.0

Wall thickness: 0.125

Part/Runner volume (in^3): 1.5

Number of dimensions: 75

Number of side actions: 0

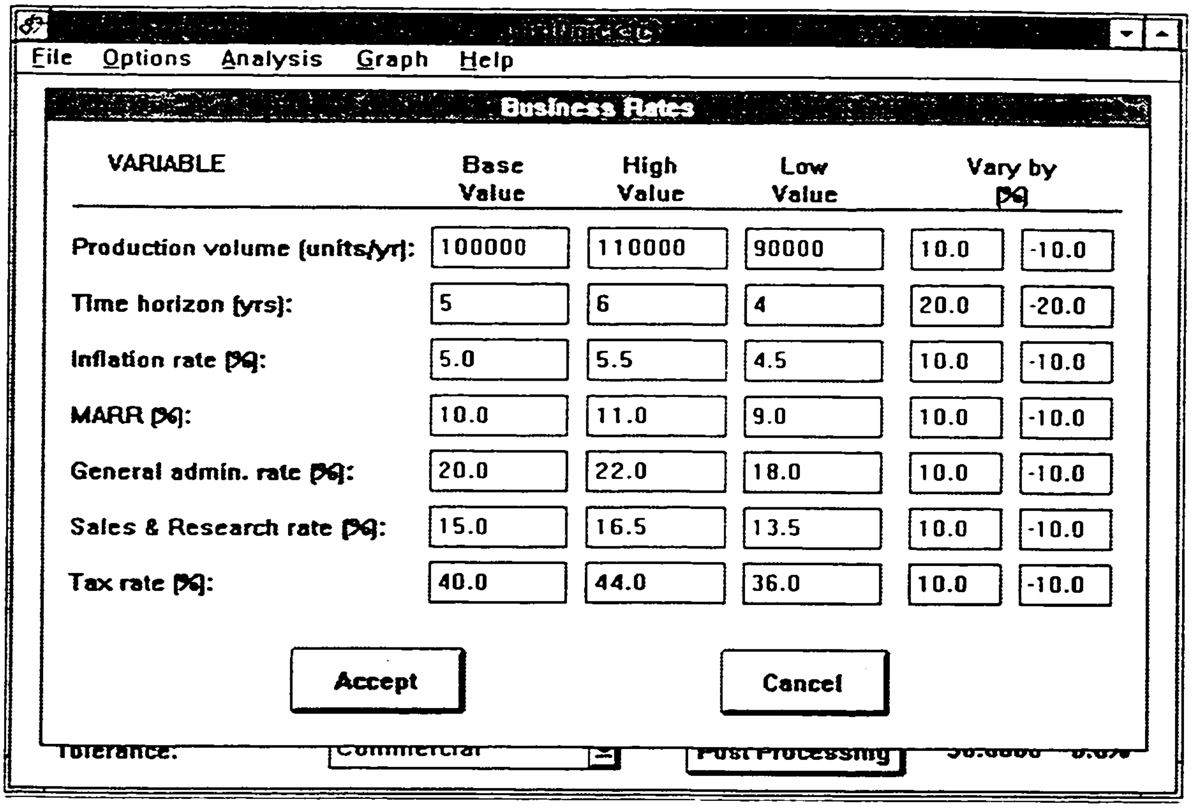
Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

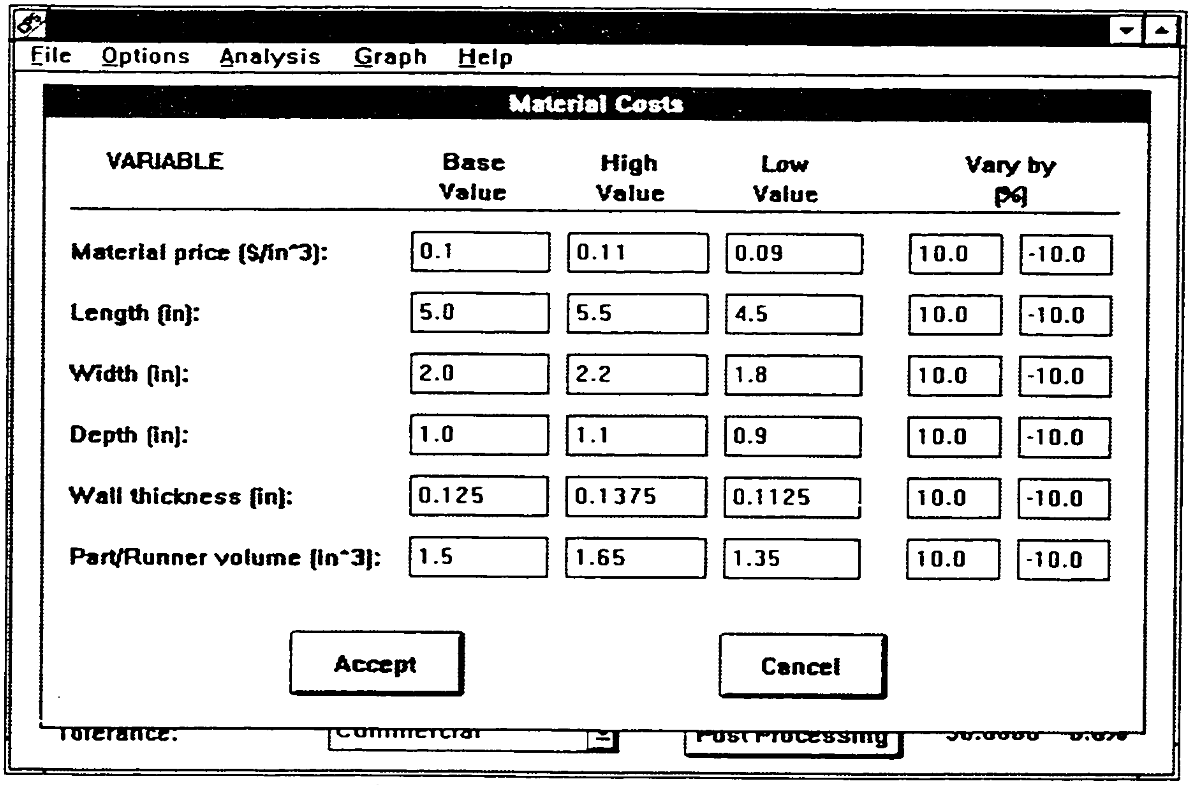
Group Cost Areas	Cost	%
Material	$0.2350	46.6%
Mold	$0.0244	4.8%
Processing	$0.2402	47.7%
Setup	$0.0042	0.8%
Post Processing	$0.0000	0.0%

SCREEN 1: Main Screen



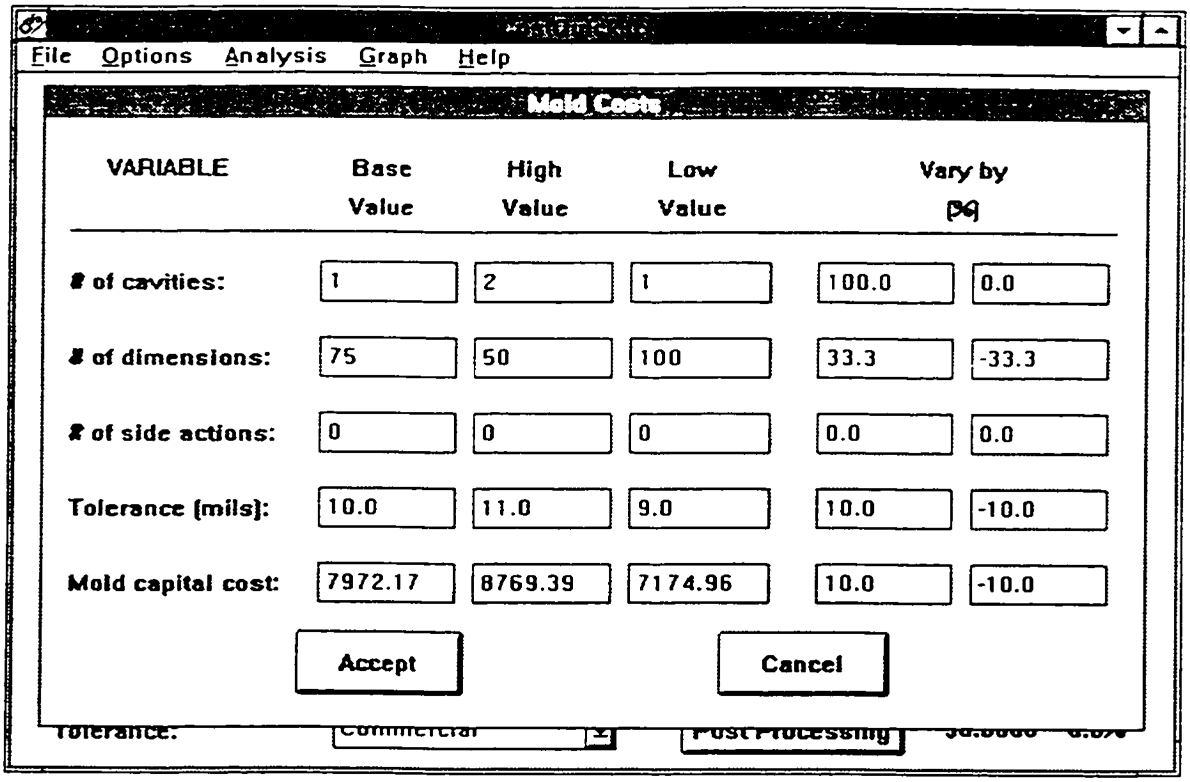
VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
Production volume (units/yr):	100000	110000	90000	10.0	-10.0
Time horizon (yrs):	5	6	4	20.0	-20.0
Inflation rate (%):	5.0	5.5	4.5	10.0	-10.0
MARR (%):	10.0	11.0	9.0	10.0	-10.0
General admin. rate (%):	20.0	22.0	18.0	10.0	-10.0
Sales & Research rate (%):	15.0	16.5	13.5	10.0	-10.0
Tax rate (%):	40.0	44.0	36.0	10.0	-10.0

SCREEN 2: Business Rates



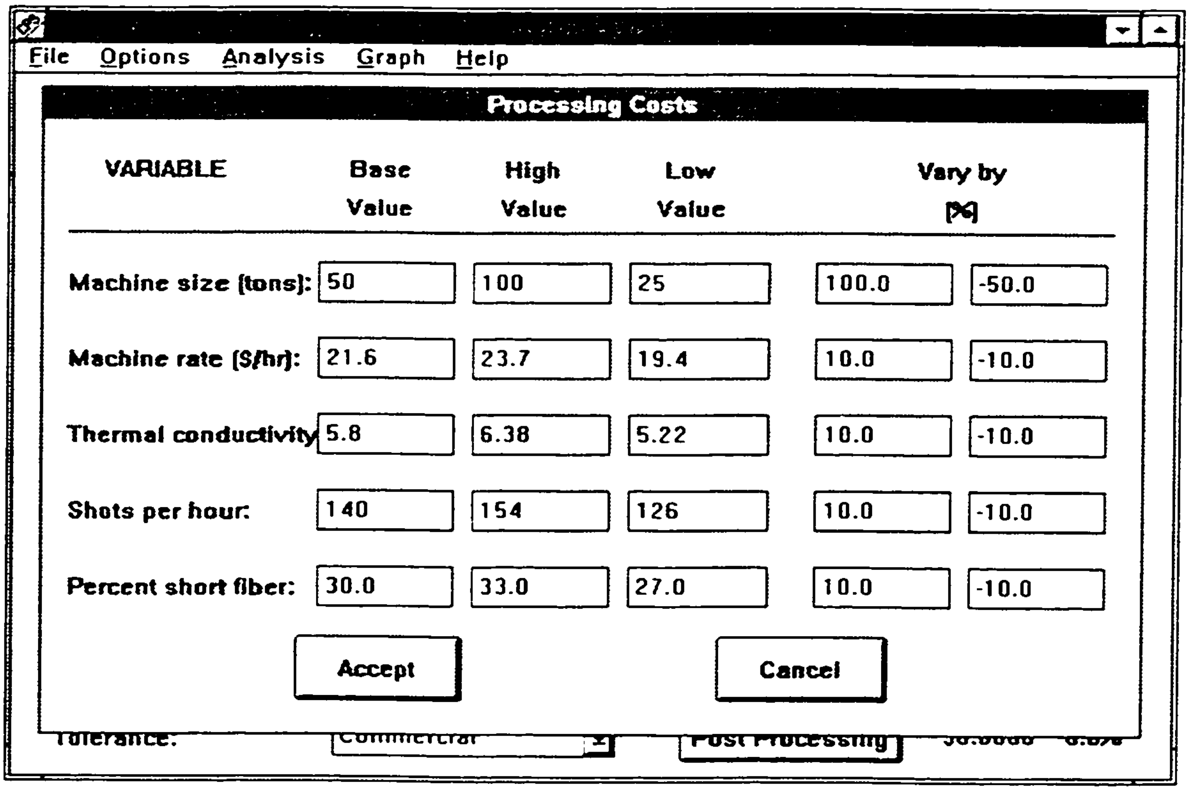
VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
Material price ($/in^3):	0.1	0.11	0.09	10.0	-10.0
Length (in):	5.0	5.5	4.5	10.0	-10.0
Width (in):	2.0	2.2	1.8	10.0	-10.0
Depth (in):	1.0	1.1	0.9	10.0	-10.0
Wall thickness (in):	0.125	0.1375	0.1125	10.0	-10.0
Part/Runner volume (in^3):	1.5	1.65	1.35	10.0	-10.0

SCREEN 3: Material Group Cost



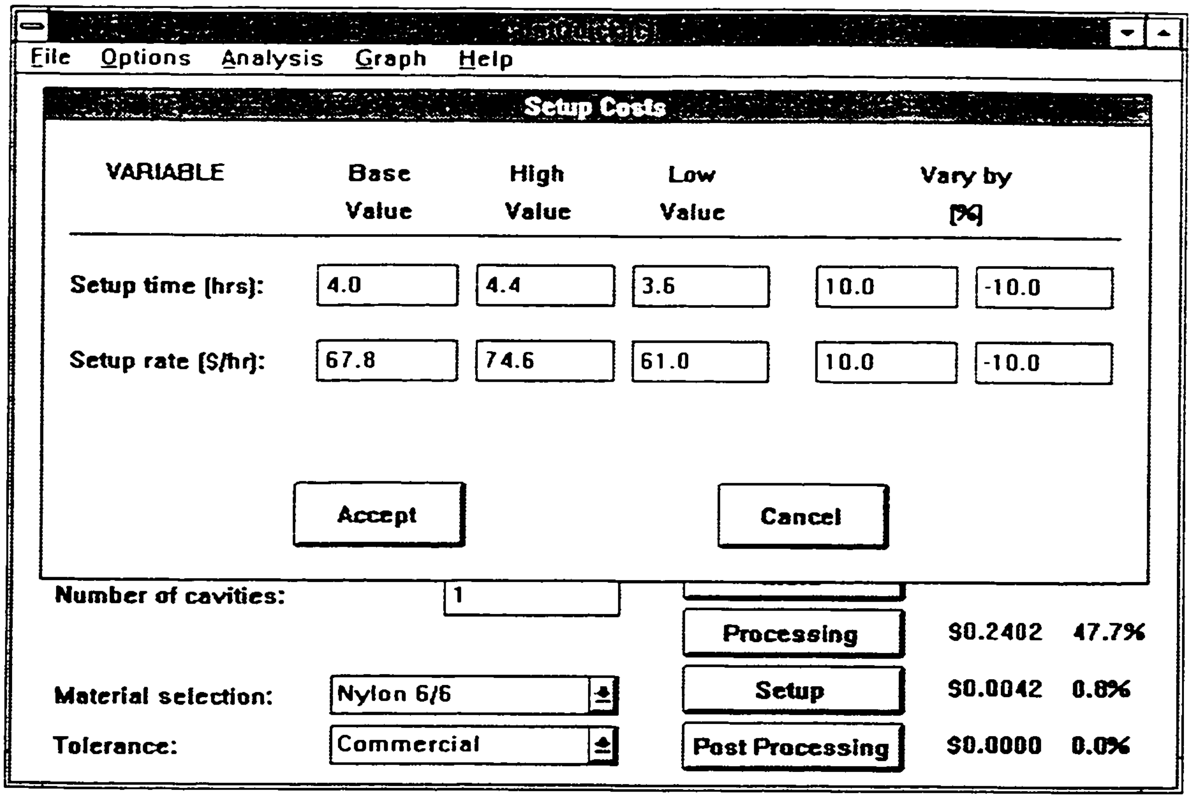
VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
# of cavities:	1	2	1	100.0	0.0
# of dimensions:	75	50	100	33.3	-33.3
# of side actions:	0	0	0	0.0	0.0
Tolerance (mils):	10.0	11.0	9.0	10.0	-10.0
Mold capital cost:	7972.17	8769.39	7174.96	10.0	-10.0

SCREEN 4: Mold Group Cost



VARIABLE	Base Value	High Value	Low Value	Vary by (%)	
Machine size (tons):	50	100	25	100.0	-50.0
Machine rate ($/hr):	21.6	23.7	19.4	10.0	-10.0
Thermal conductivity	5.8	6.38	5.22	10.0	-10.0
Shots per hour:	140	154	126	10.0	-10.0
Percent short fiber:	30.0	33.0	27.0	10.0	-10.0

SCREEN 5: Processing Group Cost



Setup Costs

VARIABLE	Base Value	High Value	Low Value	Vary by [%]	
Setup time (hrs):	4.0	4.4	3.6	10.0	-10.0
Setup rate ($/hr):	67.8	74.6	61.0	10.0	-10.0

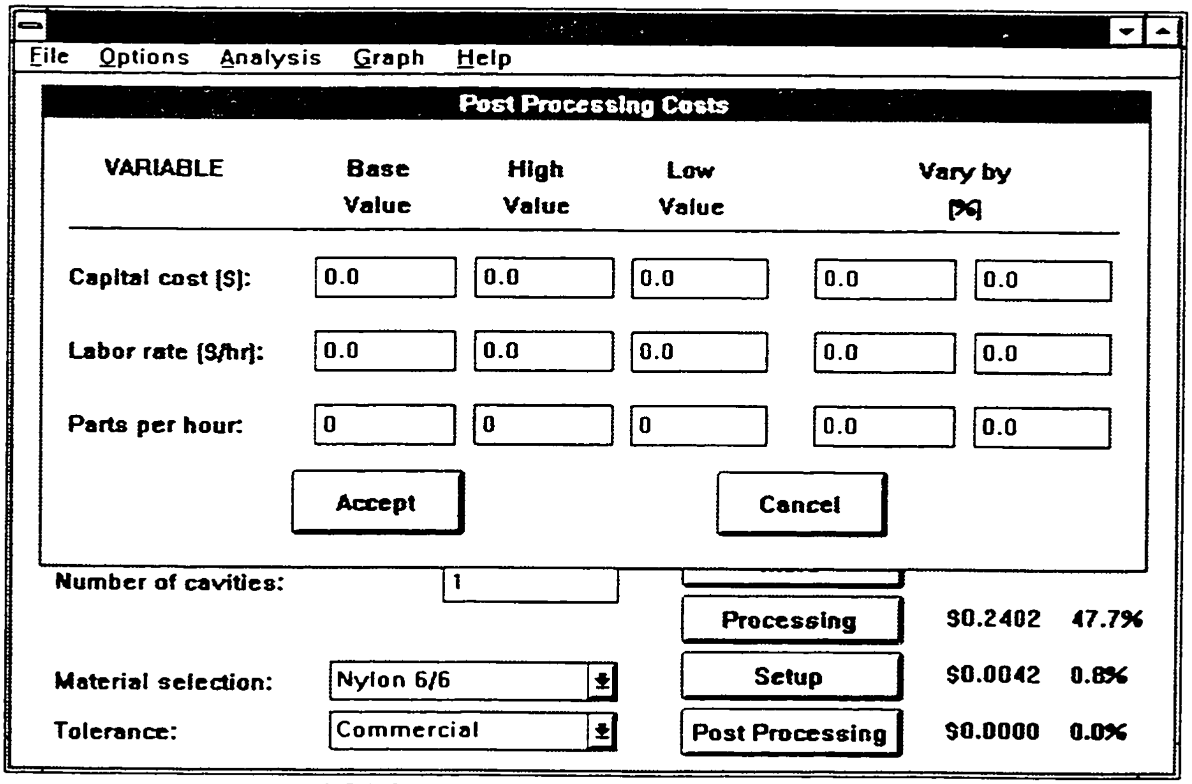
Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

Processing	$0.2402	47.7%
Setup	$0.0042	0.8%
Post Processing	$0.0000	0.0%

SCREEN 6: Setup Group Cost



Post Processing Costs

VARIABLE	Base Value	High Value	Low Value	Vary by [%]	
Capital cost ($):	0.0	0.0	0.0	0.0	0.0
Labor rate ($/hr):	0.0	0.0	0.0	0.0	0.0
Parts per hour:	0	0	0	0.0	0.0

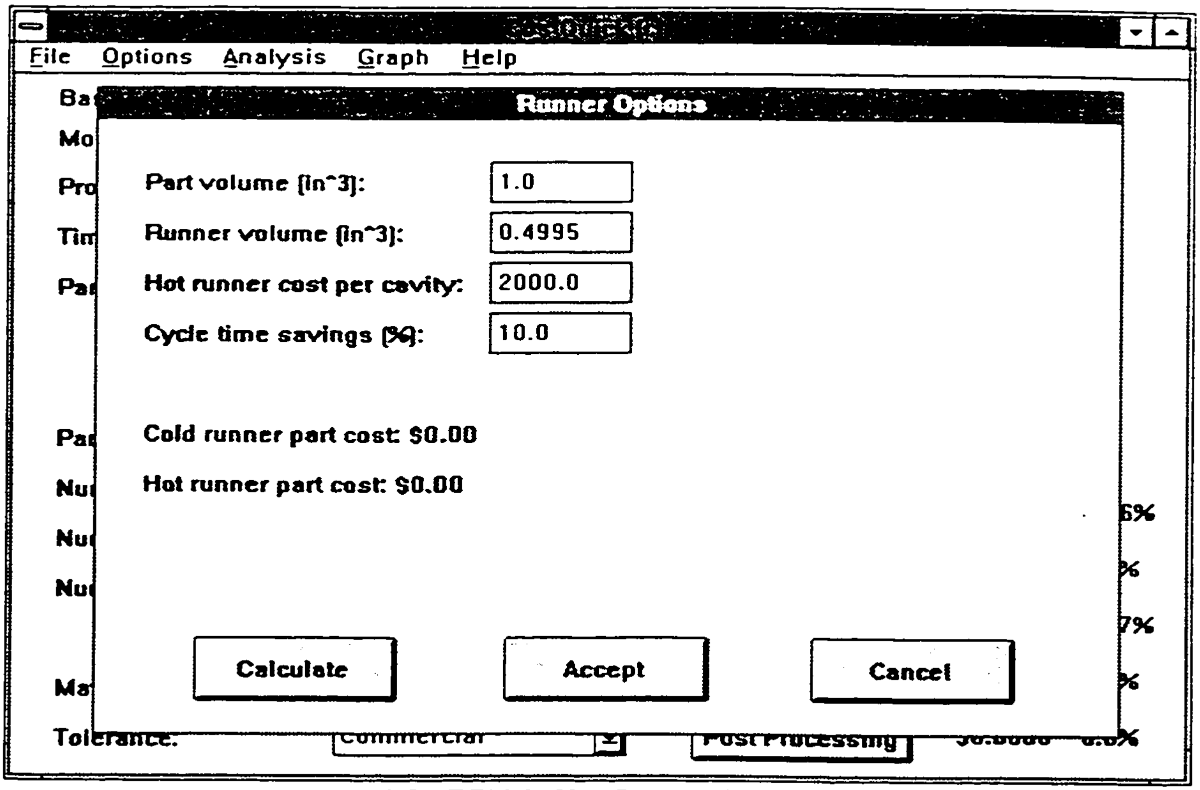
Number of cavities: 1

Material selection: Nylon 6/6

Tolerance: Commercial

Processing	$0.2402	47.7%
Setup	$0.0042	0.8%
Post Processing	$0.0000	0.0%

SCREEN 7: Post Processing Group Cost



Part volume [in^3]: 1.0

Runner volume [in^3]: 0.4995

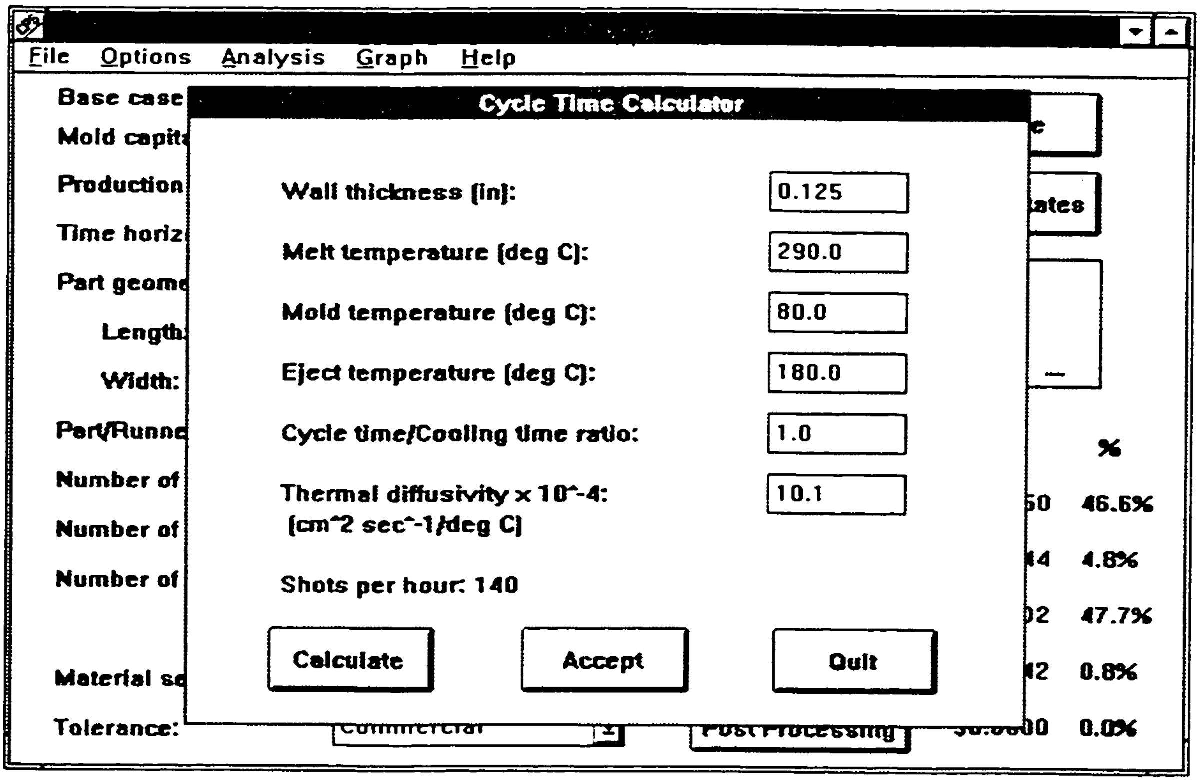
Hot runner cost per cavity: 2000.0

Cycle time savings [%]: 10.0

Cold runner part cost: $0.00

Hot runner part cost: $0.00

SCREEN 8: Hot Runner Screen



Wall thickness [in]: 0.125

Melt temperature [deg C]: 290.0

Mold temperature [deg C]: 80.0

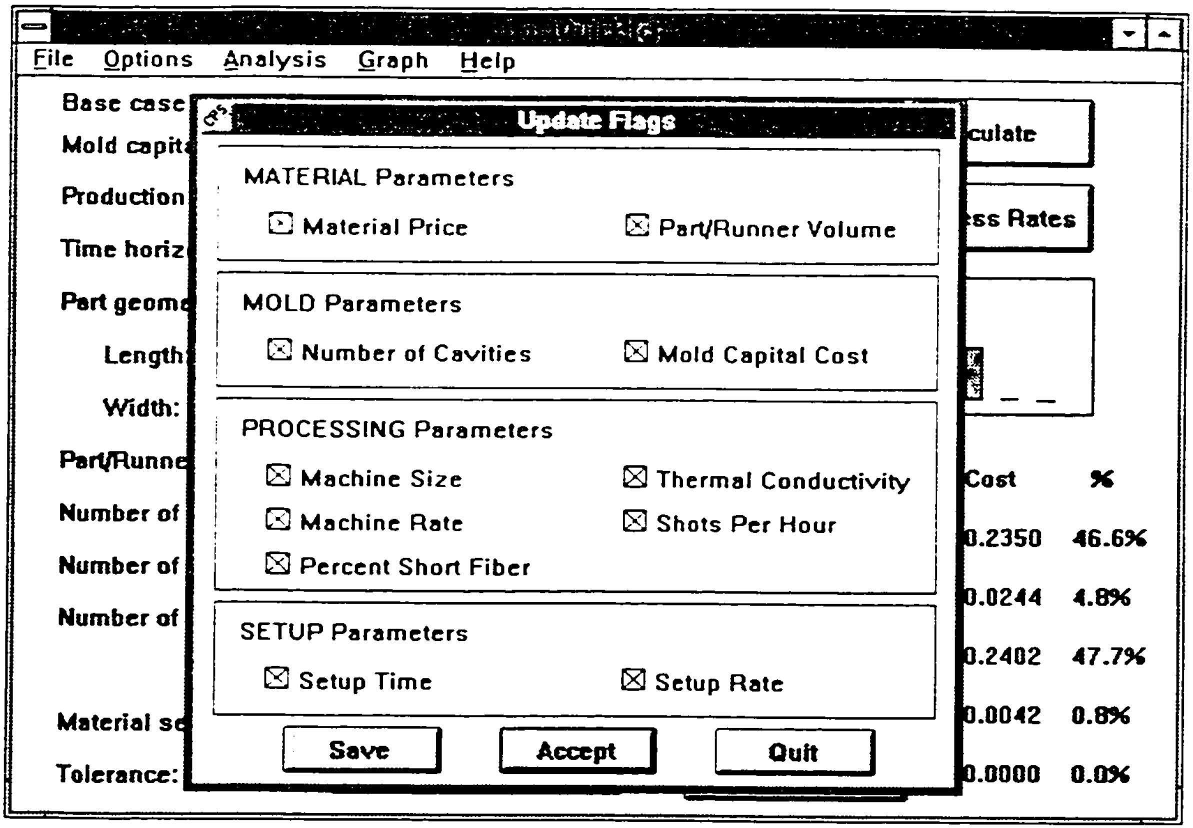
Eject temperature [deg C]: 180.0

Cycle time/Cooling time ratio: 1.0

Thermal diffusivity x 10^-4: (cm^2 sec^-1/deg C) 10.1

Shots per hour: 140

SCREEN 9: Cycle Time Screen



Update Flags

MATERIAL Parameters

☒ Material Price ☒ Part/Runner Volume

MOLD Parameters

☒ Number of Cavities ☒ Mold Capital Cost

PROCESSING Parameters

☒ Machine Size ☒ Thermal Conductivity

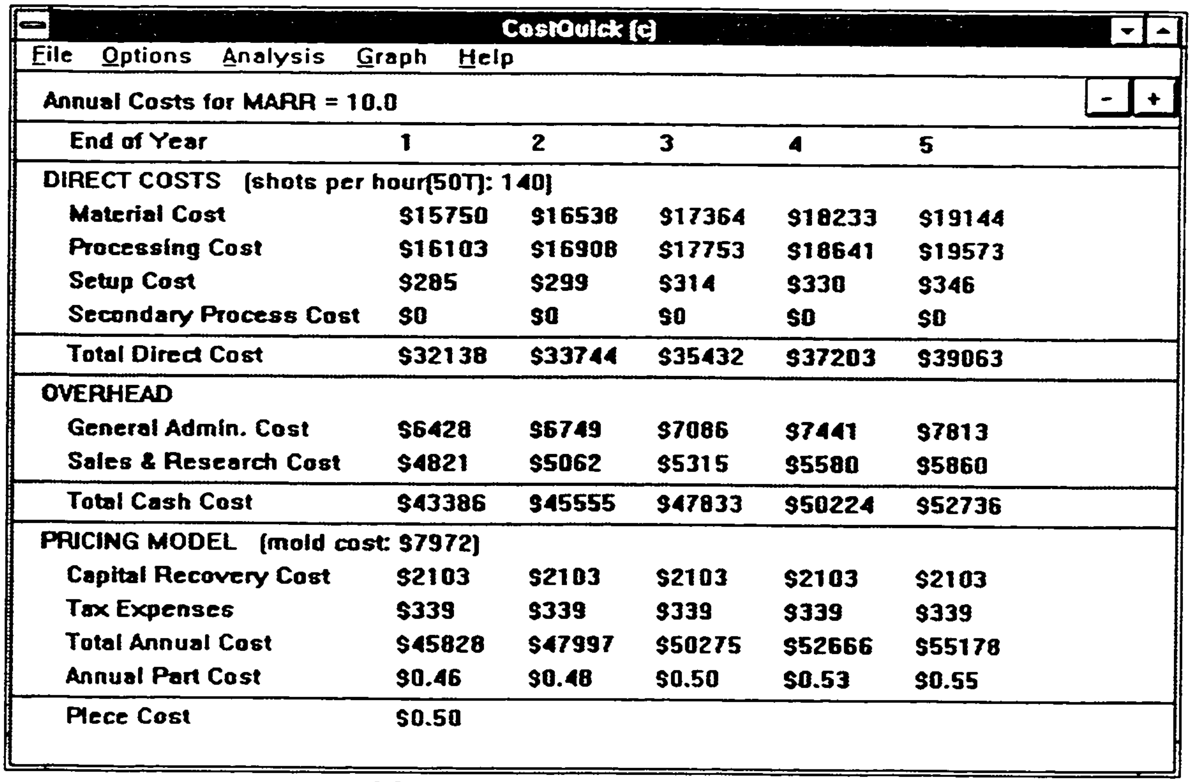
☒ Machine Rate ☒ Shots Per Hour

☒ Percent Short Fiber

SETUP Parameters

☒ Setup Time ☒ Setup Rate

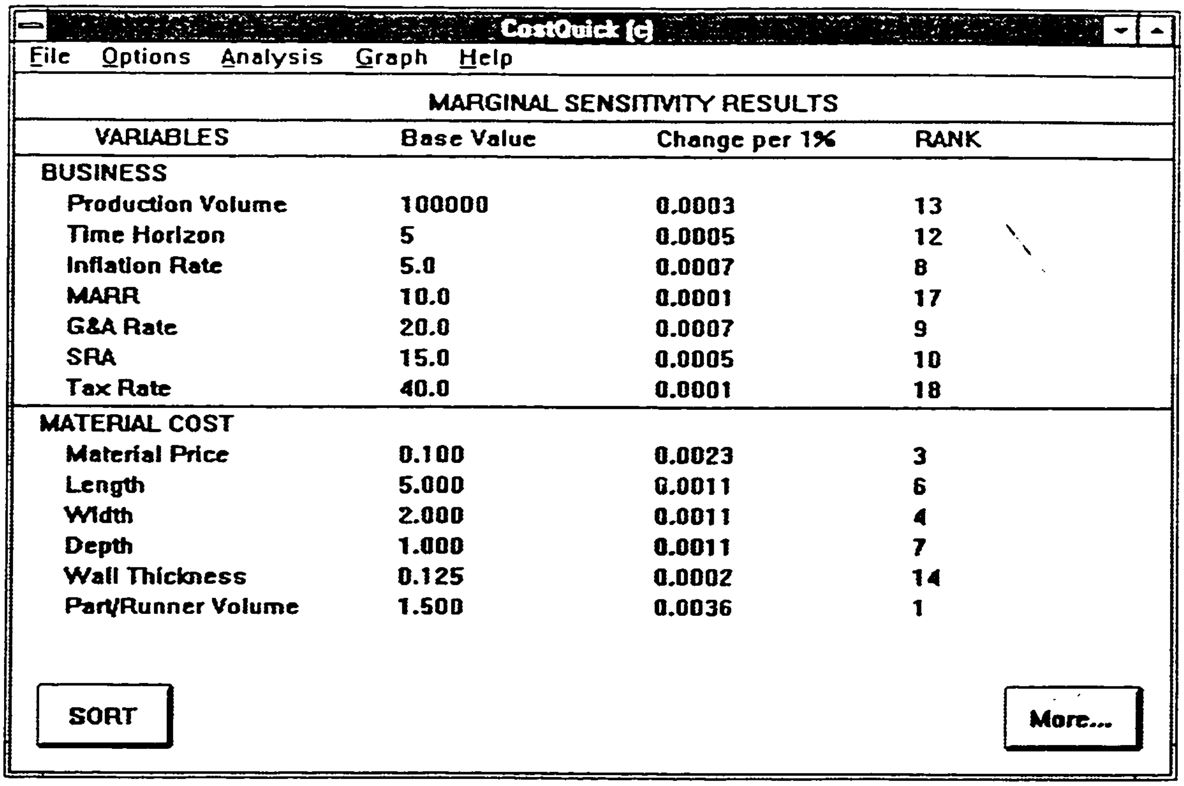
SCREEN 10: Update Flags Menu Screen



Annual Costs for MARR = 10.0

End of Year	1	2	3	4	5
DIRECT COSTS (shots per hour(50T): 140)					
Material Cost	$15750	$16538	$17364	$18233	$19144
Processing Cost	$16103	$16908	$17753	$18641	$19573
Setup Cost	$285	$299	$314	$330	$346
Secondary Process Cost	$0	$0	$0	$0	$0
Total Direct Cost	$32138	$33744	$35432	$37203	$39063
OVERHEAD					
General Admin. Cost	$6428	$6749	$7086	$7441	$7813
Sales & Research Cost	$4821	$5062	$5315	$5580	$5860
Total Cash Cost	$43386	$45555	$47833	$50224	$52736
PRICING MODEL (mold cost: $7972)					
Capital Recovery Cost	$2103	$2103	$2103	$2103	$2103
Tax Expenses	$339	$339	$339	$339	$339
Total Annual Cost	$45828	$47997	$50275	$52666	$55178
Annual Part Cost	$0.46	$0.48	$0.50	$0.53	$0.55
Piece Cost	$0.50				

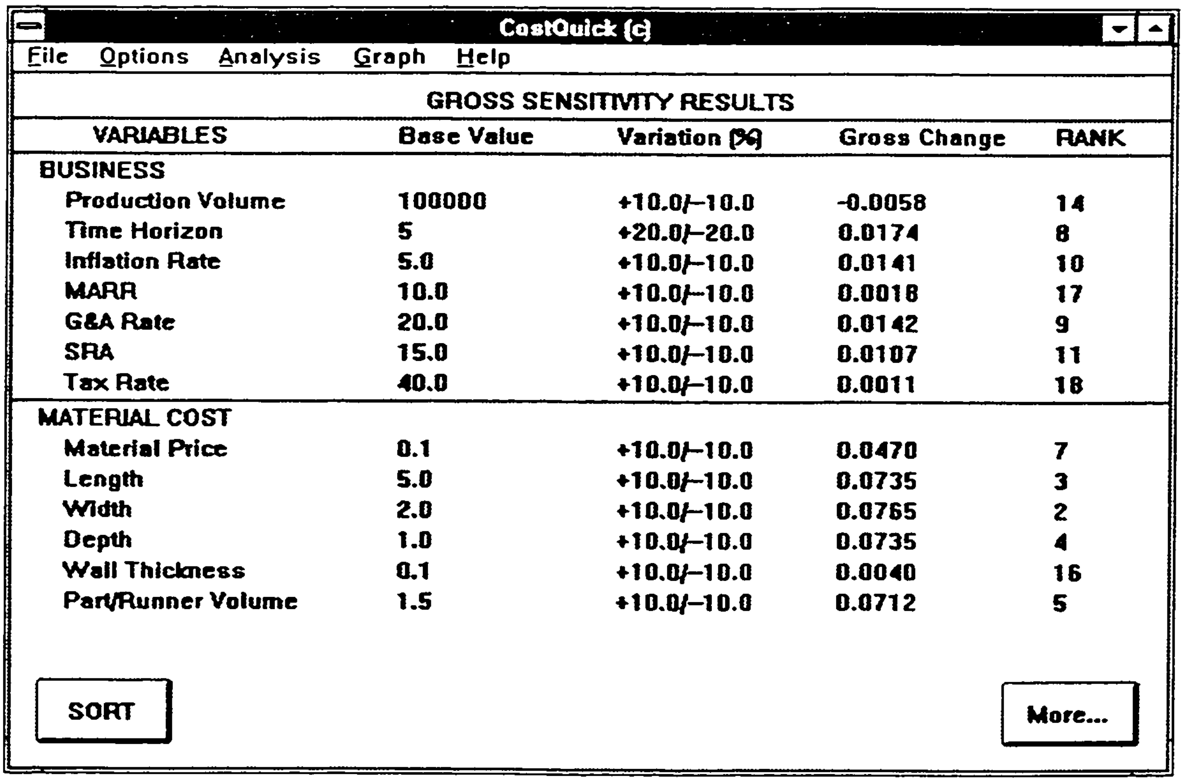
SCREEN 11: Annual Cost Screen



MARGINAL SENSITIVITY RESULTS

VARIABLES	Base Value	Change per 1%	RANK
BUSINESS			
Production Volume	100000	0.0003	13
Time Horizon	5	0.0005	12
Inflation Rate	5.0	0.0007	8
MARR	10.0	0.0001	17
G&A Rate	20.0	0.0007	9
SRA	15.0	0.0005	10
Tax Rate	40.0	0.0001	18
MATERIAL COST			
Material Price	0.100	0.0023	3
Length	5.000	0.0011	6
Width	2.000	0.0011	4
Depth	1.000	0.0011	7
Wall Thickness	0.125	0.0002	14
Part/Runner Volume	1.500	0.0036	1

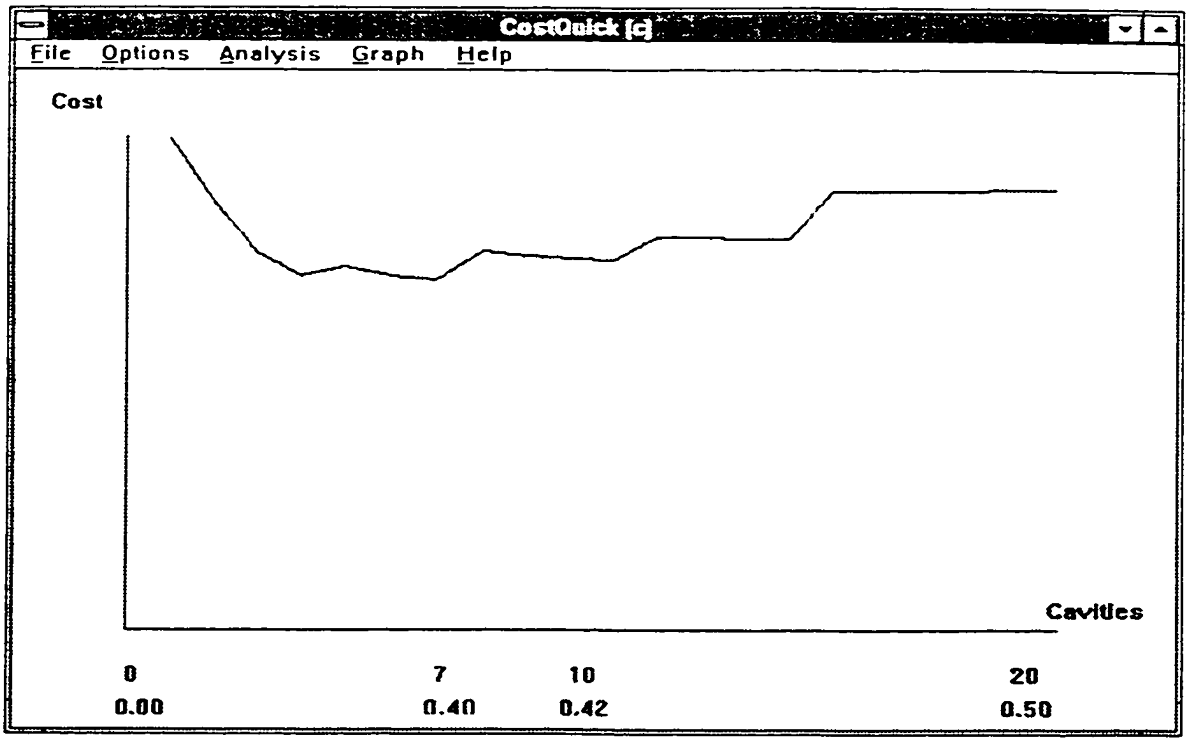
SCREEN 12: Marginal Sensitivity Analysis Screen



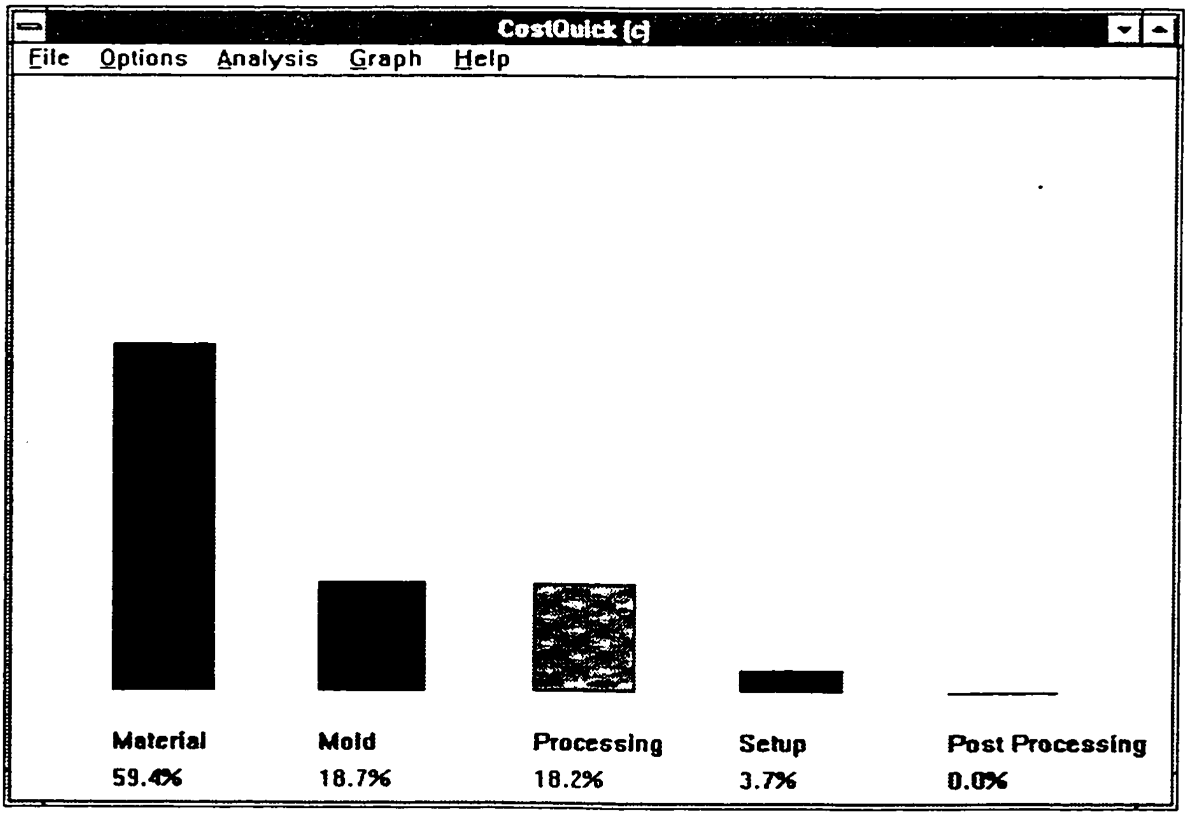
GROSS SENSITIVITY RESULTS

VARIABLES	Base Value	Variation (%)	Gross Change	RANK
BUSINESS				
Production Volume	100000	+10.0/-10.0	-0.0058	14
Time Horizon	5	+20.0/-20.0	0.0174	8
Inflation Rate	5.0	+10.0/-10.0	0.0141	10
MARR	10.0	+10.0/-10.0	0.0018	17
G&A Rate	20.0	+10.0/-10.0	0.0142	9
SRA	15.0	+10.0/-10.0	0.0107	11
Tax Rate	40.0	+10.0/-10.0	0.0011	18
MATERIAL COST				
Material Price	0.1	+10.0/-10.0	0.0470	7
Length	5.0	+10.0/-10.0	0.0735	3
Width	2.0	+10.0/-10.0	0.0765	2
Depth	1.0	+10.0/-10.0	0.0735	4
Wall Thickness	0.1	+10.0/-10.0	0.0040	16
Part/Runner Volume	1.5	+10.0/-10.0	0.0712	5

SCREEN 13: Gross Sensitivity Analysis Screen



SCREEN 14: Cavity Optimization Screen



SCREEN 14: Group Cost Screen

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WORK EXPERIENCE

General Instruments, Hatboro Pa.	**1997- Present**
Director of Licensing,	
Engineering Information, Hoboken N.J.	**1994- 1997**
Vice President Business Development	*1996- 1997*
Vice President Operations and Quality	*1994- 1996*
Deutsch Metals Company, Gardenia Ca.	**1990- 1994**
Product Manager	
U.S. Navy	**1984- 1990**
Naval Officer,	

ACADEMIC WORK EXPERIENCE

Stevens Institute of Technology	**1992 - 1996**
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DMI Resident Engineer	*1992 -1994*
Stanley Fellow	*1993*
3M Research Fellow	*1992*

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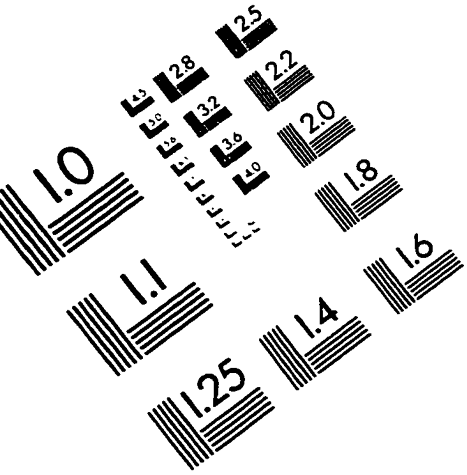
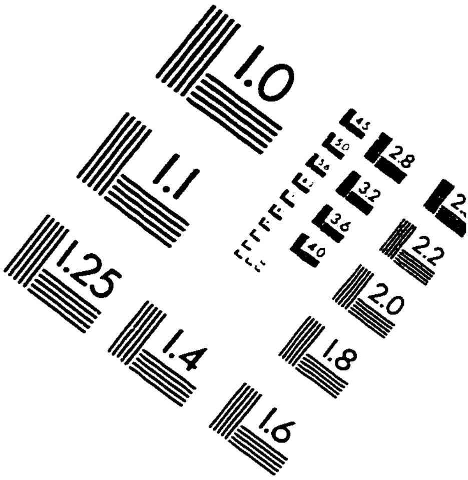
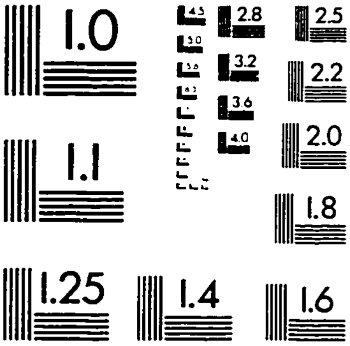
B.S. General Engineering (1984)
U.S. Naval Academy, Annapolis Md.

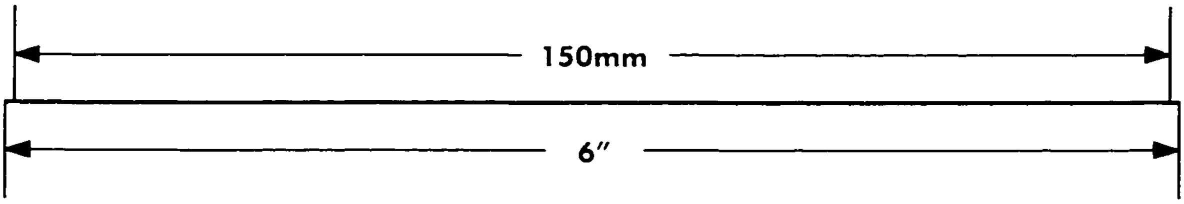
M.E. Mechanical Engineering (1994)
Stevens Institute of Technology, Hoboken N.J.

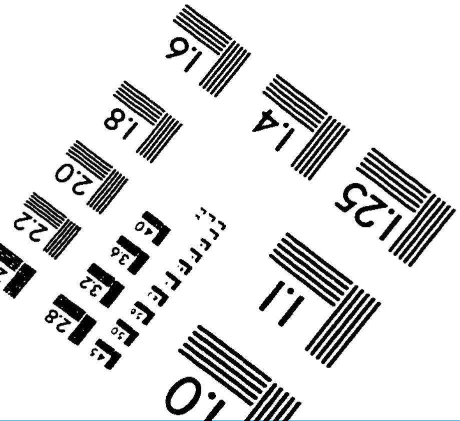
IMAGE EVALUATION TEST TARGET (QA-3)

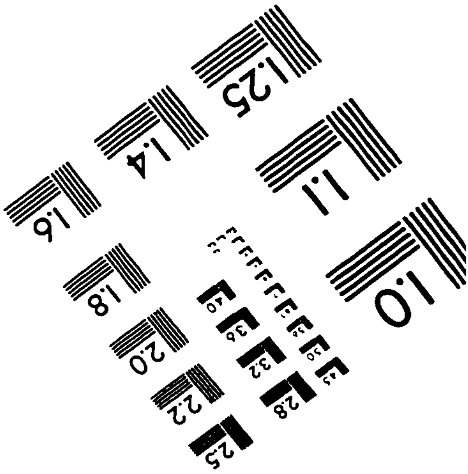












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