Improvements in Design and Manufacture of Circuitry Insert Molded Switch Components

by

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Abstract

Circuitry insert molding is becoming more widely utilized as a competitive process to manufacture switch components. A study was completed to determine how industry can improve the design and manufacture of these components. A benchmarking study of industry practices was completed for first, second, and third tier suppliers within the supply chain for switch components. Operations at one plant were also evaluated to identify areas for improvement within the manufacturing process itself.

The benchmarking study provided a great deal of insight about how different firms develop insert molded components and helped identify industry best practices. Based on the benchmarking results, ten recommendations were presented to help firms improve their development process. The two most critical areas for improvement for most firms include implementing concurrent engineering and involving subsuppliers within the development cycle. The benchmarking results were also used, along with lessons from case studies and industry interviews, to develop design checklists to help improve switch manufacturability.

The processing issues addressed during the operations study included understanding the impact of cycle time variability due to manual operations, determining the impact of drool caused by nozzle/mold disengagement during the process, and developing an improved operating strategy for increased throughput. The methods used in this phase of the research included process experimentation and operator interviews. The primary lesson learned was that drool during nozzle/mold disengagement can be a significant contributor to defects and needs to be managed.

Thesis Supervisors:	Dr. David Hardt Professor of Mechanical Engineering
	Dr. Karl Ulrich Associate Professor of Management

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1.1 Introduction

This thesis summarizes the work completed during a joint project between United Technologies Corporation (UTC) and the Massachusetts Institute of Technology (MIT) Leaders For Manufacturing (LFM) Program on the subject of insert molding. The project specifically addressed the needs of Input Controls, a division within United Technologies Automotive (UTA). The project's goals were to improve Input Control's ability to design and manufacture insert molded parts which are assembled into electromechanical switches for automotive orgininal equiment manufacturers (OEM's). The results of this project were generated through experiments, interviews, and case studies completed at the Input Controls Taylor, Michigan, molding plant and the Dearborn, Michigan, Product and Manufacturing Engineering Departments.

1.2 Insert Molding Process Description

Insert molding is based on the injection molding process where molten plastic is injected into a mold retaining the mold cavity's geometry upon cooling. However, insert molding also combines the favorable properties of an insert along with the plastic. Desirable insert properties might include electrical conductivity, wear resistence, or higher strength properties. The insert, typically a non-plastic component, is placed inside the open mold before the injection molding cycle begins. After the mold closes, the polymer material is injected into the mold and around the insert. The mold controls the amount of encapsulation around the insert and produces an integrally assembled final part.

This project focused on rigid circuitry insert molded parts. These parts typically consist of plastic molded around metal stampings to form part or all of an electromechanical switch such as those found in the instrument panel of automobiles. Examples of circuitry insert molded parts are illustrated in **Chapter 2**.

1.3 Overview of UTA Input Controls

This section provides a brief overview of the UTA Input Controls Division. The project work was completed at the Taylor Plant and the Dearborn Product and Manufacturing Engineering Departments.

1.3.1 Products

Input Controls provides a wide variety of components and subassemblies to the automakers. Their product line includes: electromechanical controls such as turn signals, light switches; windshield wipers; headlamps; and diagnostic modules. These products are generally specified by the OEM's in terms of electrical loading or function, pin-out geometry for mate-up to adjacent parts, and enviromental conditions. The suppliers provide a great deal of engineering value in the development of the parts.

1.3.2 Internal Development Roles and the Role of Suppliers

Input Controls develops and produces components and subassemblies using several configurations of the development team. The most common methods and design teams are shown in **Figure 1.2.1**. The final step, assembly, is always done in-house; however, the part design, mold development, and part component production can either be done in-house our by outside suppliers. Input Controls uses the different flow paths to balance internal engineering utilization.

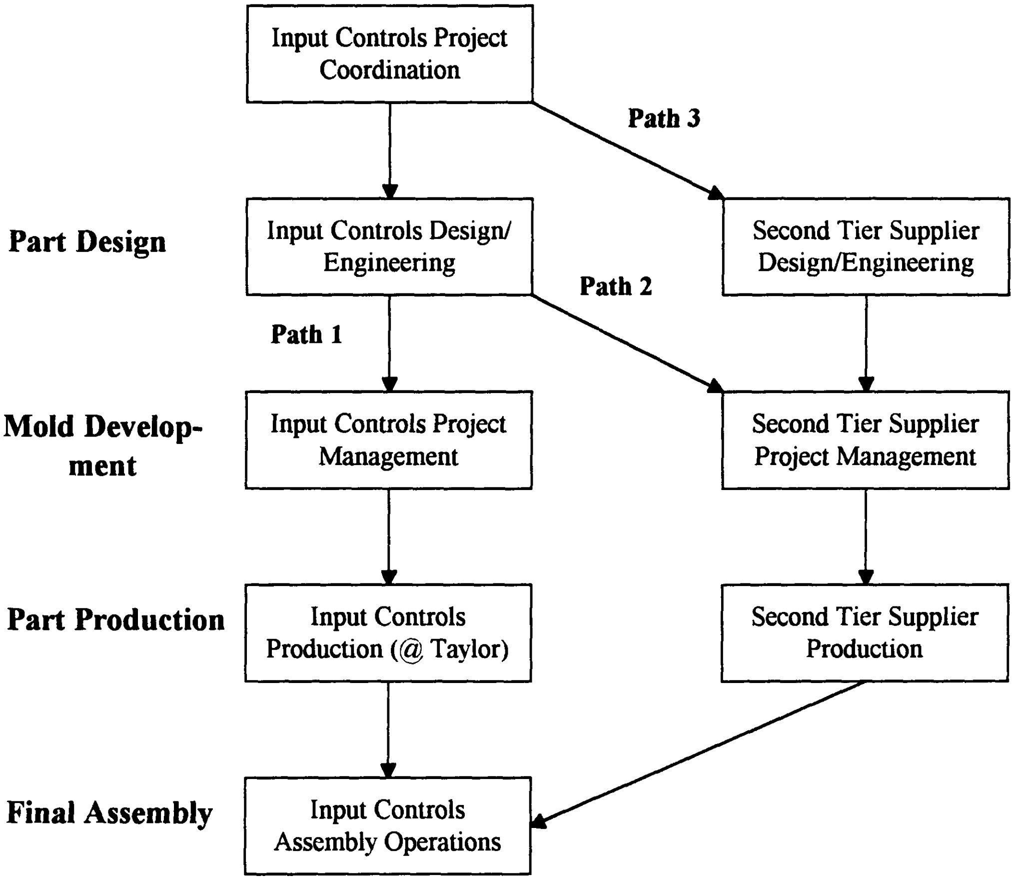

Figure 1.2.1: Input Controls Development Process Flow and Team Members

Although the flow appears simple enough through the various paths in **Figure 1.2.1**, in reality, the flow can become very confusing given that there are approximately 100 people split into several design groups within Input Controls Product Engineering, half a dozen second tier suppliers, and five assembly plants. The actual flow resembles that shown in **Figure 1.2.2**.

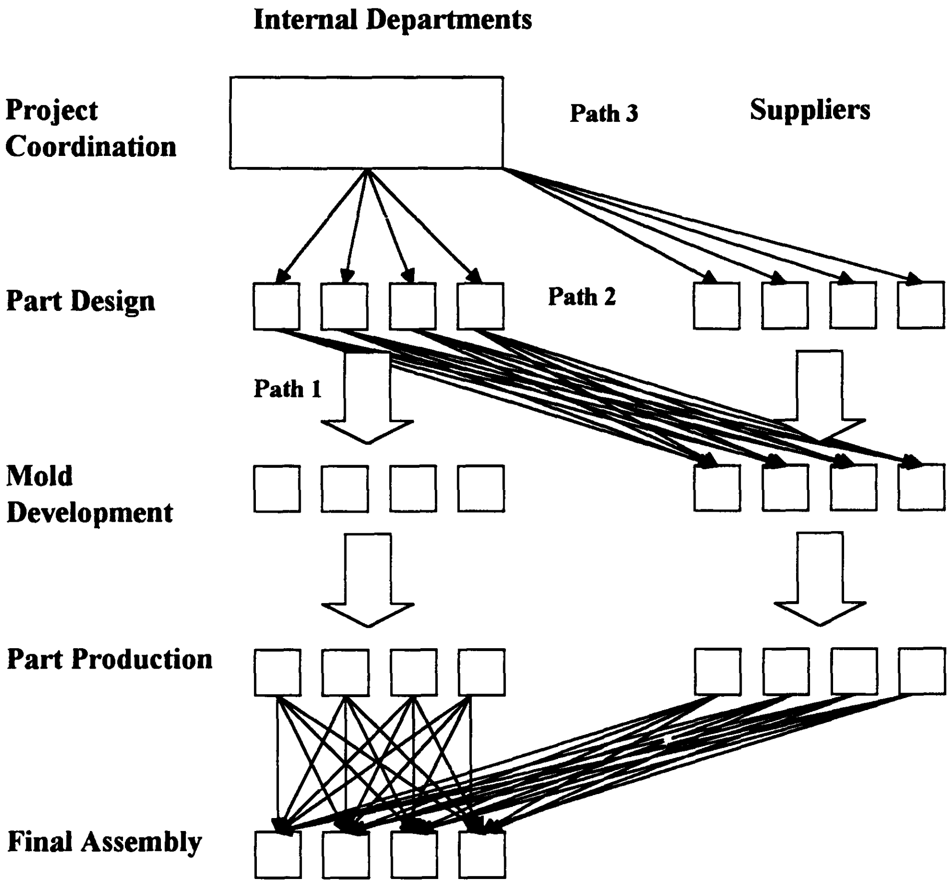

Figure 1.2.2: Illustration of Complexity of Input Controls Development Process Flow Considering GroupsWithin Each Function

The result is a complex system with requires a great deal of management to maintain order and prevent the confusion of roles within the team. The complexity of the development cycle has been a significant barrier for Input Controls in its desire to evolve toward a concurrent engineering strategy.

1.3.3 Taylor Molding Plant Overview

The Taylor, Michigan, molding plant is a three year old green field plant. They strictly supply Input Controls assembly plants and have no outside customers. The majority of their production is traditional molded products, but they also produce insert molded parts. They are currently expanding their insert molding capacity with additional insert molding machines.

The Taylor facility is a modern well equiped molding facility. It was carefully designed with up-to-date processing equipment layed out in small cells, reliable material handling equipment feeding the majority of the machines from one central location, and logical inventory and shipping facilities.

The plant also has a progressive employment philosophy. All employees are referred to as associates, and everyone is salaried. Job descriptions are purposefully vague in order to allow employees to do whatever it takes to meet the ultimate goal -- to produce quality parts. Production runs in three eight hour shifts for five days a week. Process technicians on each shift set-up the machines and lead troubleshooting efforts. Utility technicians handle raw material and finished part flow and watch the machines for any process disturbances.

1.4 Goals and Motivation for Research

The goals for this project were to improve Input Controls ability to design and manufacture insert molded parts. Several technical and managerial issues needed to be resolved in order to accomplish these goals. On the technical side, the manufacturing process needed to be investigated to determine the root causes of part defects and to generate potential solutions; and the development process needed to be investigated to determine how to improve the design for manufacturability of the parts. On the managerial side the challenge was to determine how to implement changes to the processing strategy and to the development process to improve performance in terms of speed, cost, and quality.

There were three main issues which motivated this project.

1. *Insert molding volume is expanding*. Input Controls is experiencing increased demand for insert molded parts from its customers. The process offers reduced part count and provides improved reliability through an integral part assembly free from secondary fasteners such as rivets. Additionally, industry reports suggest that insert molding of electrical parts will be the next wave in major application opportunities within the auto industry.[1] Therefore, Input Controls must improve its ability to design and produce insert molded parts if it wants to capture part of the expanding market.

2. *Insert molded products have much higher defect rates at Taylor than traditional parts*. The insert molding process is not well understood at Taylor in terms of being able to produce defect free parts. Additionally, it has not been addressed significantly in the literature. Therefore, one of the main motivations for this project was to help Taylor understand the major contributors to defects in insert molded parts and to to help them evaluate and implement potential solutions.

3. *The development process at Input Controls for insert molded parts is confusing and often includes significant rework.* Input Controls utilizes second and third tier suppliers in a variety of roles within the development cycle. Given the size of the engineering organization at Input Controls and the number of suppliers they use, the roles each party plays on the development team can become confusing and difficult to manage. Input Controls is trying to evolve to a concurrent engineering strategy. If they are to be sucessfull, they will have to understand how they can work with their suppliers effectivley with the goal of improving their speed, cost, and quality.

1.5 Summary of Research

Research for this project included a literature search, a benchmarking study of industry practices, case studies and interviews with designers, and experimentation. The literature search was used to validate the focus on insert molding and to guide the benchmarking and experimentation work.

There is very little literature available on the subject of insert molding. Most of the existing literature discusses different applications and case studies where insert molding was used versus the alternatives. Several articles provided overviews of the issues to consider when designing insert molded parts but did not provide specific recommendations and did not focus on circuitry parts. Several of the articles focused on automating the process of placing the insert inside the mold. Thus, there appeared to be a void in the literature and, thus, good justification to research how circuitry insert molded parts should be developed and processed.

Benchmarking was chosen as the methodology to investigate the industry best practices in developing circuitry insert molded products. Three individual benchmarking studies were completed. First, Input Controls direct competitors were benchmarked in terms of how they develop products and how they work with suppliers. Second, Input Controls component suppliers were benchmarked in terms of how they develop products and how they work with their customers as well as mold and stamping suppliers. Finally, mold suppliers were benchmarked in terms of how they work with their customers and the role they play during part design.

Case studies were completed with part designers in Product and Manufacturing Engineering Departments, a manufacturing engineer at Taylor, and an outside design firm. The case studies focused on design for manufacturing issues and both good and bad applications of insert molding.

Experimentation at Taylor was completed to determine the primary contributors to defects in insert molded parts. Two experiments were completed. The first experiment was used as a scoping study to isolate areas to be addressed during follow-up studies. The second experiment addressed the areas identified in the first experiment.

There were three primary deliverables for the project. First, the benchmarking studies yielded a great deal of knowledge about how other firms develop insert molded products and what some of the industry best practices are. Based on the benchmarking studies, ten recommendations were developed to help Input Controls improve their development process. Second, using the lessons learned from the case studies and interviews, a design checklist was developed for part, mold, and insert design. An implementation procedure for the checklist was also developed. Finally, the experimentation resulted in several conclusions about how Taylor can improve their insert molding process capability. Significant improvements in cycle time and defect rate were demonstrated during the experiments.

The three deliverables above were each presented to Input Controls in individual reports to facilitate technology transfer. Chapters 4, 5, and 6 of this thesis each present one of the reports.

1.6 Thesis Overview

Chapter 2 provides an overview of the insert molding process and the key technologies including traditional injection molding. This information is presented to help the reader understand the experimentation work at Taylor.

Chapter 3 presents an overview for the product development process for traditional injection molded products as well as the insert molding process. This information establishes a basis for understanding the benchmarking study and the design checklist work.

Chapter 4 discusses the benchmarking study and develops the recommendations to help improve Input Controls development process. A recommended procedure for completing a benchmarking study is also presented.

Chapter 5 presents the design checklist work and describes how to go about creating a design checklist as well as why the checklist format was used in the Input Controls case.

Chapter 6 outlines the results, conclusions, and recommendations of the experimentation work at the Taylor plant.

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[1] Michael C. Gabriele, "What It Takes To Serve the Automotive 'Transnationals,'" Plastics Technology, September 1992, p. 87.

2.1 Introduction

This chapter summarizes the process of insert molding. It identifies the process parameters and discusses how they can be used to control the process.

2.1.1 Injection Molding Overview

Conventional injection molding is a process whereby a solid thermoplastic polymer is heated until it reaches a state of fluidity, transferred under pressure (injected) into a closed hollow space (mold cavity), and cooled in the mold until it reaches a solid state in the shape of the mold cavity.[1] Thermoplastic polymers soften with the application of heat and reharden upon cooling. The injection molding process is also used for thermoset materials which solidify by the application of heat and for reactionary polymers with solidify through a chemical reaction. The process is similar; however, modifications are made to the cycle to accommodate the nature of these other materials. This study focuses solely on thermoplastic materials.

2.1.2 Insert Molding Overview

Insert molding is based on the injection molding process, but it also combines the favorable properties of an insert into the finished part. Desirable insert properties might include electrical conductivity, wear resistance, or higher strength properties. The insert, typically a non-plastic component, is placed inside the open mold before the injection molded cycle begins. After the mold closes, the polymer material is injection into the mold and around the insert. The mold controls the amount of encapsulation around the insert and produces an integrally assembled final part.

Examples of insert molded parts are shown in **Figure 2.1.1**. The reasons why each of the parts in **Figure 2.1.1** was insert molded is different. The tough shell is molded around a soft, light core to provide the optimal elastic performance of the golf ball. The sturdy plastic housing is molded around copper alloy stampings and an electrical wire to produce a cheap durable wall plug. The precise plastic housing is molded around the terminal lead inserts to form a compact precise electrical plug for a computer. The plastic structure is molded around the delicate mesh to form a compact, integral filter assembly. These parts show the inherent flexibility of insert molding. It can be utilized to lower costs, improve precision, reduce part size, improve durability, improve functionality, etc.

Computer Connector

Integral Filter Assembly

Golf Ball

Electrical Plug

Figure 2.1.1 Examples of Insert Molded Parts

This project focused on rigid circuitry insert molded parts. These parts typically consist of plastic molded around metal stampings to form part or all of an electrical circuit. These parts can be assembled to form switches. These types of parts are prevalent in the automotive and appliance industries and are expanding into other markets. It should be noted that this study did not include wire connectors, but rather focused on rigid conductor inserts. An example of a circuitry insert molded part is shown in **Figure 2.1.2**.

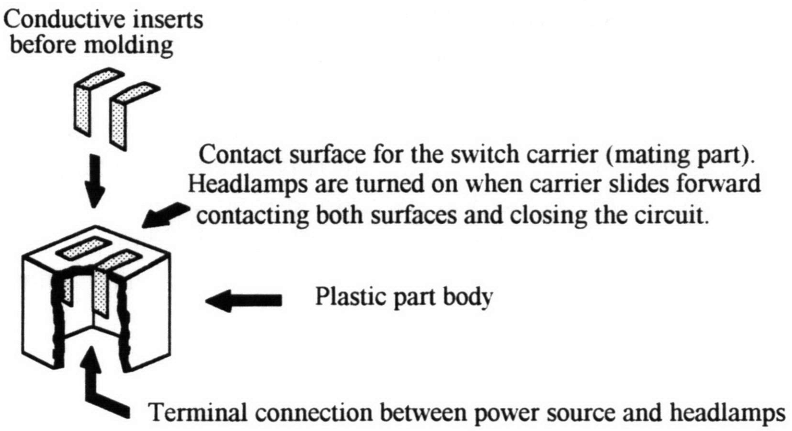


Figure 2.1.2 Example of A Circuitry Insert Molded Part

Note: This part is simplified for illustration purposes. Insert molding allows more part complexity than alternative processes such as riveting, ultrasonic insertion, etc.

2.1.3 Insert Molding Challenges

Properly designed and manufactured insert molded products can provide superior performance over alternative assembly procedures; however, they also impose new challenges for the design and manufacturing teams. The insert and the polymer in the finished part react to one another, and they also can respond differently to stress over their lifetime.[2] Consequently, it is critical to consider an array of compatibility issues in the design phase. Dow Plastics' John Bozelli, plastics specialist, relates a catastrophic compatibility problem with insert molding suffered by AT&T:

> *"They changed over from phenolic to a thermoplastic for an insert-molded switch. the switches worked fine for about two years, but then started cracking -- millions and millions of them. They had to bring the cracked parts back in and use arc welding to remelt the plastic around the inserts. That relieved the hoop stress."*[3]

In addition to technical design challenges in the insert molding development process, there are also logistical and communication issues as the parts, inserts, and molds are typically designed by different team members. Developing the design concept for a part is typically the first hurdle and often sets much of the mold and insert design along with the process capability. Consequently, it is advantageous to have a cross functional team involving the customer, mold supplier, stamping supplier, as well as the product and manufacturing representatives. This is discussed in Chapter 3.

2.1.4 Advantages and Disadvantages of Circuitry Insert Molding

Competing processes to assemble conductive inserts with a plastic base include rivets, traditional press fits, heated press fits, ultrasonic insertion, and push-through stake terminals. The relative advantages and disadvantages of each of these processes versus insert molding is shown in **Table 2.1.1**.

Process	Advantages	Disadvantages
1. Insert Molding	● Improved quality and reliability through: + fewer parts + improved flatness of contact surfaces + better terminal alignment ● Improved durability through integral assembly.	● Flexibility is reduced due to: + difficulty to add or remove functions without complete geometry redesign + design changes require changing stamping dies and molds. ● Tooling costs are generally higher including prototyping and molds
2. Rivets	● Cost ● Process is well understood	● Requires heat stable resins to prevent loosening from temperature cycles. ● Tolerance stack-ups can be significant.
3. Standard Press Fit	● Simple one piece design vs. rivets. ● Fast process cycle time.	● Inconsistent pull out forces. ● Large dimensional variation in pin placement.
4. Heat Press Fit	● Simple one piece design vs. rivets.	● Inconsistent pull out forces. ● Slow cycle time due to heat input. ● Large dimensional variation in pin placement.
5. Ultrasonic Insertion	● Simple one piece design vs. rivets.	● Inconsistent pull out forces. ● Slow cycle time due to ultrasonic process. ● Large dimensional variation in pin placement.
6. Push-through Stake Terminals	● Simple one piece design vs. rivets.	● Part tolerance stack-ups cause variability in terminal placement. ● Reduced flatness of contact surface.

Table 2.1.1 Advantages and Disadvantages of Competing Process To Circuitry Insert Molding

2.2 Injection Molding Process Description

This section outlines the injection molding process which is the basis for the insert molding process.

2.2.1 The Injection Molding Machine

The injection molding machine has two principle components to perform the cyclical steps of the injection molding process: the injection unit and the clamp unit (see **Figure 2.2.1**). To keep them in proper alignment they are mounted on a machine base which also houses the power and control units.[4]

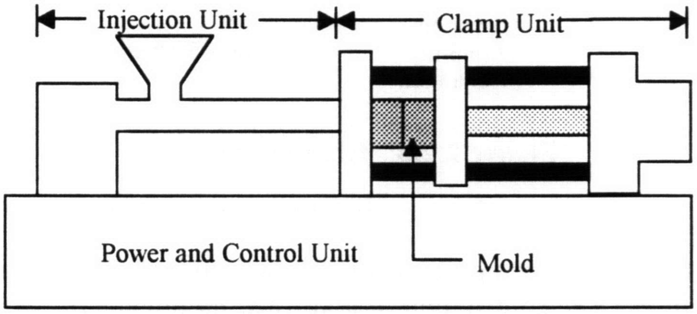


Figure 2.2.1: Injection Molding Machine

The injection unit is typically made up of a material hopper, a reciprocating screw within the barrel, barrel heaters, and an injection nozzle (see **Figure 2.2.2**). The injection unit melts or plasticizes the material fed from the hopper and injects it into the mold by forcing the screw forward inside the barrel.

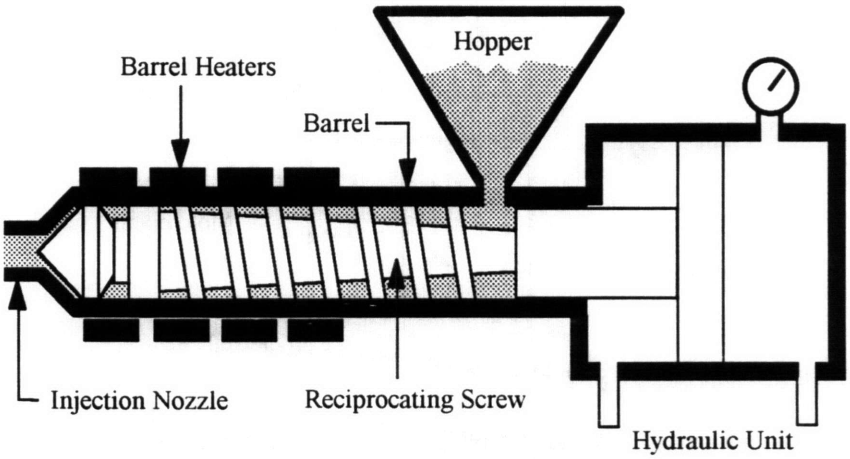


Figure 2.2.2: Injection Unit

The clamping unit opens the mold and ejects the finished part and closes it for the next cycle as shown in **Figure 2.2.3**. Machines are typically sized by their maximum clamping force which sets the maximum part cross sectional area that can be molded. Several types of clamping mechanisms are used in machines including single and double toggle devices to increase the clamping force.

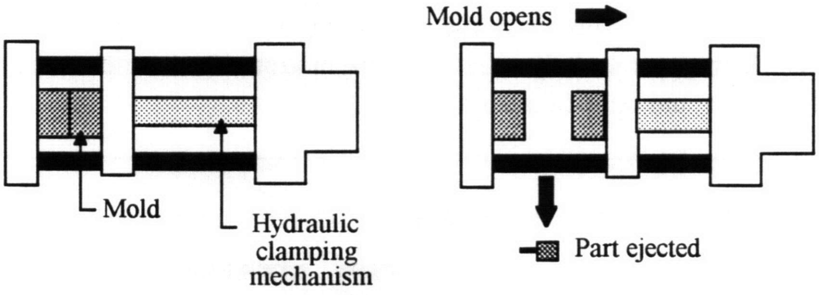
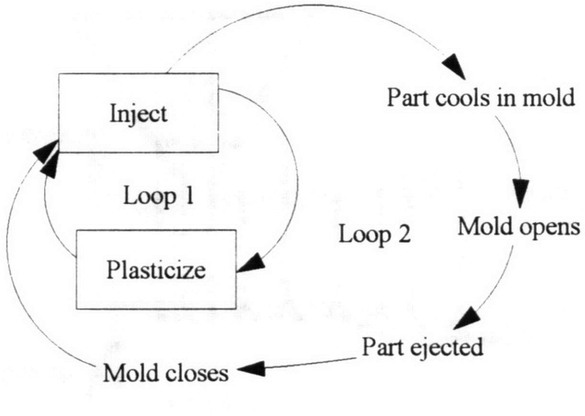


Figure 2.2.3: Clamping Unit

The power unit is typically made up of a hydraulic system including a pump, piping, and required control valves. The control unit or controller modulates the energy from the power unit to run the injection and the clamp unit. The controller controls the machine during each process phase and determines the appropriate time to transfer from one phase to another.

Figure 2.2.4 illustrates the three primary phase in the injection molding process: plasticization, injection, and molding. **Figure 2.2.4** also shows the cyclical nature of the process. Each phase is discussed in detail in the next three sections.



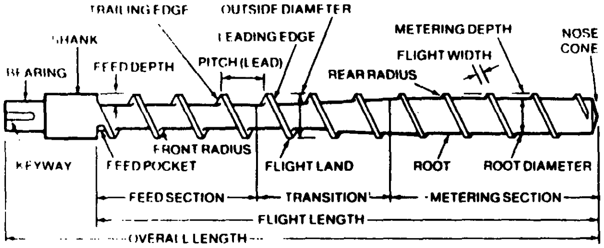
Note: "Molding step is made up of cooling, mold open and close, and part ejection. Injection can not start until both Loop 1 and Loop 2 have been completed.

Figure 2.2.4: Injection Molding Process Steps and Flow

2.2.2 Plasticizing Phase

The first phase of injection molding is to plasticize or heat the plastic to the point where it will flow under pressure. This energy is transferred to the polymer primarily through mechanical energy from an extrusion screw. The screw imparts energy into the material by shearing the polymer resulting in thermal energy generated through mechanical friction. The injection molding screw differs from an extrusion screw because it also acts as a plunger during injection forcing the plastic into the mold. Consequently, this type of machine is called a reciprocating screw injection molding machine.

The reciprocating screw was first used to plasticize polymer in an injection molding machine in 1951 in the United States by William H. Willert and was patented in 1956. It was the first real advance in injection molding since its development in 1878 by the Hyatt brothers in Boston, Massachusetts.[5] Because of their molecular structure, plastics have low thermal conductivities; thus it is difficult to transmit heat through them rapidly. This limited the cycle time in the early machines which primarily used



Feed Section: This section can occupy from zero to 75 percent of the screw length. It's length depends on how much heat has to be added to melt the material. The pellet or powder is general fed by gravity into this section and is conveyed some distance down the barrel, during which time it becomes soft. Heating is accomplished by both conduction and mechanical friction.

Melt (Transition) Section: This section can occupy anywhere from 5 to 50 percent of the screw length. This "compression" zone has to be sufficiently long to make sure that all of the plastic is melted. This section is where the soffened plastic is transformed into a continuous melt.

Metering Section: This section averages 20 to 25 percent of the total screw length for most plastics. In this section, the plastic is smeared and sheared to give a melt having a uniform composition and temperature for delivery to the mold. As high shear action will tend to increase the melt's temperature, the length of the metering zone is dependent upon the resin's heat sensitifity and the amount of mixing required.

Figure 2.2.5 Conventional Injection Molding Screw

Figure and descriptions of sections were taken from *Injection Molding Handbook*, p 16-17.

external heater bands to heat the plastic in the barrel. The reciprocating screw, however, could transfer energy very quickly into the plastic. Additionally it could mix the material in the barrel improving the homogenity of the melt. The combination of these two factors greatly reduced cycle time.

Screw design is a complex task and involves a series of trade-offs. For example, screw design sets the capability envelopes for the mixing and melt properites as well as the output rate and the temperature tolerance in the melt.[6] A screw has three basic sections: fead, melting or transition, and metering. Each of these sections is illustrated and discussed in **Figure 2.2.5**[7].

2.2.3 Injection Phase

Once the plastic is melted and mixed into a homogeneous charge in the barrel, it is ready to be injected into the mold. The first phase of injection is the filling phase where the hydraulic ram pressure is controllably increased forcing the screw forward. This compresses the plastic and pressurizes the melt, thus, driving it through the nozzle and into the mold. Once the mold is filled, the hydraulic pressure is maintained, usually at a reduced level, for the packing phase. During this phase the the plastic in the barrel is held in a pressurized state so as to continue to force plastic into the mold as the part shrinks during cooling and solidification. The purpose of the packing phase is to reduce shrinkage voids in the finished part and maintain the desired part weight. After the packing phase, the hydraulic pressure is reduced for the final injection phase -- holding. The holding phase ensures that the plastic injected in the first two phases is held in the mold. During the hold phase, the gate freezes off sealing the plastic into the mold. After the hold phase, the plastic is depressured in the nozzle. The hydraulic and nozzle pressure profiles during the injection phase are shown below in **Figure 2.2.6**.

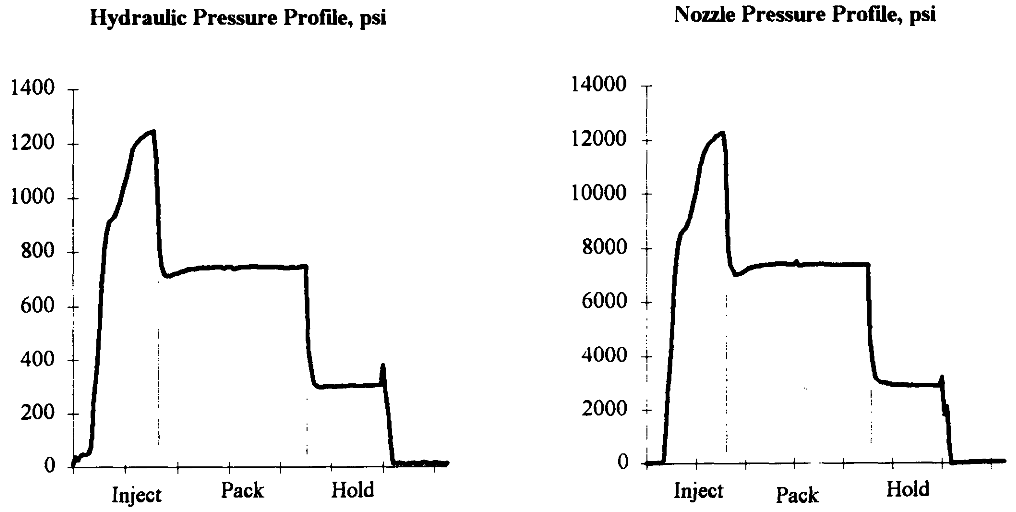


Figure 2.2.6: Hydraulic and Nozzle Pressure Profiles During Injection

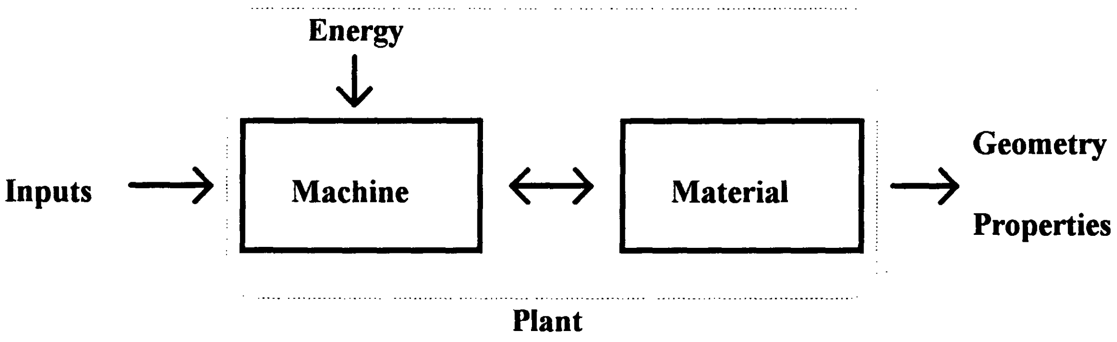
2.2.4 Molding Phase

After injection is complete, the part continues to cool in the mold. Once the part has solidified and has cooled enough to develop adequate mechanical strength, it can be ejected from the mold. The cooling phase has a large impact on the overall cycle time. Part wall thickness and mold temperature are the larges determinants of cooling time.

2.3 Process Control

2.3.1 Injection Molding Process Model

The process of insert molding can be represented by the model shown in **Figure 2.3.1.**[8] The process or plant consists of machine and material elements. Energy is applied to the system under careful control so as to produce output with the desired geometry and properties. Both the machine and the material have *properties* and *states*. *Machine properties* determine how the source of energy is transferred and modulated. *Material properties* determine how the material will respond to the applied energy. *States* are simply the energy and power conditions at any given point and time of the machine and material.



Machine Properties, P_m
Mold Shape
Mold Thermal Conductivity, K_{mold}
Gate Diameter, D_{gate}
Clamp Stiffness

Material Properties, P_w
Viscosity, $\mu(T)$
Polymer Thermal Conductivity, K_p
Molecular Weight
Density, ρ
Strain Properties, ε_T
T_{melt}

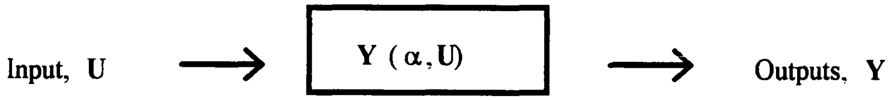
Machine Dynamic States, X_m
Pressures (hydraulic, back, etc.)
Velocities
$T_{\text{barrel, gate, mold, etc.}}$
P_{clamp}
Mode (filling, packing, cooling)
Pressures (cavity)

Material States, X_w
$T(x,y,z,t)$ (Temp. field)
$\upsilon(x,y,z,t)$ (Velocity field)
Pressure, P_p
Flow Rate, Q
Stress, σ
External Geometry

Figure 2.3.1: Insert Molding Process Model

2.3.2 Injection Molding Process Control Model

The control strategy for insert molding is driven by the process parameters shown in **Figure 2.3.1**. The model used to drive the process to the desired output by manipulating a subset of the variables is shown in **Figure 2.3.2**.



U = Input parameters, typically from X_m

α = All process parameters (P_m, X_m, P_p, X_p)

Figure 2.3.2: Insert Molding Process Control Model

The control objectives for the process are twofold. First, the process should be controlled so as to drive the actual output, **Y**, as close to the target output, Y_0, as possible. Second, variation in the actual output, **ΔY**, should be minimized. The control equation for the process can be written as shown in **equation 2.1** below.

(eq. 2.1)

$$\Delta Y = \left|\partial Y/\partial \alpha\right| \Delta \alpha + \left|\partial Y/\partial U\right| \Delta U + \mathbf{h.o.t}$$

where: $\left|\partial Y/\partial \alpha\right|$ = Process sensitivity to parameter changes or disturbances

$\left|\partial Y/\partial U\right|$ = Control parameter sensitivity

$\Delta\alpha$ = parameter changes or disturbances

ΔU = control parameter changes

$\Delta Y = [Y - Y_0]$

h.o.t. = higher order terms

Equation 2.1 in words could be written as follows:

Variation in Process Output	=	Process Sensitivity to Disturbances	x	Disturbances or Changes in Parameters	+	Control Parameter Sensitivity	x	Control Parameter Changes

There are several levels of control which need to be addressed in any process: 1) reducing process sensitivity to disturbances, 2) eliminating disturbances, and 3) rejecting disturbances through feedback control.[9] Each of these is discussed briefly below:

Reducing Process Sensitivity to Disturbances

Through techniques such as Taguchi Methods or design of experiments, the process can be set up so that it is less sensitive to variation of process inputs. For example, polymer viscosity decreases exponentially as shear rate increases as shown in **Figure 2.3.3**. If the process is set up to run at point A, any variation in the shear rate or fill rate will have a significant impact on the viscosity whereas the same level of variation at point B will have a much smaller impact on viscosity.

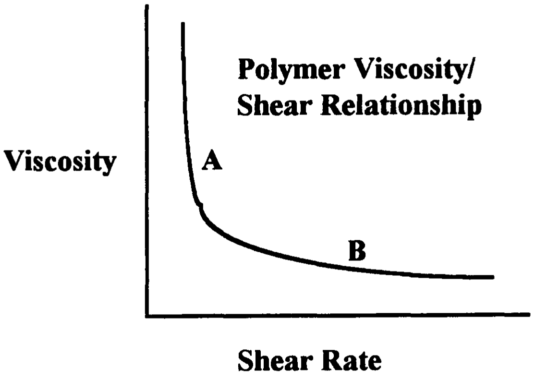


Figure 2.3.3

Eliminating Disturbances

Statistical process control (SPC) involves regularly sampling the output of the process to identify when the process has moved beyond the expected range of outputs. Once an excursion is identified, the root cause can be assigned and possibly eliminated. By repeating this process over and over, the process can be improved and the process variation reduced.

Rejecting Disturbances Through Feedback Control

Each process will have disturbances that can not be eliminated and whose effect can not be negated through reducing process sensitivity to those disturbances. Feedback control is used to counteract or reject these disturbances. For example if you are following a truck on the highway and a large object falls out the back of the truck, feedback control through your vision and body is what makes you swerve around the object and straighten out on a new path. That same control system would react differently if ten objects fell out of the truck over a five second interval. Feedback control by definition needs to respond to system errors.

2.3.3 Feedback Control Parameters

We have not yet discussed the difference between process parameters and control parameters for feedback control. As shown in **Figure 2.3.2**, control parameters are a subset of process parameters. Although most process parameters can be manipulated to help meet the control objectives, control parameters should be chosen carefully because some are better suited for this purpose than others.

The issues to be considered include:[10] 1) process sensitivity to each parameter (how much does the process change for a given change in the parameter?), 2) process response time to parameter changes (how long does it take for the process to react to a parameter change?), 3) parameter uncertainty (how "measurable" is the parameter or what is our level of confidence in the parameter?), and 4) cost (how expensive is it to use any given parameter as a control parameter?). The insert molding process parameters and their applicability as control parameters are shown in **Table 2.3.1**. The ratings shown in **Table 2.3.1** are all subjective, but they help illustrate the challenges in controlling the process. For example, the process is very sensitive to mold shape, but it is difficult to change the shape fast enough to be a responsive control parameter. There are only a few parameters which highly applicable for controlling the process as is shown in the last column.

Table 2.3.1: Control Applicability of Injection Molding Process Parameters

Process Parameter	Sensitivity	Respons-iveness	Certainty	Cost	Developm-ent Phase Addressed	Control Applic-ability
Mold Shape	H	L	H	L	D***	n/a
K_{mold}	H	L	H	L	D	n/a
D_{gate}	M	L	H	L	D	n/a
Clamp Stiffness	L	L	H	L	D	n/a
Hydraulic pressure	H	H	H	L	O	H
Screw velocity/position	H	H	H	L	O	H
T_{barrel}	L	L	H	L	O	L
T_{mold}	M	L	M	L	O	L
P_{clamp}	L	H	H	L	O	L
Mode (fill, pack, cool)	H	H	H	L	O	H**
Cavity pressure	H	H	H	H	O	H
Viscosity, $\mu(T)$	H	L	L	H	O/D	L
Therm. Conductivity, K_p	M	L	L	H	D	n/a
Cp	M	L	L	H	D	n/a
Density, ρ	M	L	L	H	D	n/a
Strain Properties, ε_T	M	L	L	H	D	n/a
T_{melt}	H	M	M	H	O/D	L
Molecular Weight	M	L	M	H	D	n/a
$T(x,y,z,t)$	H	M	L	H	O/D	L
$\upsilon(x,y,z,t)$	M	M	L	H	O/D	L
Pressure, P_p	H	H	M	H	O/D	M
Flow Rate, Q	H	H	H	L	O/D	H*
Stress, σ	M	M	M	H	O/D	L
External Geometry	H	L	H	H	O/D	L

* Flow rate, Q, is a redundant parameter because it is linearly related to screw velocity.

** Fill mode is a redundant parameter because it is determined from screw position, cavity pressure, or hydraulic pressure.

*** Development phase addressed -- parameter can be changed in the design or operations phase or both.

2.3.4 Feedback Control Strategies

Injection is the most challenging phase of injection molding in terms of process control. The plasticizing and molding phases are not trivial, but their control parameters are static (constant during each cycle and from one cycle to another). For example, the cooling time and the mold open time are the same for each molding phase for any given part. The injection phase control parameters, on the other hand, are dynamic and are driven based on feedback during the process. For example, if a machine is set so as to fill the cavity with plastic at a constant injection rate, the force will have to be increased as the mold fills to overcome the increasing flow resistance caused by the growing slug of plastic inside the mold.

As shown in **Table 2.3.1**, several process parameters meet the requirements of dynamic control variables as outlined in **Section 2.3.3**. The most applicable control parameters for the injection phase include: hydraulic pressure, screw velocity/position, and cavity pressure (redundant parameters -- plastic flow rate and fill mode -- omitted). Hydraulic pressure and screw position have been used extensively in the past. Cavity pressure has not been used as extensively because the technology is more costly to implement, and it adds to control complexity which can have negative impacts such as lowering process reliability and increasing training requirements.

There are several control strategies used to manage the injection phase of the injection molding process. There are two broad issues which need to be addressed by the injection control strategy. First, the process needs to be controlled during each phase of injection (injection, pack, or hold) cycle. Second, the controller needs to trigger the transition from one phase to another at the right time. The typical control methodologies for each of these tasks are shown in **Table 2.3.2**.

Table 2.3.2: Control Methodology to Control Injection Phases and Transition Points

Injection Phase or Transition Point	Control Methodologies
Injection	1) screw velocity control 2) hydraulic pressure control
Switch over from injection to packing	1) transition at specific screw position 2) transition when hydraulic pressure reaches a specific level (it will rise as the mold fills) 3) transition when cavity pressure reaches a specific level.
Packing	1) screw velocity control 2) hydraulic pressure control

Injection Phase or Transition Point	**Control Methodologies**
Switch over from packing to holding	1) transition at specific screw position 2) transition after a certain elapsed time
Holding	1) hydraulic pressure control

2.3.5 Overall Control Strategy

Injection molding compared to machining or grinding is not easily controlled. Most of its process parameters are difficult to measure or manipulate in real time. Although feedback process control for injection molding has improved dramatically in recent decades, it can only carry the process so far because there are so many other parameters which can play a significant role in the outcome of the final product but can not be controlled through feedback control.

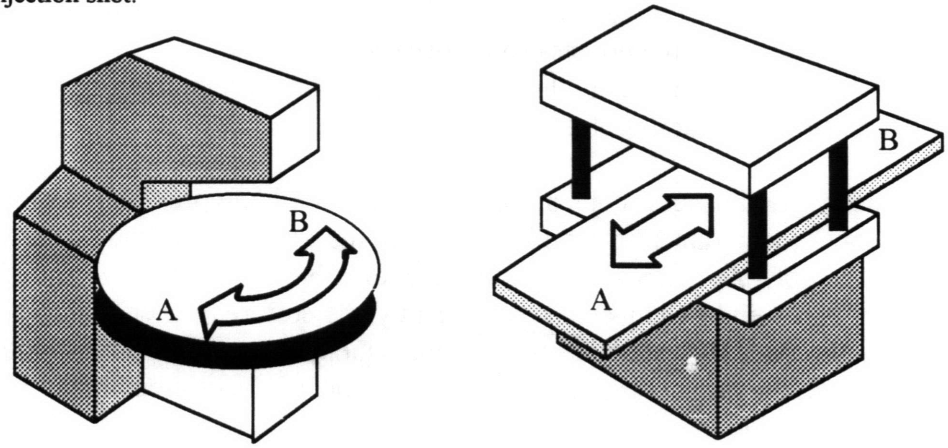
For this reason, good process control for the injection molding process rests on controlling both the parameters outside and within the grasp of feedback control. For example, if the polymer material in the hopper doesn't have a uniform moisture level, the variability of part weight will increase significantly. Therefore, it is critical to be consistent and reduce the variability of all process inputs outside the control loop. If this is done well, the process is likely to be controllable to the desired limits. If the process inputs outside the control parameters are not held constant, the process is not likely to be able to be controlled to the desired level no matter how good the controller and control strategy.

Statistical process control (SPC) techniques can play a key role in reducing process variability by identifying events which are outside the normal operating range. Several process parameters can be used to identify spikes or process shifts. Once the occurrence is identified, the cause can be isolated and eliminated. Design of experiments techniques can also yield significant process improvements by helping to center the process in the control range which minimizes variation.

2.4 Insert Molding Process

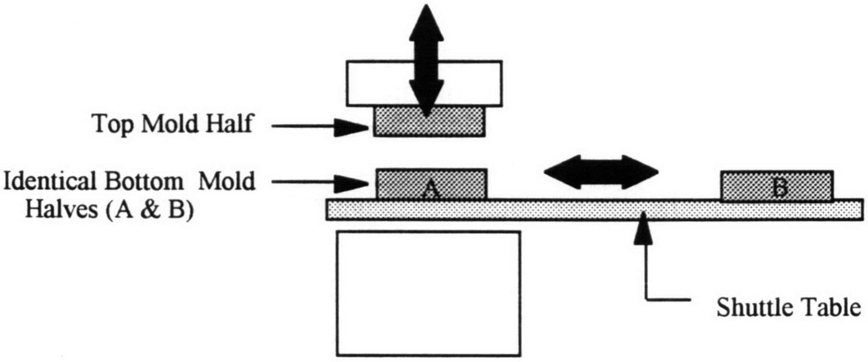
The insert molding process uses the injection molding process; however, several steps are added to accommodate the inserts. Insert molding machines are normally modified from traditional injection molding machines to aid in placing the inserts into the mold. Most insert molding machines fit into one of two categories -- shuttle or rotary table type machines. Both are shown in **Figure 2.4.1**. Neither is considered best, and the decision to use one or the other is generally based a case by case basis.

Identical bottom mold halves are place at points A and B and moved under the mating half every other injection shot.



Rotary Table Machine

Shuttle Table Machine

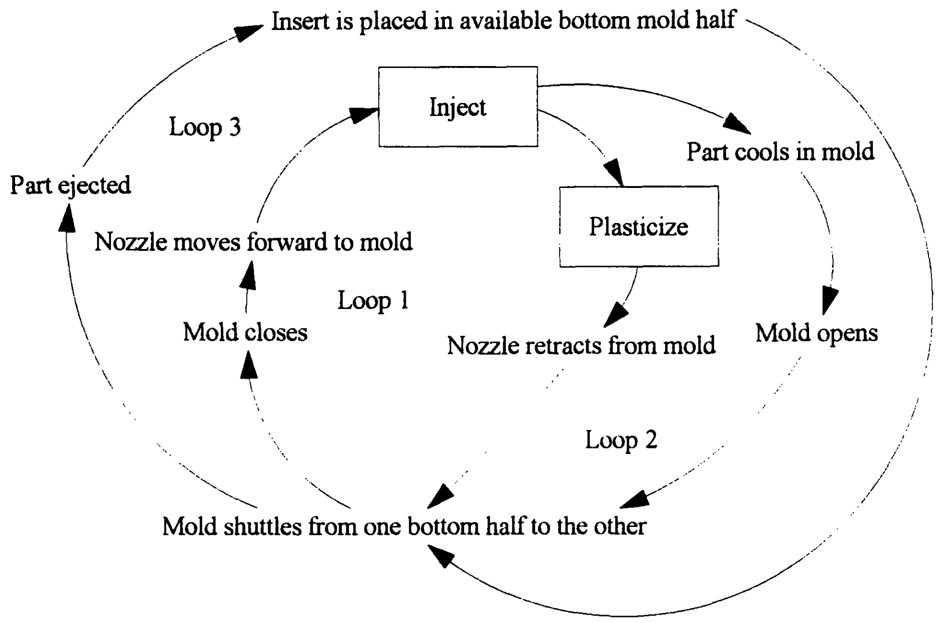


Shuttle Action of Shuttle Table Machine

Figure 2.4.1: Types of Insert Molding Machines

Note the parting line for the mold is horizontal in the **Figure 2.4.1** versus vertical for the traditional machine shown in **Figure 2.2.3**. When the top mold half is in the raised position, the table shuttles from one mold bottom to the other for the next cycle.

As the machines are slightly different, the insert molding process also diverges slightly from the traditional cycle to allow for insert handling. The steps of the general process are summarized below in **Figure 2.2.4**.



Note: The mold can not shuttle until the mold is opened, the nozzle is retracted, and the insert is placed in the mold to be filled with the next shot.

Figure 2.4.2 Insert Molding Process Flow

Insert molding uses the same process control techniques as does standard injection molding. However, the process is much more complex compared to the traditional process flow shown in **Figure 2.2.4** because of the requirement for the placing the inserts inside the mold.

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[1] Weir, Clifford I. (1975). Introduction to Injection Molding. Brookfield, CT: Society of Plastics Engineers. p. 1.

[2] Furholmen, David. "Insert Molding Improvement of Properties and Cost Reduction." *Multiple shot, Insert, and Co-injection Molding -- 1991 SPE Chicago and Milwaukee Regional Technical Conference Notes.* p. 15.

[3] Kirkland, Carl. "Boost part repeatability with insert molding." *Plastics World.* August 1990. p. 34.

[4] Weir, Clifford I., *Introduction to Injection Molding*, (1975) Society of Plastics Engineers, Inc., Brookfield, CT, p. 3.

[5] Rosato, D.V. (1986). *Injection Molding Handbook.* New York. Von Nostrand Reinhold Co. Inc. p. 4.

[6] Rosato, D.V. (1986). *Injection Molding Handbook.* New York. Von Nostrand Reinhold Co. Inc. p. 15.

[7] Rosato, D. V. (1986). *Injection Molding Handbook.* New York. Von Nostrand Reinhold Co. Inc. p. 16-17.

[8] Class notes from MIT Subject 2.830, "Control of Manufacturing Processes," by D.E. Hardt, 1993.

[9] Class notes from MIT Subject 2.830, "Control of Manufacturing Processes," by D.E. Hardt, 1993.

[10] Class notes from MIT Subject 2.830, "Control of Manufacturing Processes," by D.E. Hardt, 1993.

3.1 Introduction

This chapter discusses the product development cycle for circuitry insert molded parts. Four broad issues are presented: 1) industry structure, 2) elements within the development process, 3) the move toward concurrent engineering, and 4) supplier management.

3.2 Industry Structure

This section presents an overview of the different players and their roles in the automotive circuitry insert molding industry. The industry structure is evolving as the automakers continue to transition from mass production to lean production. Mass production is characterized by industry suppliers competing against one another for each job by a bidding process whereas lean production involves a limited number of suppliers working as "partners" in the development process leaving cost as a secondary issue.

3.2.1 Tiers Within the Supply Chain

The typical supply chain in the circuitry insert molding industry is shown in **Figure 1.1.1**. Input Controls is one of the first tier suppliers who interact with the OEM's.

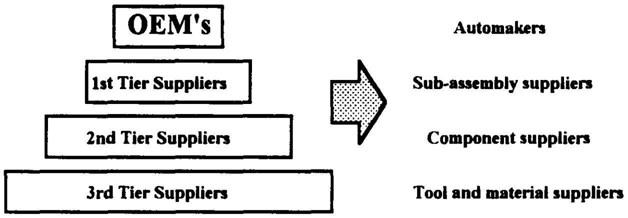

Figure 1.1.1 Typical Circuitry Insert Molding Supply Chain in Auto Industry

3.2.2 Traditional Roles Within the Supply Chain

In the traditional mass production environment, participants in the supply chain believed that the best way to control costs of suppliers further down the supply chain was to identify a group of potential suppliers and offer business to the lowest bidder. While simple in theory, reality is quite different. When suppliers see the drawings, they know from long experience that they are involved in a complex game, where none of the real rules are written into the bid tender.[1]

The suppliers realize that their customer who is the OEM or the supplier higher in the supply chain is under extreme pressure to reduce costs. They also realize that any given job does not represent a one time revenue but rather a flow of revenues over an uncertain window. For example, if an auto sells well to the public, the supplier will be able to produce significant volumes over a long window and be able to drive down production costs over that window. Additionally, the replacement market can also result in significant volume over a decade. In this scenario, suppliers may bid below cost to get the contract in hopes of recovering costs over the long term.

In this type of operating environment, supplier relationships and information flow become very complex. Although suppliers are forced to bid for work, they have little incentive to put in a significant amount of work into a project until they know if they will get the job. This, in turn, makes them reluctant to work with other members of the supply chain in the early stage of projects.

3.2.3 Changing Roles and Future Challenges

OEM's and suppliers are migrating away from the multiple supplier bidding process and are evolving toward alliance type relationships. In these new relationships, each firm reduces the number of suppliers they use and focus on working together as partners to improve the resulting product. For example, today Tech Mold, a mold supplier in Tempe, Arizona, is regularly awarded a contract and asked to participate in product design as a partner whereas a decade ago the customer would have developed the product internally and sent out the part drawing to several mold shops for a bid.[2]

As OEM's and higher tier suppliers begin to reduce their supplier pool, they are evaluating supplier capabilities as a way to narrow down to a few key suppliers. Depending on a firm's internal capabilities, they may look for a variety of skills within any given supplier. For example, Nissan in Smyrna, Tennessee, looks for strong development and engineering capabilities when they select a supplier while AutoAlliance International Inc. in Flat Rock, Michigan, looks for a supplier's ability to keep its process under control.[3] In Nissan's case, they rely heavily on their suppliers to provide support in part development and tool engineering.

Several challenges face the supply chain as participants work to create formal and informal alliances and evolve away from the traditional bidding process. Issues which need to be addressed are communication between tiers; fostering long term relationships through guaranteed work volumes, shared costs, or long term pricing agreements; and establishing roles within the development process.

Although the issues above will be difficult to address, the most challenging issue will be changing the culture of the supply chain participants away from the ideology of the traditional bidding organization. This will mean changing the relationship values from mistrust to trust, concealed information to open information, "cover your bets" to "win-win." Robert J. Grubb, President of DTM Products, Inc., outlines three areas where OEM attitudes must change in the molding industry:[4]

1) OEM's part designers must recognize that the molder's ability to produce quality parts involves legitimate questions at the design stage -- that is, quality isn't just molded in, but rather designed in.

2) OEM's must recognize the complexity of the molding process and think of the molder as a value-added department of its own firm.

3) Molders must be rewarded for their successful efforts in design and production.

3.3 Elements Within the Development Process

This section discusses the major steps within the development process. The development process for circuitry insert molded parts is very complex. Once the bidding and initial prototyping work is complete, and the OEM requests that the part be developed, the supply chain faces three main design tasks in order to develop the part: designing the part, insert, and mold. Each of these steps is in itself very complicated and involves a variety of issues including manufacturability, cost, quality, and time to market. Each step is briefly outlined below.

3.3.1 Part Design

Part design impacts everything in the insert molding process. Once the part design is finalized, the insert design and much of the mold design and process capability are set as well. Therefore, no good part design comes from a designer who hasn't carefully considered the insert and mold design implications. Parts initially designed in a "vacuum" invariably result in design changes later in the process once the proposed design is reviewed by the insert and mold designers.

Much of part design is fixed by the OEM's when they specify the part. They specify the required electrical loading which sets the conductor cross sectional area, the electrical pin-out configuration which sets much of the part and insert geometry, the environmental conditions which determine the materials and insert surface treatment, and potentially many other details.

Although the OEM specifications significantly restrict the part design, the designer still has a great deal of latitude in which to complete the detailed design. For example, the OEM may specify maximum part dimensions but not the overall geometry other than the mate-up surfaces. Therefore, there is a great deal of room for creativity in any design. The supplier who can design a part which addresses insert, mold, and processing concerns will have a competitive advantage over the supplier who can't incorporate these issues into part design.

3.3.2 Insert Design

The insert design is critical from the standpoint that it is an integral part of the production process and of the finished part. The way inserts are handled and processed often depends on their design. For example, a complex insert is often very difficult to package and transport after it is produced at the stamping plant and typically can only be inserted into the mold by hand. On the other hand, if you limit insert complexity with the idea of automating insertion, you often must utilize a number of simple inserts to take the place of a single complex insert. The trade-off is not straight forward.

3.3.3 Mold Design

The mold design determines process capability. A good mold design provides a robust process while a poor mold design results in poor process capability and a narrow or infeasible processing window. The robustness of a mold can be designed in at a cost. Mold suppliers who are competing for work based on cost will consciously cut corners on mold durability and maintainability. Therefore, if a firm wants a durable mold which is easy to maintain, it must specify the desired mold characteristics so as to control durability. Alternatively, it could develop a long term relationship with the mold supplier and communicate what it values in a mold (and be prepared to pay for it).

3.4 The Move to Concurrent Engineering

Concurrent engineering may be viewed as facilitating, managing and improving relationships.[5] The involved parties include the customer, design, manufacturing, marketing, purchasing, participating suppliers, etc. The goal of improving these relationships is to have the parties involved in the development process work together during the entire cycle to develop a better product in less time. The lack of up front representation on the product development team of any pertinent discipline will result in expensive downstream design changes with attendent quality impacts and schedule delays.[6]

The insert molding industry, as well as most industry, is moving toward concurrent engineering. This section discusses several issues involved with the transition of the circuitry insert molding industry to concurrent engineering. The first two sections discuss the goals in more detail, and the last two sections outline what is required to implement concurrent engineering.

3.4.1 Development Time Compression

The traditional insert molding development cycle timeline is shown in **Figure 1.3.1**. A concurrent engineering approach is shown in **Figure 1.3.2**.

Figure 1.3.1 illustrates the separation of tasks found in the traditional development cycle. The cycle proceeds in a step wise fashion as each team completes one step and passes it off to the next team for the next step. The cycle is characterized by recycle loops as each team provides after-the-fact design input for previous steps.

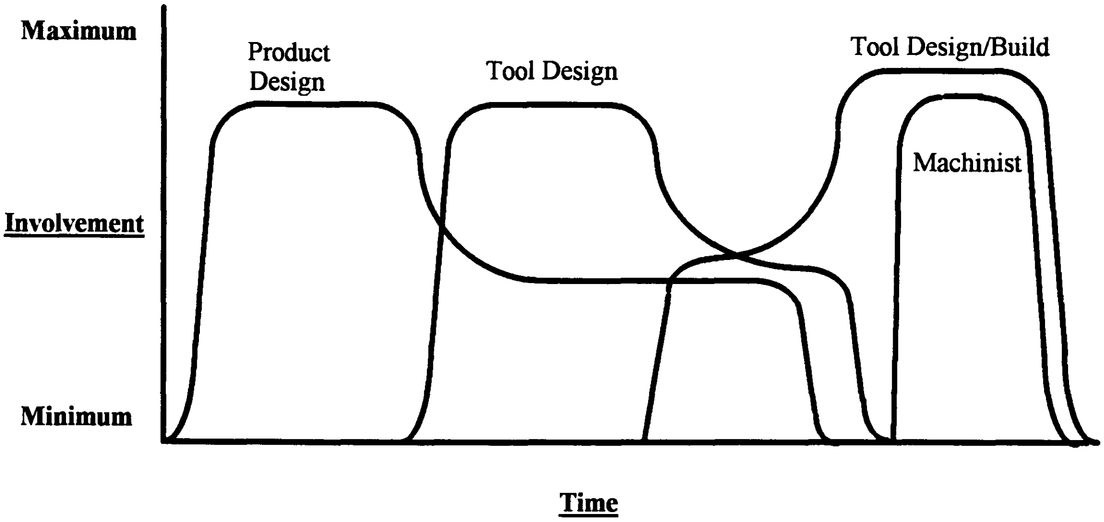

Figure 1.3.1: Traditional Development Cycle

Figure 1.3.2 illustrates the benefits of the concurrent cycle.[7] Team members meet together early in the development cycle to provide design input, thus, reducing recycles. It is important to note that the participants do not have to belong to the same company or organization.

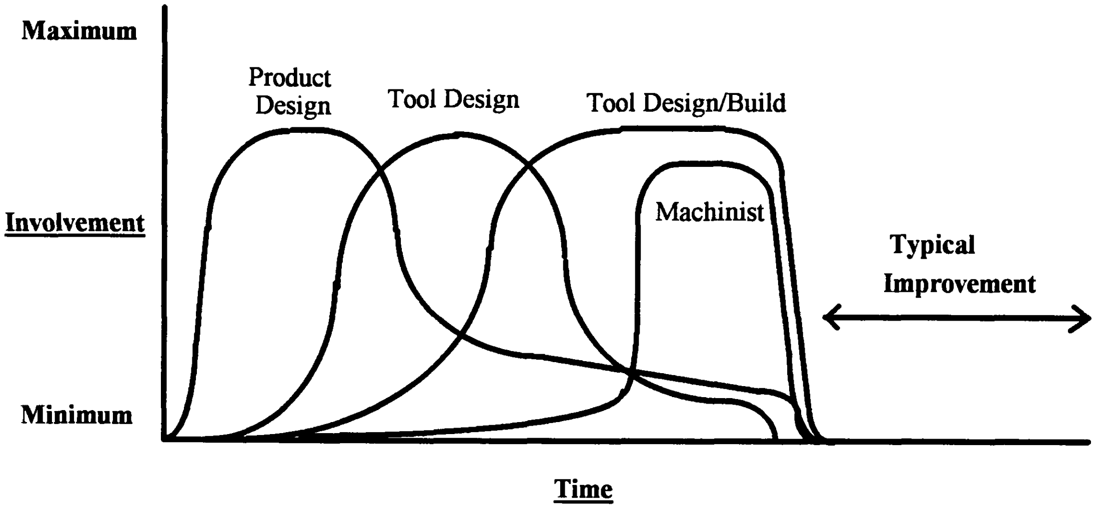

Figure 1.3.2: Concurrent Development Cycle

Note: **This figure was modified from a figure presented on p. 64 of the AT&T Technical Journal, July/August 1992.**

3.4.2 Design for Manufacturability

The early involvement of all the participants on the development team can have dramatic impacts on the manufacturability of the product. For example, based on the mold supplier's input, you may alter the proposed design of an injection molded part in a way that doesn't impact product function but in a manner which makes it easier to fabricate the mold. The result is lower cost and faster time to market. In this way, concurrent engineering can simultaneously improve quality, time to market, and cost.

3.4.3 Equipment Required for Concurrent Engineering

There isn't a single list of equipment that a firm needs to implement concurrent engineering. There is a need for support tools to help facilitate information exchanges among development team members.[8] These tools can be expert computer systems, co-location of team members, regularly scheduled design meetings, design checklists, etc. The tool any given firm chooses should depend on the firm's culture and needs of the team members. At Sikorsky Aircraft, an internal study concluded that design guidelines were needed to help ensure manufacturing and tooling issues were considered during the design process.[9] At a smaller firm, a weekly design team meeting may be adequate.

3.4.4 Implementation of Concurrent Engineering

The evolution from a sequential product development process to concurrent engineering requires major changes in the fabric of an organization. Four vital elements of decentralization into concurrent engineering teams are management behavior, teamwork, individual skills, and business processes.[10]

Management Behavior

Creating new values or different ways of thinking and acting is the most difficult task that any leader can undertake.[11] Unless management creates an environment nurturing concurrent engineering, it will surely fail. Concurrent engineering teams are far more effective in environments where supervisor-subordinate barriers are broken down and replaced with mutual respect and trust.[12]

Teamwork

Concurrent engineering by its name implies a higher level of teamwork. Sequential product development cycles involve people working together in a step-by-step fashion -- when one person is finished with his/her phase, the project is passed on to the next individual. Concurrent engineering, on the other hand, requires people to work side-by-side throughout the process. To be effective, team members must be able to communicate and have a common aim.

Individual Skills

The development team must have the appropriate skills to develop the product.

> *Everyone on the team should have some familiarity with all the design practices. A large portion of the practitioners need strong competence in many design practices. A few people need to possess deep expertise.*[13]

Management's job is to create a team with the appropriate skills through careful selection and training.

Business Processes

It's not important whether you win or lose, but how you play the game. That's a familiar quote, but a quote more applicable to concurrent engineering would be *you won't win unless you worry about how you play the game.* Business process must be continuously improved for each firm. Employees at all levels need to focus on how they do their job and make a conscious effort to change. Managers need to consider how to manage better, designers need to consider how to design better, and everyone must consider how he/she impacts everyone else and how the interaction can be improved. This is not a program, but a culture of empowerment and desire for improvement. Competitive levels of improvement can not be achieved by introducing the next contemporary topic such as decentralization this month, concurrent engineering next month, and something else later.[14]

3.5 Supplier Management

This section outlines the need for progressive supplier management and some of the issues involved with a firm's ability to fully utilize supplier strengths within the development process.

3.5.1 Value of Suppliers

No one knows as much about a business or process than the one who actually runs the business or process. Suppliers can play a key role in the product development cycle if encouraged to participate. Japanese and European firms have been more progressive in this regard and consider it standard practice to involve suppliers early in the development process. This pattern of involvement, and the existence of longer term relationships in Europe, is consistent with the fact that many of the major innovations in the European auto industry have come from suppliers -- e.g. ABS, traction control, turbo-charging, to name a few.[15]

3.5.2 Power of Suppliers

Good suppliers can have leverage over their customers in the fact that they can often choose who they will do business with. Ken Stork, corporate director of materials and purchasing for Motorola Inc., Schaumburg, Ill., warns that firms that hesitate to become good customers "may find that all the good suppliers are already committed to their competition."[16]

3.5.3 Being a Good Customer or Supplier

Although there is a growing recognition in American industry that suppliers can play and integral part in the development process, customer firms and their suppliers need to address internal culture barriers and existing business processes which restrict integration. Clark addresses this issue as follows:[17]

> *But it is important to note that such benefits* [integration in the development process] *are based in a relationship of reciprocity. Not only do suppliers have valuable capability, but the auto firm manages the process so that capability plays an important role. Moreover, the auto firms cultivate capability in their suppliers. This involves investment, sharing of knowledge, providing space and facilities for "guest engineers,' and helping suppliers to solve problems. On the supplier's side, there is a commitment to build capability and a willingness to assume a critical role in the development process. Further, among the better suppliers there is a focus on service that results in supplier engineers searching for ways to find and meet the needs of the customer's design and the development process. in effect, the better suppliers look for opportunities to create value for their customers. This is far different than simply meeting specified requirements with minimum effort.*

To achieve Clark's paradigm, both customer firms and suppliers will have to see the advantages of closer long term relationships and be willing to work through difficult cultural issues.

Several issues are key in creating a good customer/supplier relationship. A customer firm can tell if it is being a good customers if it is doing the following:[18]

1) Understands that partnership is a two way street.
2) Is proactive -- and committed to helping suppliers improve dramatically.
3) Uses supplier rating systems that are consistent.
4) Rewards the best suppliers.
5) Uses benchmarking to set goals for suppliers.
6) Listens to suppliers -- and is willing to take corrective action.
7) Encourages early supplier Involvement in product development.

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[1] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), p. 141.

[2] John deGaspari, " Building Higher Value Into Injection Molds," Plastics Technology, April 1993, p. 61.

[3] Michael C. Gabriele, "What It Takes To Serve the Automotive 'Transnationals'," Plastics Technology, September 1992, p. 87.

[4] Robert J. Grubb, "How to Achieve World-Class Quality," Plastics Technology, July 1993, p. 73.

[5] George Trapp, "Workshop on Concurrent Engineering," Conference Proceedings, 13th Annual Converence and Exposition -- National Computer Graphics Association, March 1992, p. 766.

[6] H. Barry Bebb, "How to Implement Concurrent Engineering," ASME 1993 DE-Vol. 52, p. 9.

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[7] Bernie D. Tull, Jr., "Quality and Productivity in Injection Mold Tool Construction: A View From Manufacturing," AT&T Technical Journal, July/August 1992, p. 64.

[8] Elsayed A. Orady, Iqbal Shareef, "Expert System Design Philosophy for Application of Simultaneous Engineering in Industry," Design for Manufacturability, ASME 1993 DE-Vol. 52, p. 151.

[9] David E. Larson, Anthony F. Luscher, Jacob C. Korngold, Warren R. DeVries, " Design of Composite Rotorcraft Transmission Housings for Resin Transfer Molding," Design for Manufacturability, ASME 1993 DE-Vol. 52, p. 21.

[10] H. Barry Bebb, "How to Implement Concurrent Engineering," ASME 1993 DE-Vol. 52, p. 9.

[11] Keith H. Hammond, "Why Big Companies are so Tought to Change," Business Week, June 17, 1991, p. 28.

[12] H. Barry Bebb, "How to Implement Concurrent Engineering," ASME 1993 DE-Vol. 52, p. 10.

[13] H. Barry Bebb, "How to Implement Concurrent Engineering," ASME 1993 DE-Vol. 52, p. 10.

[14] H. Barry Bebb, "How to Implement Concurrent Engineering," ASME 1993 DE-Vol. 52, p. 12.

[15] Kim B. Clark, "Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development," Management Science, Vol. 35, No. 10, October 1989, p. 1252.

[16] John H. Sheridan, "Are You a Bad Customer?" Industry Week, August 19, 1991, p. 27.

[17] Kim B. Clark, "Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development," Management Science, Vol. 35, No. 10, October 1989, p. 1261.

[18] John H. Sheridan, "Are You a Bad Customer?" Industry Week, August 19, 1991, p. 27.

4.1 Introduction

This chapter outlines the process of benchmarking, the methods used in this study, the results of the study, and lessons learned about the benchmarking process. **Sections 4.2 - 4.5** are part of a company report previously issued to UTA (company names and proprietary numbers have been disguised). **Section 4.6** discusses lessons learned during the study about how to effectively benchmark competitors and suppliers.

4.2 Summary of Study

This report summarizes the benchmarking work and results of the joint project between UTRC, MIT's Leaders For Manufacturing Program, and Input Controls completed in 1993 for the Product and Manufacturing Engineering Groups on the subject of insert molding. The project had two goals: 1) to determine how Input Controls could work better with its suppliers and 2) to compare Input Controls to its competitors in order to create an impetus for change.

4.2.1 Background

Circuitry insert molding is a process where plastic is molded around a metal stamping to form part or all of an electrical circuit. These components comprise the majority of switches used in the instrument panel of cars. Input Controls', a first tier supplier to the auto makers, is striving to improve its ability to design and develop circuitry insert molded parts both internally and through second tier suppliers. Input Controls believes insert molding is one of the key growth areas in their industry. Their business challenge is to improve their competitive position in terms of time to market or speed, cost, and quality.

Circuitry insert molding is based on injection molding. However, it also involves other technologies like stamping design, human factors engineering, robotics, and circuit design. Although design is typically completed by the first tier suppliers in the industry, a large percentage of the production is done through second tier suppliers, and typically the molds and the inserts are provided by third tier suppliers. Executing as a team across all three tiers and combining all the technologies into an efficient development cycle that results in a quality part is a challenging endeavor.

4.2.2 Purpose of the Benchmarking Study

Competitive benchmarking is the process of measuring a company's products and services against those of its toughest competitors. It was chosen as the methodological approach for this project for two reasons. First, it would help identify the industry best practices, so they could be implemented at Input Controls. Second, it would help evaluate the company's current practices versus the best practices found and, thus, create an impetus for change toward those practices.

Armed with this information, Input Controls, can formulate short and long term strategies for their insert molding operations. In the short term, the challenge will be to address how they can work more effectively with their suppliers. In the long term, Input Controls can use the information to help implement a strategy appropriate to meet future business challenges.

4.2.3 Benchmarking Methodology

Given the structure of the circuitry insert molding industry and the working relationships between the first, second, and third tier suppliers, the project team decided to complete separate benchmarking studies for each tier. By benchmarking within the individual tiers, we were able to understand how each tier viewed the same issues from different perspectives. For example, we could look at whether second tier suppliers wanted to participate in part design and compare it to how the first tier suppliers felt about second tier participation in part design.

4.2.4 Results

Most of Input Controls direct competitors appear to have more mold design expertise than Input Controls which equates to being able to design a more manufacturable part by understanding the part design's impact on the mold. Input Controls has very little mold design expertise and no capability to build molds. The first tier competitors who responded in the survey had both mold design and construction capability. Additionally, there were two second tier suppliers who did a significant amount of part design. Both designed and fabricated most of their own molds. All of the second tier suppliers had mold design capability.

Input Controls direct competitors appear to design most of their parts in-house rather than farming the work out to suppliers as does Input Controls for about a third of their parts. Most of the second tier suppliers do not design a significant amount of the parts they produce suggesting they aren't set up to for part design work. Only two out of ten second tier suppliers design more than 20 percent of the parts they produce.

Suppliers, above all, want three things. First, they want to participate in part design whether it's done under their own roof or Input Controls'. Second, suppliers want to have direct contact with engineers rather than purchasing. Finally, Suppliers want a quick response to questions and proposals. Second and third tier suppliers will likely always play a critical role in Input Controls' business. As such, it makes sense for Input Controls to improve its working relationship with its suppliers. Most suppliers thought Input Controls was better than the average competitor at meeting their needs, but they felt Input Controls was worse than their best customers in this regard.

Electronic data interchange (EDI) between suppliers faces two hurdles. The first is a compatibility issue -- is the right data transferred to the receiving end? Second, is the quality of the data satisfactory to start with (i.e. does the three dimensional object have any geometry errors)? On average, the mold suppliers get about half their part design data on disk, and only about half of that is of high enough quality to use (25 percent of all designs). Having the discipline on the design end to create an accurate three dimensional object is vital to capture time and quality improvements through EDI.

"Presourcing" suppliers is an excellent way to leverage their strengths and to get their input in design. Most second tier suppliers presource a large percentage of their molds and inserts. They tend to presource molds so as to get onto the mold supplier's schedule and to presource stampings to get them to participate on the development team. This is likely due to the fact that most second tier suppliers have internal mold design expertise but little internal stamping expertise.

4.2.5 Recommendations for Improving Input Controls Development Process

The recommendations for the project primarily focus on reducing development time as it is more easily measured and can drive other goals such as improving quality and reducing cost. The final recommendations are outlined in detail in **Section 4.5.3** and are summarized below:

1) Supplier capabilities should be evaluated for strategic fit within Input Controls. Input Controls should respond to suppliers based on their fit -- work with supplier to change, find a new supplier, or reward the supplier to solidify the relationship.

2) Second tier suppliers should be aligned with specific teams within Input Controls. For example, one Input Controls group might work with suppliers A, B, and C while another works with D, E, and F. This will reduce the number of required relationships and streamline communication.

3) Mold design expertise should be purposefully included on each product design team early in the project. This can be accomplished through hiring someone internally to participate on the design teams, capturing the expertise of a presourced second tier supplier, or presourcing the molds and including the mold designer on the team.

4) Performance measures or metrics should be developed to monitor improvement efforts. Time is the most important issue and can be directly and indirectly measured.

5) Purchasing-engineering teams should be established so there is only one purchasing agent who works with any given engineering group and its supplier pool. This will help build long term relationships and streamline communication.

6) Mold and stamping suppliers should be presourced for projects to be designed internally and produced at Taylor. This will help capture the suppliers' expertise in the part design.

7) Quality standards for EDI drawings should be implemented to ensure accurate geometry and dimensions before the design is released to the supplier. This will help capture time and quality improvements by reducing human translation work.

8) A formal procedure to capture lessons learned for each project should be developed. The evaluation should include customer feedback, supplier feedback, and internal scrutiny.

9) Pre-production prototyping should be done in hardened steel. If possible, the prototype work should be done by the shop who will make the production tool.

10) Input Controls should invest in rugged mold design and maintainability.

4.3 Background of Benchmarking Study

This section outlines the background of the benchmarking work at Input Controls.

4.3.1 Circuitry Insert Molding at Input Controls

The Role of Circuitry Insert Molding at UTA Input Controls

Circuitry insert molding is a process where plastic is molded around a metal stamping to form part or all of an electrical circuit. The plastic provides structural support and acts as an insulator around the conductive stamping. Some of the advantages over competing process like riveting, ultrasonic insertion, and staking terminals include improved reliability, circuit size reduction, and dimensional precision of electrical pin-outs.

Input Controls, a first tier supplier to the auto makers, is striving to improve its ability to design and develop circuitry insert molding parts both internally and through second tier suppliers. They believe insert molding is one of the growth areas of their industry and, consequently, want to develop the core competencies required to be competitive.

Circuitry Insert Molding Challenges

Circuitry insert molding can be more of an art than a science. As the process is based on injection molding, it utilizes its core technologies -- part design, mold design, and processing. However, it also involves other technologies like stamping design, human factors engineering, robotics, and circuit design. Combining these technologies into an efficient development cycle that results in a quality part is a challenging endeavor. Companies who produce circuitry insert molded parts usually develop expertise internally as there is little outside information available. The industry leaders are primarily second tier suppliers who concentrate on insert molding.

Input Controls faces many hurdles in expanding its internal circuitry insert molding production since there is little information outside of second tier supplier expertise to aid in the effort. Growing internal expertise is paramount but finding additional third tier suppliers for molds and stampings is also critical. Third tier suppliers can play invaluable roles on the design team for circuitry insert molded parts as they develop and apply their own expertise in this field. Consequently, it is important to find third tier suppliers experienced in circuitry insert molding.

Future Input Controls Business Challenges

Time, cost, and quality have all been drivers in the automotive supplier business in recent years. However, as the automakers move to more frequent product releases and smaller production runs, time compression in the development cycle is becoming more important. This will probably be the most important issue in over the next few years and will force the automakers and their suppliers to work together to improve performance.

4.3.2 Development Cycle and Role of Suppliers

Development Cycle for Insert Molded Components

The traditional insert molding development cycle timeline is shown in **Figure 4.3.1**. A concurrent engineering approach is shown in **Figure 4.3.2**. Input Controls is moving toward a concurrent approach through several efforts in order to shorten development time. Input Controls current development cycle ranges from 12 - 30 months from bid proposal to production.

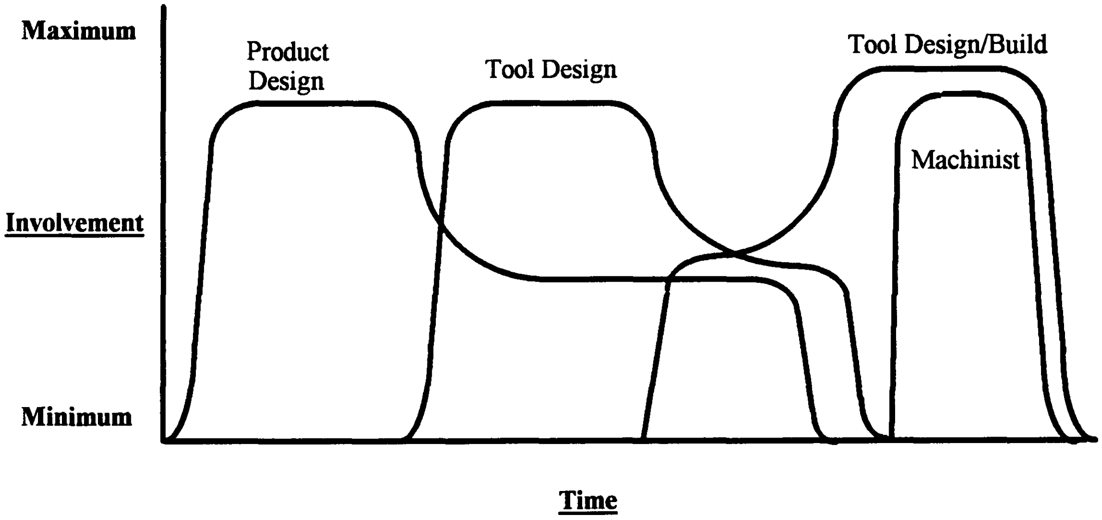


Figure 4.3.1

Figure 4.3.1 illustrates the separation of tasks found in the traditional development cycle. The cycle proceeds in a step wise fashion as each team completes one step and passes it off to the next team for the next step. The cycle is characterized by recycle loops as each team provides after-the-fact design input for previous steps.

Figure 4.3.2 illustrates the benefits of the concurrent cycle. Team members meet together early in the development cycle to provide design input, thus, reducing recycles. It is important to note that the participants do not have to belong to the same company or organization.

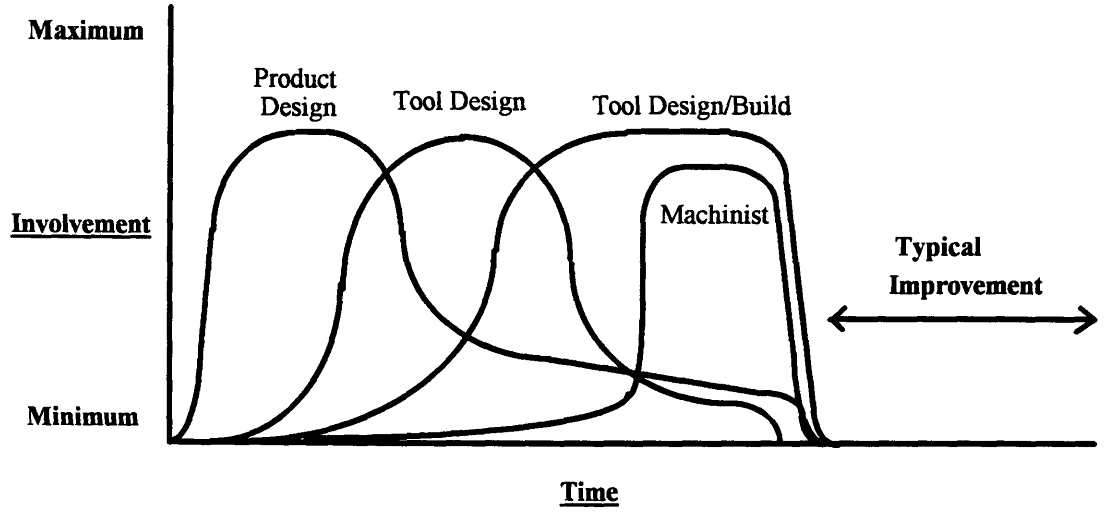


Figure 4.3.2: Concurrent Development Cycle

Role of Suppliers Within the Development Cycle

Although the general steps within the development cycle are similar for all first tier suppliers, the role of second and third tier suppliers within each step varies widely. Input Controls currently utilizes second and third tier suppliers in the four scenarios shown in **Figure 4.3.3**.

Whereas Input Controls uses four scenarios, most of its competitors only use two. The most widely used is the Detailed Design scenario (see **Figure 4.3.3**) where the first tier supplier fully designs the part internally and farms out the tool development and production to a second tier supplier. The other, less common route is the Internal Job scenario where the first tier suppliers do all the development and production work internally except for the tool design and build.

The fact that Input Controls uses the four scenarios distinguishes it and could possibly provide an advantage. However, it also challenges the Input Controls organization because it greatly adds to the complexity of the development process. Project teams need to be able to work with suppliers using each approach. Additionally, supplier selection becomes more important as the suppliers may not be equally capable to work in all four scenarios.

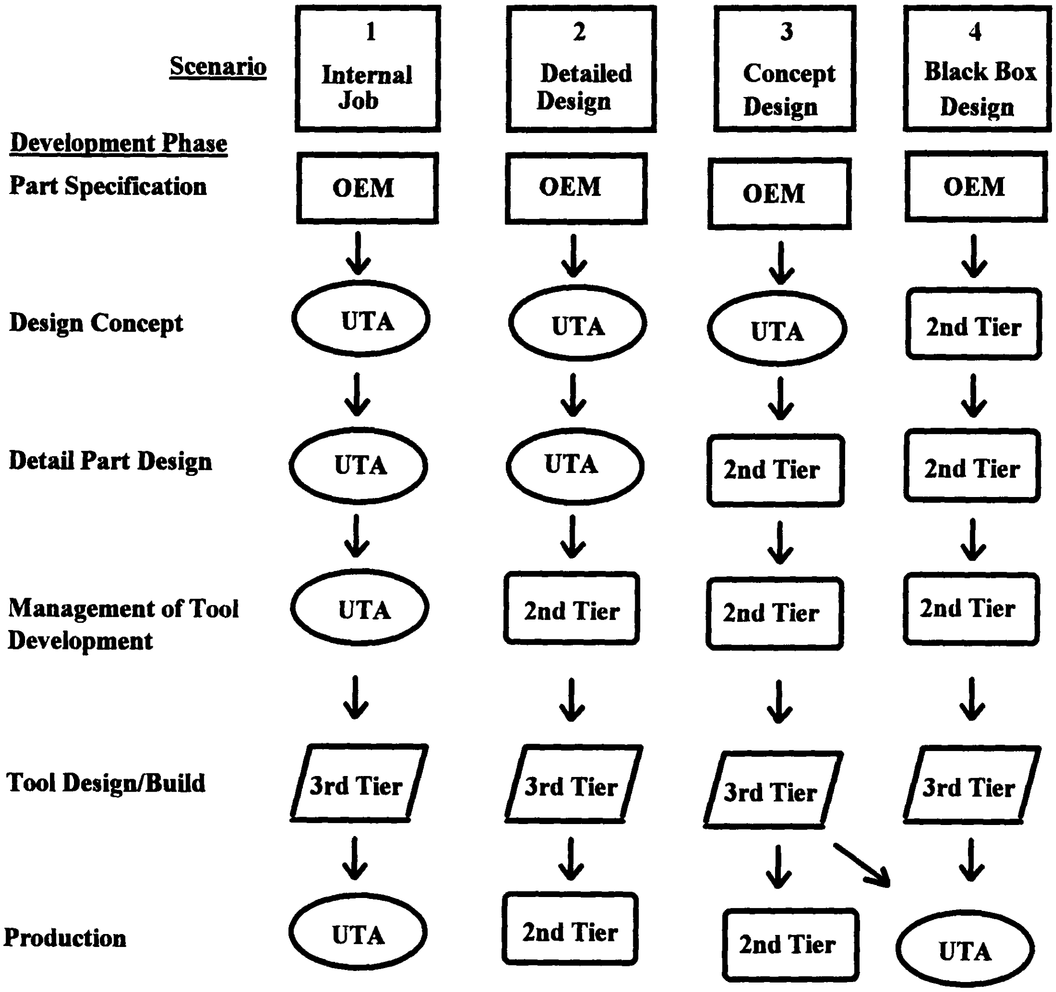


Figure 4.3.3 Input Controls Utilization of 2nd and 3rd Tier Suppliers for Design and Production of Insert Molded Components

4.3.3 Benchmarking Study

This section summarizes the benchmarking study completed with first, second, and third tier suppliers of circuitry insert molded parts.

What is Benchmarking?

A Chinese proverb says, "if we don't change our direction, we might end up where we're headed." Benchmarking is a direction-setting exercise, and it is nothing more than a quality tool, just one of many ways to improve and become more productive ("A Bible for Benchmarking, by Xerox," Financial Executive, July/August 1993).

Xerox's formal definition of benchmarking is the continuous process of measuring our products, services and practices against those of our toughest competitors or companies renowned as leaders. This can be accomplished in a number of ways but normally includes industry analysis, company surveys, and site visits. Benchmarking is effective for two reasons. First, the industry best practices are identified. Second, a company's self evaluation of its current practices versus the best practices identified creates an impetus for change toward those practices.

Purpose of Benchmarking Study

The primary purpose of the benchmarking study was to help us understand the effectiveness of each of the scenarios shown in **Figure 4.3.3**. Specifically, we wanted to determine: 1) when one scenario might be more effective than the others, 2) what can be done to improve the effectiveness of each scenario, and 3) how UTA Input Controls compares to its competitors in terms of in-house capabilities and leveraging second and third tier suppliers.

Armed with this information, Input Controls can formulate short and long term strategies for their insert molding operations. In the short term, the challenge will be to address how they can work more effectively within each scenario. In the long term they will need to move toward a strategy appropriate for their future business challenges, specifically: bringing more parts in-house, shortening the overall development cycle, and developing in-house circuitry insert molding expertise. While formulating the strategies may be straight forward, implementation is likely to be difficult given the size of the organization and the inertia of existing relationships.

Benchmarking Methodology

Given the structure of the circuitry insert molding industry and the working relationships between the first, second, and third tier suppliers, we decided to complete separate benchmarking studies for each tier. By benchmarking within the individual tiers, we were able to understand work practices from a "customer" viewpoint for each task. We were also able to compare relative importance for the same items across different tiers. For example, third tier suppliers may think CAD electronic data interchange (EDI) is critical whereas first tier suppliers may not care at all.

Of the three tiers, we spent more time and effort on the second tier suppliers because they have the most expertise in circuitry insert molding. Our hope was that we could extract some of their best practices for Input Control's internal design work. Also, the second tier suppliers currently provide the majority of the Input Controls circuitry insert molded parts, so it is very worthwhile working to improve the process. In the short term, improving the working process with the second tier suppliers is vital.

4.4 Results of Benchmarking Study

The results are presented in three stand alone sections for the second, first, and third tier supplier benchmarking studies. Each section begins with the background behind each study and ends with conclusions. The conclusions from the combined effort of all three studies is in **Section 3.5**.

4.4.1 First Tier Competitor Results

Background

The goal of the first tier benchmarking study was to determine how our first tier competitors leveraged second tier suppliers in the development process. Our hope that we could learn from the comparison of their practices to Input Controls.

Unfortunately, only four companies including Input Controls participated in the study. One participant, Company A, gets its primary customers from the electronics, telecommunication, and computer industries. The other participants primarily serve automotive OEM's. Although the sample size was very small for the study, several interesting results did surface. These results are summarized below.

Results

The numerical summary of the results below are included in the Appendix. The plots below were generated from the data in the Appendix.

Insert Molding Usage and Production

The relative volume of insert molded parts varies between the suppliers as is shown in **Figure 4.4.1** below. Company C insert molds almost 80 percent of its parts. The other three insert mold 5, 12, and 10 percent of their volumes. The level of in-house production also varies between companies for circuitry insert molded parts. Company C, produces approximately 98 percent of its insert molded parts in-house. This sharply contrasts the 0, 10, and 10 percent in-house production rates for the other three firms.

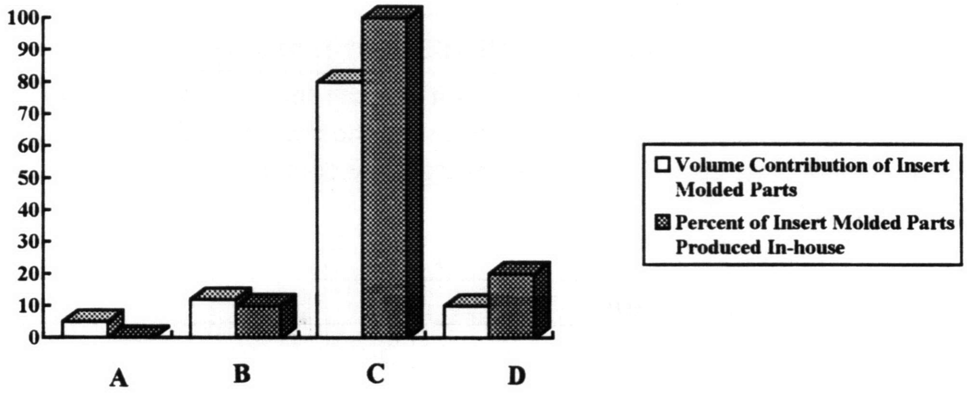


Figure 4.4.1: Insert Molding Usage and In-house Production

In-house Design

Three out of the four firms design all their parts in-house while the other, Company D, only does approximately 50 percent of its part design internally as is shown in **Figure 4.4.2**.

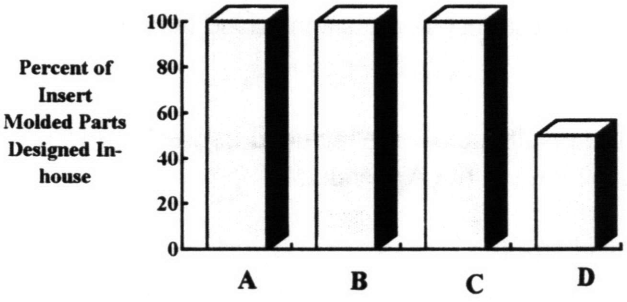


Figure 4.4.2 Percent of Insert Molded Parts Designed In-house

Companies A and C design and build some of their molds in-house. Company D doesn't build any in-house. Company B did not respond the this question (see **Figure 4.4.3**).

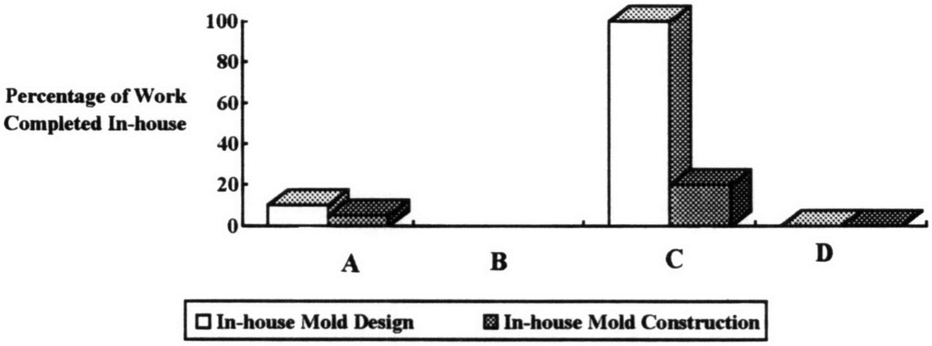


Figure 4.4.3: In-house Mold Design and Build Work

Characteristics of Best Second Tier Suppliers (From First Tier Perspective)
When asked what characteristics they most valued in their second tier suppliers, three participants placed the highest priority on mold design as is shown below in **Table 4.4.1**. The other firm, company D, also values mold design; however, part design also ranked very highly as second tier suppliers do much of their part design.

Table 3.2.2: Most Valued Attributes of Second Tier Suppliers**

	A	B	C*	D
Attribute 1	Mold Design	Mold Design	n/a	Part Design
Attribute 2	Timely Changes	Timely Changes	n/a	Mold Design

* Company C doesn't utilize second tier suppliers for its insert molded part design or production.
** There were 10 attributes to choose from on the survey.

Conclusions
The small sample size of the study prevents us from making any firm conclusions. However, two trends did surface and should be noted.

1) Three out of four of the first tier competitors who responded to the survey fully design all of their parts in-house rather than farming the work out to second tier suppliers. Firm D is the only company who uses second tier suppliers to design parts. It is important to note that this does not mean that firms A, B, and C design their parts in a vacuum and then forward the design to the suppliers. Several of the first tier suppliers and second tier suppliers noted that involving suppliers in the design work up front can make internal designs easier to manufacture for the suppliers.

2) Two of the first tier competitors who responded to the survey have more internal mold design expertise than firm D. Firm D doesn't design any of its molds while two out of three of the firms who responded in the survey did (one did not respond either way). This conclusion assumes that experience correlates with expertise.

4.4.2 Second Tier Supplier Results

Background -- Second Tier Supplier Study

There were two underlying goals for the second tier benchmarking study. First, since Input Controls competes with second tier suppliers through its internal design and production, we wanted to learn as much as possible about the best practices of the second tier benchmarking partners, so they could be incorporated into Input Controls where applicable. Second, as the second tier suppliers currently and will likely always provide a significant percentage of Input Control's insert molded parts, we wanted to learn how we could improve our working relationship with the second tier suppliers so as to produce parts more effectively as a team.

Eleven companies (including Input Controls) participated in the study. The study was completed through two surveys -- an initial all encompassing survey to provide a broad spectrum of information and a follow-up survey to probe areas of interest identified in the first survey. The results are summarized below.

Results -- Second Tier Supplier Study

The results of the second tier benchmarking study are summarized under individual headings below.

Customer Information

As expected, the primary customers for the second tier suppliers are first tier suppliers like Input Controls. However, a number of them also provide components directly to OEM's (up to 50 percent of production in one case). The typical second tier supplier has 30-60 customers, but most get at least 50 percent of their work from their top three customers. Automotive suppliers make up the largest percentage of each company's largest customers as is shown below in **Figure 4.4.5**.

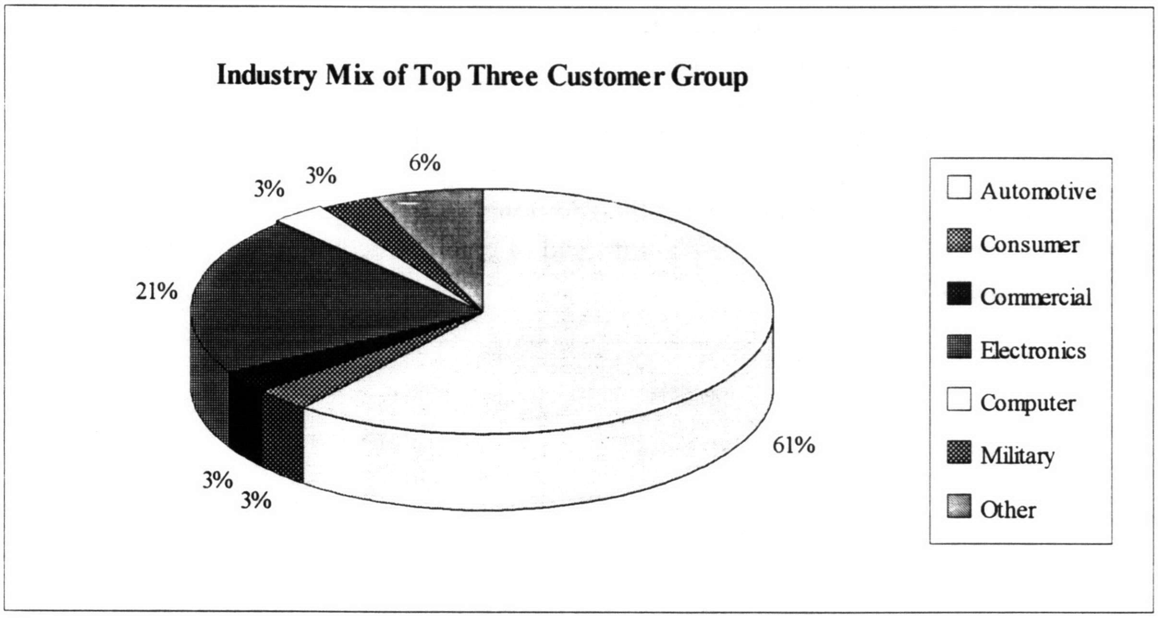


Figure 4.4.5

Second Tier Supplier Capacity Information

All but one of the companies have only one molding plant. The exception has two. On average, each company has just over 30 injection molding machines. The largest has 62 and the smallest has only 5 (Note this is the total number of machines and includes standard production machines as well as insert molding machines). The average standard machine size is 90 tons with the largest being a 400 ton machine. The average insert molding machine size is 75 tons with the largest and smallest being 350 tons and 24 tons respectively.

Insert Molding Usage

The percentage of total production dedicated to insert molding varies widely between companies as shown in **Figure 4.4.6**. Four of the eleven companies have over 80 percent of their total production dedicated to insert molding. Rigid circuitry stampings make up over 75 percent of the inserts used by the companies as is shown in **Figure 4.4.7**. The relative low volume of insert molded components can have subtle effects such as in costing the products. In a traditional accounting system, for example, the regular parts would subsidize the insert molded parts if a constant overhead rate was used because the insert molded parts actually incur higher maintenance costs than regular parts. The subsidy would occur if the additional maintenance is buried in the overhead and spread across the entire plant instead of being directly charged to the insert molded parts.

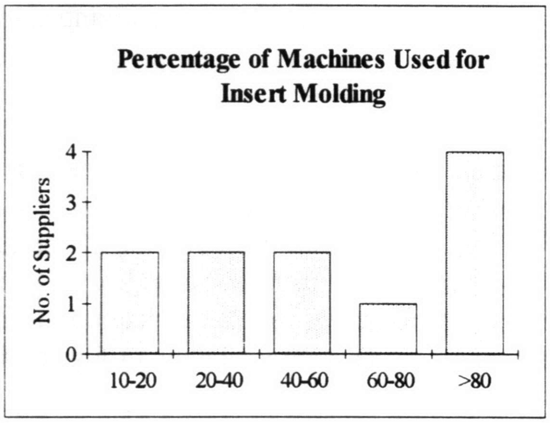


Figure 4.4.6

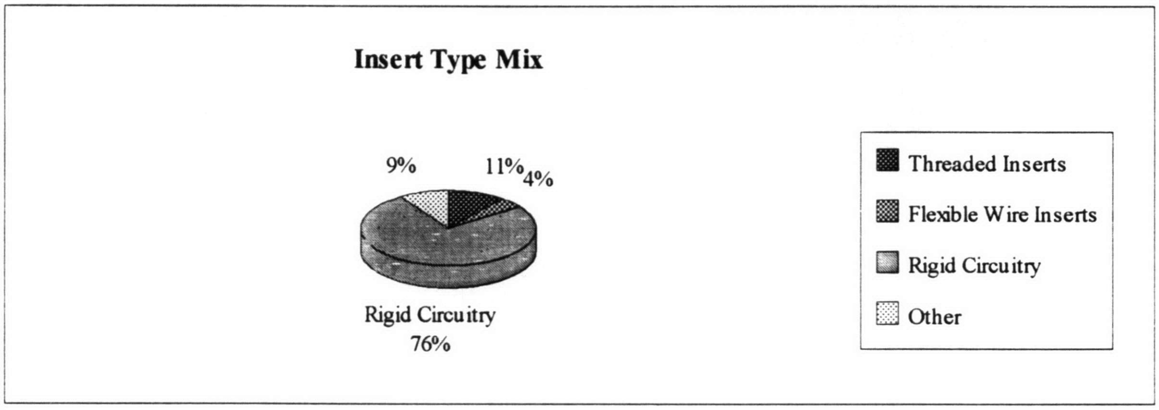


Figure 4.4.7

Justification for Insert Molding

Excluding the customers specifying insert molding, the most common reason given by suppliers for choosing insert molding was improved reliability over alternatives like staking, riveting, ultrasonic insertion, and other competing processes. The next highest ranking advantages included consistency of insert placement and lower cost.

Material Selection

Excluding the customers specifying material, the most common criteria for selecting material other than performance is designer familiarity. The relative usage of different materials is shown in **Figure 4.4.8**.

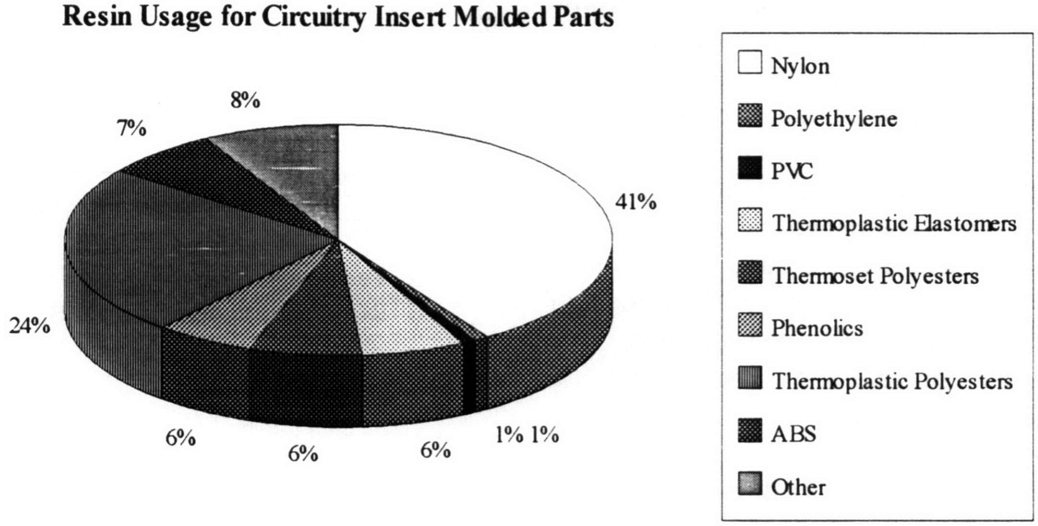


Figure 4.4.8

Percentages in plot: Nylon (41%); Thermoplastic Polyesters (24%); Polyethylene (1%); PVC (1%); ABS (7%); Other (8%); Phenolics (6%); Thermoset Polyesters (6%); Thermoplastic Elastomers (6%)

Use of the Premold Technique

Usage of the premold/overmold technique (one component of the part is insert molded and then used as an insert in another molding operation to make a complex part) varies widely. One supplier didn't use it at all while another used it on over 30 percent of its production. The average is approximately 15 percent of total circuitry insert molding production. The most common reasons given for choosing a premolding design were insert complexity and part geometry.

Insert Design and Processing

Copper and brass alloys make up 75 percent of all circuitry inserts. Approximately 50 percent of all inserts are plated prior to be used in the process. Relatively few of the inserts are placed in the molds via automation. On average, about 4 percent of all parts use automated insert placement. Of those, almost 50 percent are fed to the robots with a strip feeder -- some directly from the upstream stamping operation.

Processing Strategy

The use of secondary blanking and forming operations varies significantly as is shown in **Figure 4.4.9**. Approximately 35 percent of all parts produced involve a blanking operation, and 15 percent involve a forming operation. Although it's impossible to form conclusions without seeing the parts involved, the data does suggest that there are two schools of thought in regard to blanking. Three companies use it over 75 percent of the time suggesting they use more complex stampings and separate the circuit contacts after molding. In contrast, five companies use it less than 25 percent of the time suggesting that they use more individual stampings and do not require blanking after molding.

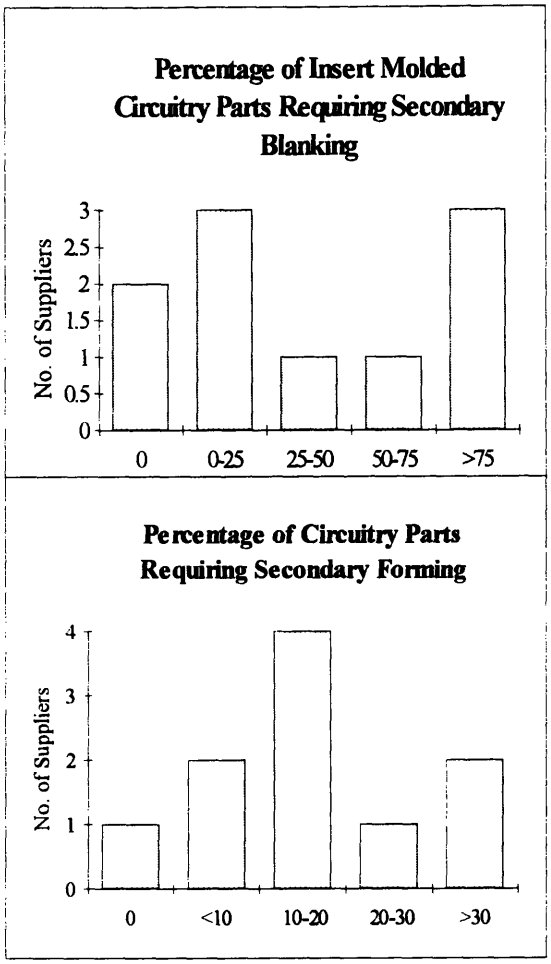


Figure 4.4.9

The data also suggests that the suppliers do not view process control as a barrier to using multicavity molds. Suppliers were asked the question, "Given a production requirement exceeding the capacity of a single machine with a single cavity mold, would you choose to produce using single cavities on multiple machines or multiple cavities on single machines?" As shown in **Figure 4.4.10**, 80 percent of the companies chose the multiple cavity/single machine scenario suggesting that cost is a bigger concern than process control (process control is enhanced with single cavity configurations). Accordingly, Input Controls should specify single cavitation up front unless it wants to get multicavity molds.

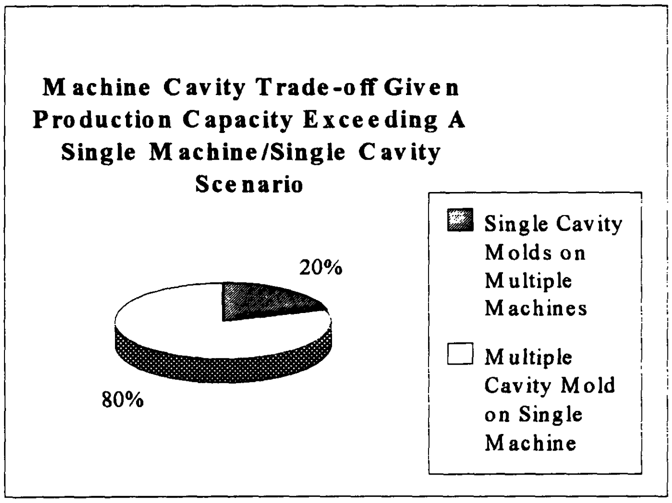


Figure 4.4.10

The Design Process

Considering part design as a whole for all the suppliers, 25 percent is done in-house by the supplier, 58 percent is done by the customer, and 17 percent is done by outside designers. **Figure 4.4.11** shows the breakdown of how much internal design work each supplier typically provides in any given year. Six out of ten provide minimal design services designing 10 percent or less of all the parts they produce. Two design between 20 and 25 percent of their parts. Two design more than 75 percent of their parts. Equating experience with expertise would suggest that the two who design more than 75 percent of their parts have more part design expertise than the suppliers who design 25 percent or less of their parts.

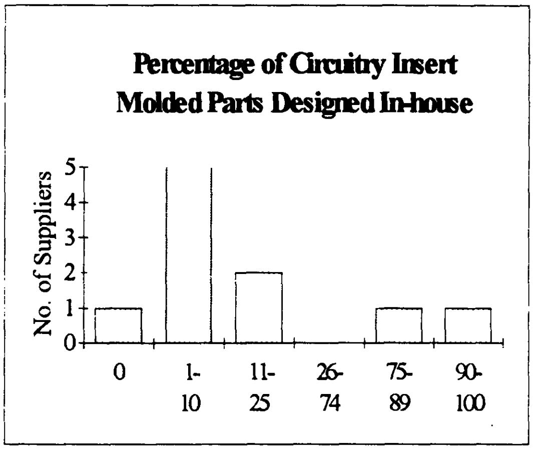


Figure 4.4.11

Customer Design Relationship

We asked the suppliers what level of customer design they normally received and what level was most effective in their organization. There were three choices: 1) full design -- everything fully specified by the customer, 2) concept design -- concept specified but details left to the design team, and 3) black box specification -- no detail specified other than minimal requirement specifications.

Over 60 percent of the designs received were fully designed by the customers. However, as shown in **Figure 4.4.12**, the suppliers rated the concept design as the most effective methodology. The data doesn't provide any clear conclusions, but it does suggest that their is a gap between what the suppliers would like to receive in terms of design information and input and what they actually do receive. Fifty percent of the suppliers did not get their first choice design level as a norm (i.e. a supplier may like full designs best but may get concept designs more often than not).

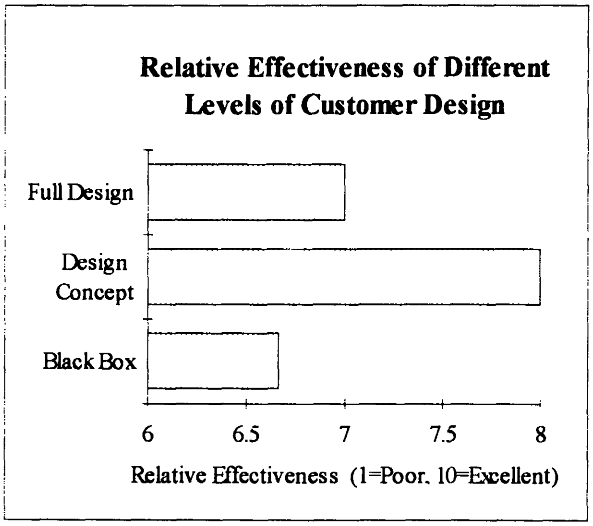


Figure 4.4.12

Design Data Transmission

Over 75 percent of full designs and 90 percent of design changes are still transferred from the customer to the supplier using traditional drawings, sketches, and specifications. The remainder is transferred with CAD electronic data exchange. However, only about half of this data is fully compatible with the suppliers' CAD systems.

Change orders are often a source of conflict between the customer and supplier. **Figure 4.4.13** below prioritizes areas the suppliers would like their customers to address for change orders. Direct contact with engineers rather than purchasing or project management has the most room for improvement. Note that one supplier wanted changes via EDI while another did not in **Figure 4.4.13**.

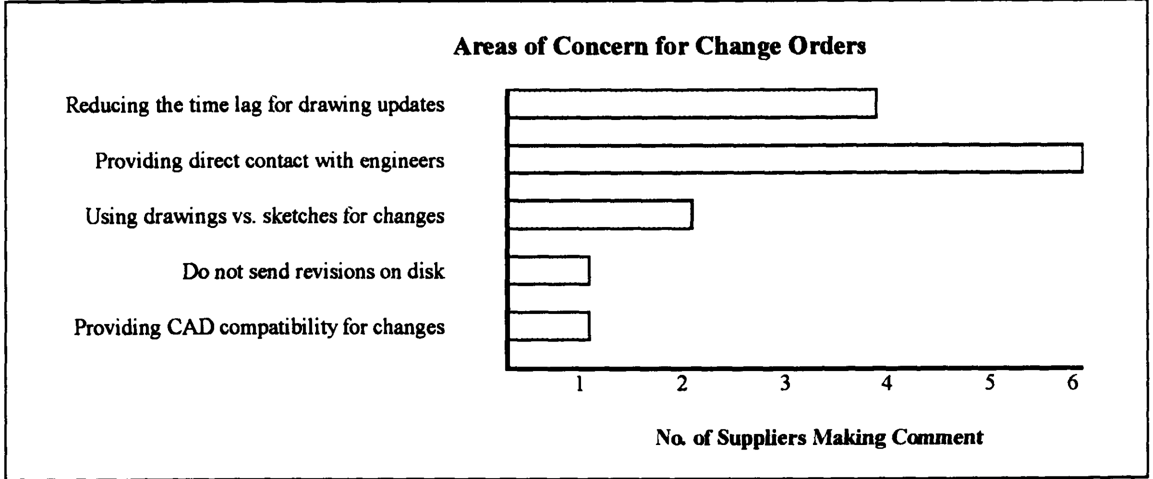


Figure 4.4.13

Attributes of Best and Worst Customers

The average attributes of the best and worst customers are shown below in **Figures 4.4.14** and **4.4.15**. The most important attributes are: 1) actively participating

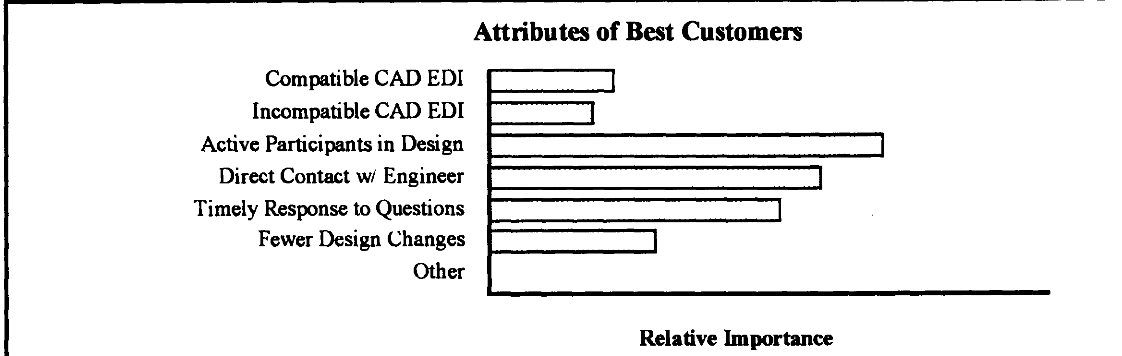


Figure 4.4.14

in design, 2) providing direct contact with engineers, and 3) responding timely to questions.

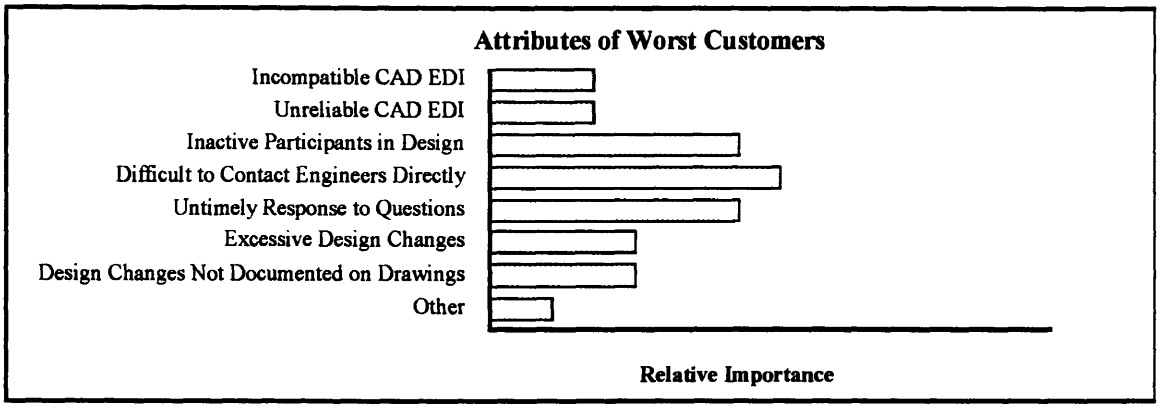


Figure 4.4.15

The data showed that the majority of both the best and worst customers (1st tier suppliers) provide full designs to the second tier suppliers. This suggests that providing a full design does not ensure a smooth project as most of the worst customers fit into that category. The data also showed that only 4 percent of the best customers provided black box specifications compared to 22 percent of the worst customers. This suggests that special attention should be provided to a black box specification project to ensure success.

Use of Written Specifications and CAE Flow Analysis

Only 10 percent of the customers of the second tier suppliers provide written guidelines for the design of insert molded parts. The suppliers find these as somewhat helpful over fifty percent of the time and not very helpful for the remainder. No one found them exceptionally helpful.

Most suppliers do not utilize CAE flow analysis extensively. One supplier uses flow analysis on 100 percent of their insert molded part designs. Three use it over 10 percent of the time, and the remainder use it less than one percent of the time. Only three of the suppliers had in-house CAE capability.

Mold Design and Construction

Nine out of ten suppliers have in-house mold design capability, and seven of these can build molds in-house. Of the nine who have design capability, all have used it in some capacity over the last year. Three designed 100 percent of their own molds, the remainder designed on average 10 percent of their new molds. Of the seven who have construction capability, only one has significant capacity building 80 percent of their molds over the previous year. Three suppliers built approximately 10 percent of their molds, and the other three didn't build any.

Third Tier Supplier Presourcing

Most suppliers presource part of their mold and stamping work as shown in **Figure 4.4.16**. Five of the suppliers presource 100 percent of their molds and stampings (these numbers include internal suppliers).

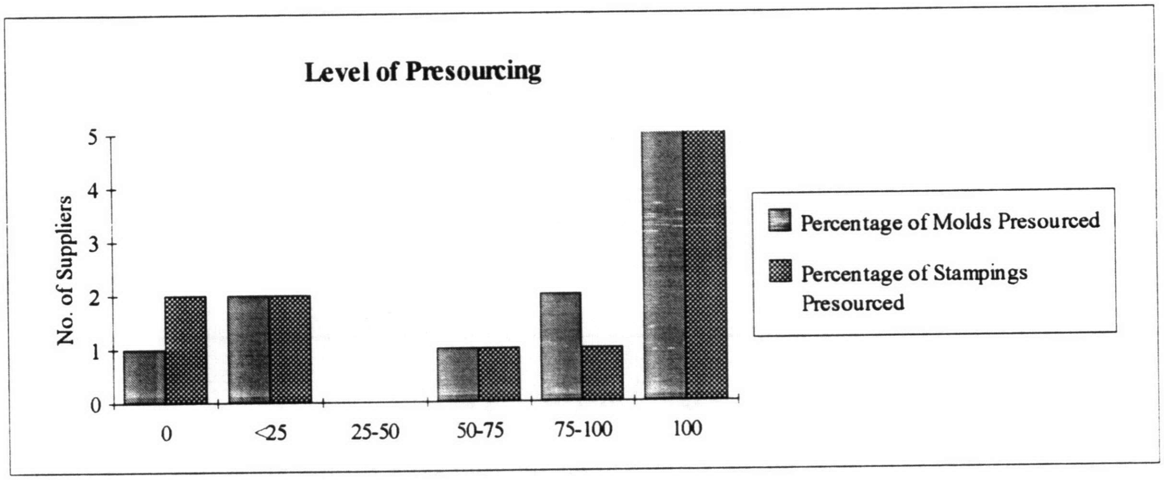


Figure 4.4.16

The reasons firms choose to presource are shown in **Figure 4.4.17**. The data suggests that suppliers presource stamping and molds for different reasons. Scheduling dominates the mold work while participation in design governs the stamping partnerships. This may result from the fact that the suppliers have more expertise in mold design than stamping design. Many firms don't like to presource because it eliminates the bidding process which potentially can increase cost. The push to presource stampings for design reasons illustrates the critical role of the stamping supplier on the design team.

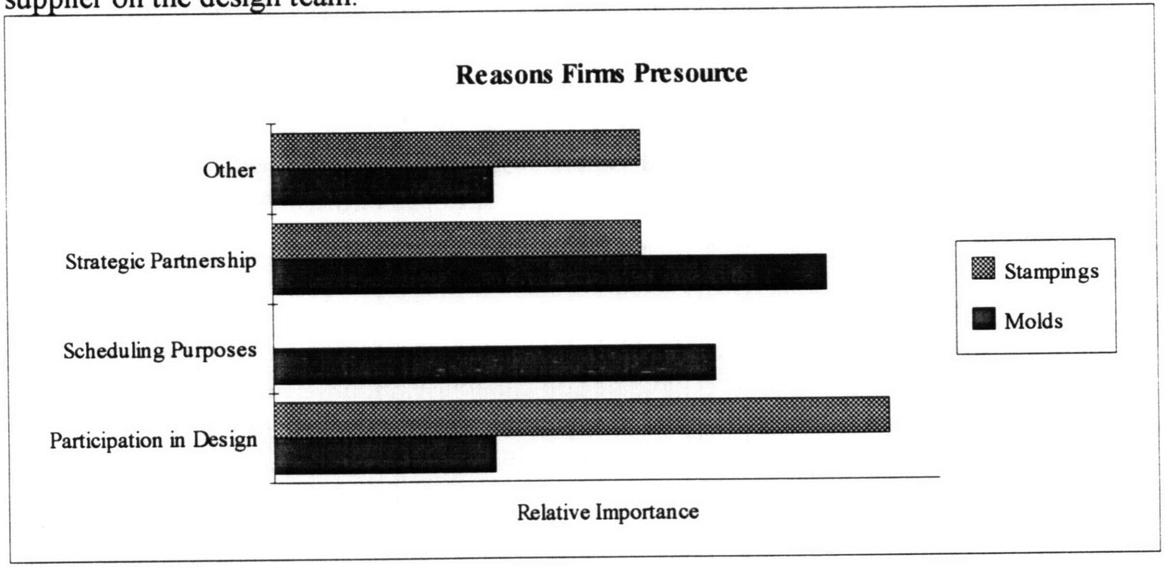


Figure 4.4.17

Strategic Alliances

Participation in strategic alliances varied widely among the suppliers as shown in **Figure 4.4.18**. Second tier suppliers tend to have more alliances with third tier suppliers than with their customers. The nature of the strategic alliances between the second tier suppliers and the customers and third tier suppliers are shown in **Table 4.4.2**.

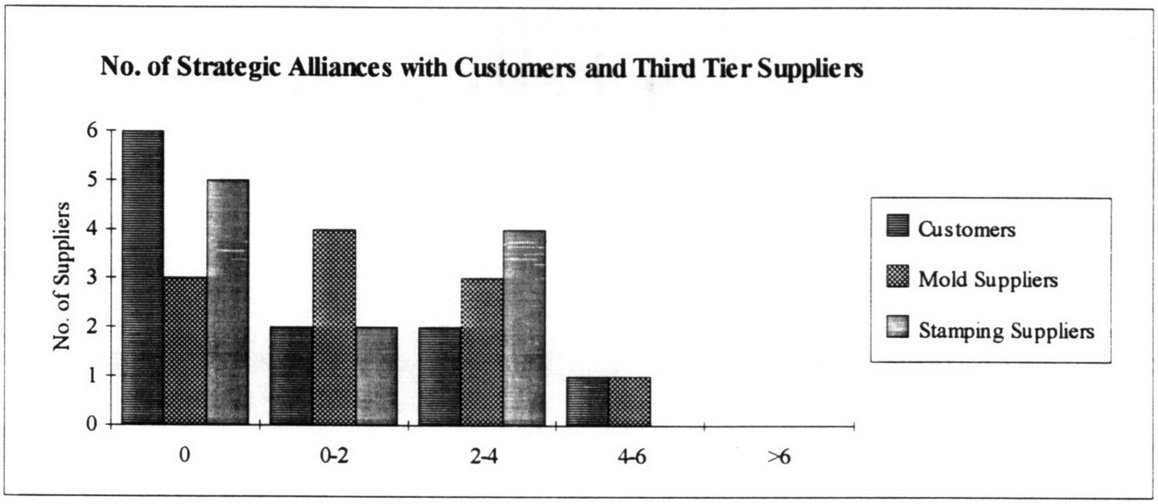
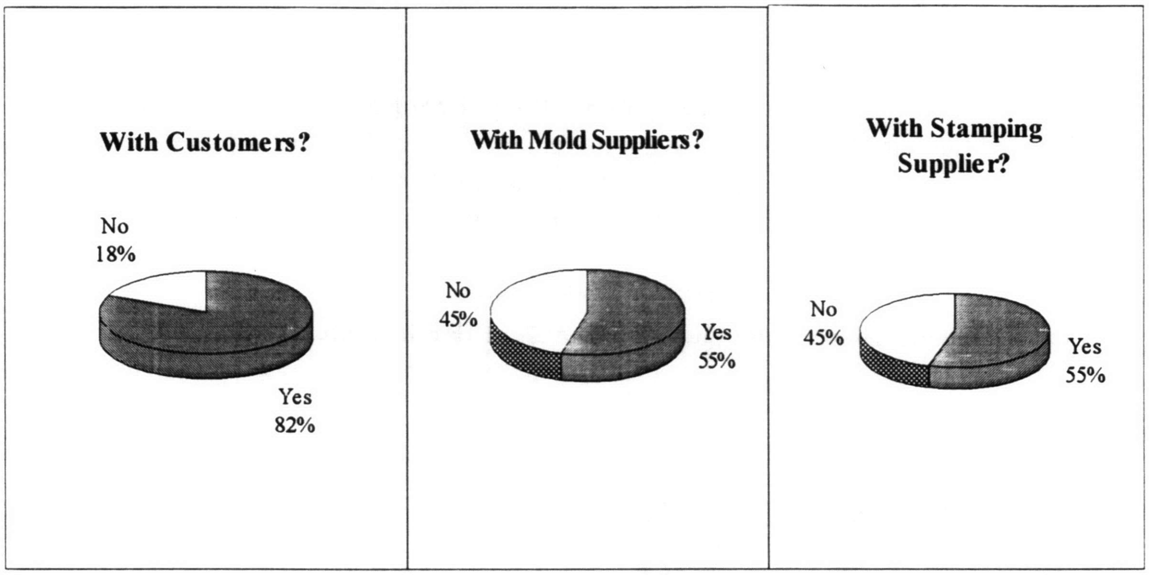


Figure 4.4.18

Table 4.4.2: Nature of Strategic Alliances

Customers	**Mold Suppliers**	**Stamping Suppliers**
Design concepts	Design participation	Design participation
Schedule sharing	In-house mold shop	Shared cost reduction efforts
Team participation	Faster turnaround on changes	Guarantee of contiuous work
Shared cost information	Shared cost reduction efforts	
Long term guarantees tied to large capital investments	Guarantee of continuos work	
	Scheduling	

Second tier suppliers were asked whether they would pursue additional strategic alliances this year. Their responses are included in **Figure 4.4.19**. They appear more eager to establish alliances with customers than with third tier suppliers. They may hope to gain additional security through the customer alliances similar to what they provide the third tier suppliers with guarantees of continuos work and shared cost reduction efforts.


With Customers?

With Mold Suppliers?

With Stamping Supplier?

Figure 4.4.19: Will Your Firm Pursue Additional Strategic Alliances This Year?

Conclusions and Implications -- Second Tier Supplier Study

The major conclusions and interesting trends from this study are as follows:

1) Suppliers are relatively small companies (<$50M gross revenue) who typically give a large percentage of work to a few customers. This provides a natural step to forming alliances with first tier suppliers like Input Controls.

2) Most suppliers have fairly high dependency on insert molding. There are a few suppliers who don't have a high volume, however. Input Controls should be wary of forming an alliance with one of the second tier suppliers who doesn't have a high volume of insert molded parts. The thought is that a higher volume brings more expertise including costing, design, and manufacturing.

3) 65 percent of materials used in circuitry insert molding is nylon or thermoplastic polyester. The remaining 35 are, for the most part, lower cost materials.

4) Multiple cavity/single machine scenarios are preferable to suppliers from a cost stand point. Input Controls needs to specify single cavitation if it is needed for flexibility, control, or maintenance.

5) A large percentage of inserts are plated by the suppliers.

6) Most suppliers do not utilize secondary blanking while others do. Although its impossible to draw any conclusions without understanding the complexity of the parts involved, this issue should be investigated further.

7) Most second tier suppliers do not design a high percentage of their parts in-house. Many design very few raising questions about their expertise in design.

8) Although they may not want to design the parts, suppliers would like to have a say in the customer's design as shown by the fact that the concept design package was chosen as the most effective scenario.

9) EDI may be nice, but it's not a high priority to suppliers at this point. However, it will likely be a competitive advantage in the future.

10) Second tier suppliers want three things from their customers more than anything else:

    i) Direct contact with engineers rather than purchasing
    ii) Participation in design with the first tier supplier
    iii) Quick response to questions and proposals

11) It appears to be more difficult to provide excellent results with a black box specification than a concept or full design. Therefore, special attention should be given to jobs using a black box specification.

12) Written part design specifications are somewhat helpful but not extremely helpful.

13) Mold design expertise is critical. The second tier suppliers who design the most parts also design and build most of their own molds.

14) Second tier suppliers leverage mold and stamping suppliers via presourcing. The stamping suppliers are usually presourced so they can participate in the part design while the mold suppliers are presourced to help schedule the work.

15) Suppliers want to participate in part design as suggested by the fact that the second tier suppliers chose concept design specifications as the most desirable methodology.

4.4.3 Third Tier Supplier Results

Background

The goal of the third tier supplier benchmarking study was to determine how we could improve our working relationship with our mold suppliers so as to produce parts more effectively as a team.

Five companies participated in the study. Three of these suppliers, A, B, and C, have built molds for Input Controls in the last year. The results are summarized below.

Results

Customer Information

The mold suppliers have a fairly small number of customers. On average, each molder had 13 customers with the fewest and maximum number of customers being 9 and 22 respectively. The suppliers also tend to get a large part of their business from their largest three customers. Across the board, the average work volume contribution of the top three customers was 55 percent with the least and maximum being 30 and 90 percent. Many of the suppliers have consciously reduced the number of customers they worked with in recent years. One supplier stated that his business improved exponentially after he culled out his worst customers. He found that 80 percent of his problems came from 20 percent of his customers.

Design Capability

Most mold suppliers design the majority of their molds in-house. One of the five suppliers uses outside designers to design 25 percent its molds. However, the other design more than 85 percent of their molds internally. The volume of insert molding business varies as shown in **Figure 4.4.20**.

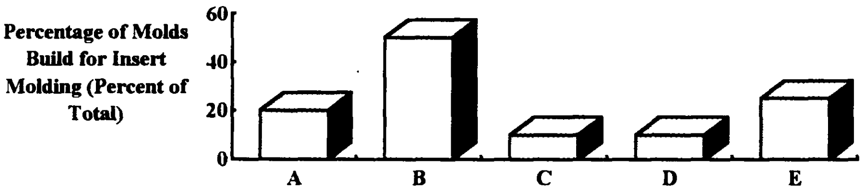


Figure 4.4.20: Insert Molding Volume

Pre-production Prototyping Methods

On average, 78 percent of pre-production prototype work is on hardened tool steels or pull-ahead cavities. Soft metal prototypes volume seems to be declining.

Strategic Alliances with Customers

None of the five suppliers had contractual alliances with customers. However, two did have strong "alliance" type relationships with some of their customers. One firm had alliances with two customers in which it invested in EDI equipment in order to be able to communicate with them. The customers guaranteed some volume of work to help the supplier make the investment. Another supplier had a strong alliance with one customer and soft alliances with several others. The customer in the strong alliance relationship gives him 60-70 percent of his work. The supplier plays an active participant in the customer's part design and responds quickly to emergencies. The customer in return guarantees steady, long term work.

Use of Electronic Data Interchange (EDI)

Although the volume of EDI appears to be growing rapidly, it's quality is not according to the suppliers. On average, each mold supplier receives over 50 percent of the customers' part designs through EDI on disk or through a modem. However, the files they receive are usually not usable in their original form. The suppliers estimate that only about half of the data they receive is good enough to be used without significant correction (see **Figure 4.4.21**). Therefore, only about 25 percent of the part designs today are transferred as intended with EDI. Another 25 percent of the designs are transferred in part through EDI and then painstakingly corrected by the mold supplier. The remaining 50 percent of the designs are transferred through traditional drawings.

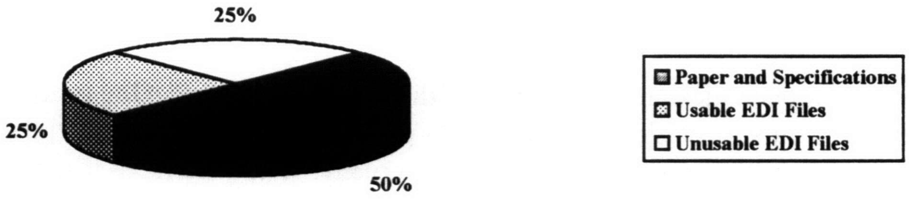


Figure 4.4.21: Methods Used by Customers to Transfer Designs to Mold Suppliers

Conclusions

1) Good tooling vendors are a diminishing resource for many manufacturers as they appear to be able to choose who they will and will not work with. Therefore, it's important to be a good customer, so that they won't dump you for a firm that's easier to work with. Being a good customer doesn't mean that we have to provide a perfect design or never change a design in the middle of a tool build. On the contrary, several mold suppliers said that their best customers didn't design better parts, they just were "nicer" to work with. Being "nice" to work with translates into getting supplier input in part design, communicating changes adequately, responding quickly to questions, paying for all the work the supplier does without excessive complaining or bickering, and providing a fairly steady volume of work.

2) If a pre-production prototype tool is going to be made, it should be presourced through the same supplier who will get to make the production tool. Presourcing mold suppliers as early as possible for both pre-production prototyping and production tooling can shorten lead time and improve part design. The advantages in our case are as follows: 1) it allows Input Controls to get on the construction schedule of a mold supplier (scheduling is one of the primary reasons second tier suppliers presourced molds), 2) it gives the tool maker a chance to give input on the part design (a tool maker is more likely to give input on the prototype if they are going to get to make the production tool), and 3) it helps the mold supplier learn how the tool should be built.

3) Utilizing electronic data interchange (EDI) itself does not guarantee improvement unless compatibility and file quality issues are addressed. There are two issues: transferring the data to the supplier in usable form and having the right data to start with. Transferring the data is a matter of hardware and software. Having the right data to start with is more often the problem. Designers need to have the right geometry in the files and have lines intersect in the appropriate places. The files can look fine in two dimensions and be filled with mistakes in a three dimensional representation. Since the supplier uses the three dimensional geometry, it's critical that the designer provides the geometry accurately. Time pressures are often used as an excuse to release a design; however, this actually slows down the process because the mold supplier has to learn about the part and then fix the geometry before starting the mold design.

4.5 Strategy and Recommendations

This section outlines a brief analysis of the circuitry insert molding industry, a strategy for Input Controls, and recommendations for implementing the strategy.

4.5.1 Industry Analysis

Industry analysis was completed by using a modified Five Forces Model. The model was developed by Michael Porter at Harvard Business School as a tool to help formulate a strategy within a particular industry. The components of the model are buyer power, supplier power, intensity of competition, barriers to entry, and substitution of other products.. Each component is summarized in **Figure 4.5.1** for the circuitry insert molding industry and discussed in detail below.

Buyer Power -- OEM's Leverage Over First Tier Suppliers

Circuitry insert molded parts are primarily used in the automotive, electronics, telecommunications, medical, and computer industries. Together, the OEM's in all these industries apply buyer leverage over first tier suppliers who design and produce insert molded parts like Input Controls. Buyer power or leverage is simply a relative measure of how much the buyer can influence the price firms can charge.

The leverage is not uniform across the circuitry insert molding industry as most first tier suppliers will segment into particular customer segments. For example, one of the four first tier benchmarking partners focuses on the electronics, telecommunication, and computer industries while other three focus on automotive companies. This segmentation helps first tier suppliers meet the unique needs of the OEM's in their target segment, but it can also make them more vulnerable to any given OEM's leverage because it reduces their customer base, thus, making each customer more important. For example, if Company A only has five customers while Company B has 20, losing a customer will be more painful for Company A.

The automotive industry has long been known for having a powerful buyer position. Input Controls is susceptible to this -- losing one of its customers would significantly impact Input Controls' business.

Supplier Power -- 2nd and 3rd Tier Leverage Over first Tier Suppliers

The second and third tier suppliers provide insert molded component parts, molds, and insert stampings to first tier supplier in all industries. Although a few second and third tier suppliers have focused on one segment, it appears that most support first tier suppliers in more than one segment unlike the first tier suppliers who specifically target the automotive industry. Only 20 percent of the second and third tier suppliers had their three largest customers in the same segment while 75 percent of the first tier suppliers did. Also, they tend to spread their business across more customers than the first tier suppliers. On average, less than 50 percent of the work for the second and third tier suppliers comes from their three biggest customers, where the first tier suppliers averaged over 60 percent of their business from their top three customers.

Supplier power or leverage is a relative measure of how much they can influence the price of raw materials or components. Input Controls' second and third tier suppliers certainly do not have as much power as the OEM's, but they do have significant leverage. Their leverage comes from the fact that they are less dependent on Input Controls than Input Controls is on them. Since they tend to have more customers and since those customers are generally across other segments, they can easily pick business up from one customer if another cuts back. This gives them power over the first tier suppliers because they can decide if they will or will not do business with any particular first tier supplier. This will become more critical with time because it appears the other segments are growing faster than the automotive circuitry insert molding segment. Therefore, as consumer electronics and other industries form a bigger piece of the pie, their strength will increase at the expense of the automotive suppliers whose piece will shrink.

Intensity of Competition -- 1st Tier Competition in Automotive Circuitry Insert Molding

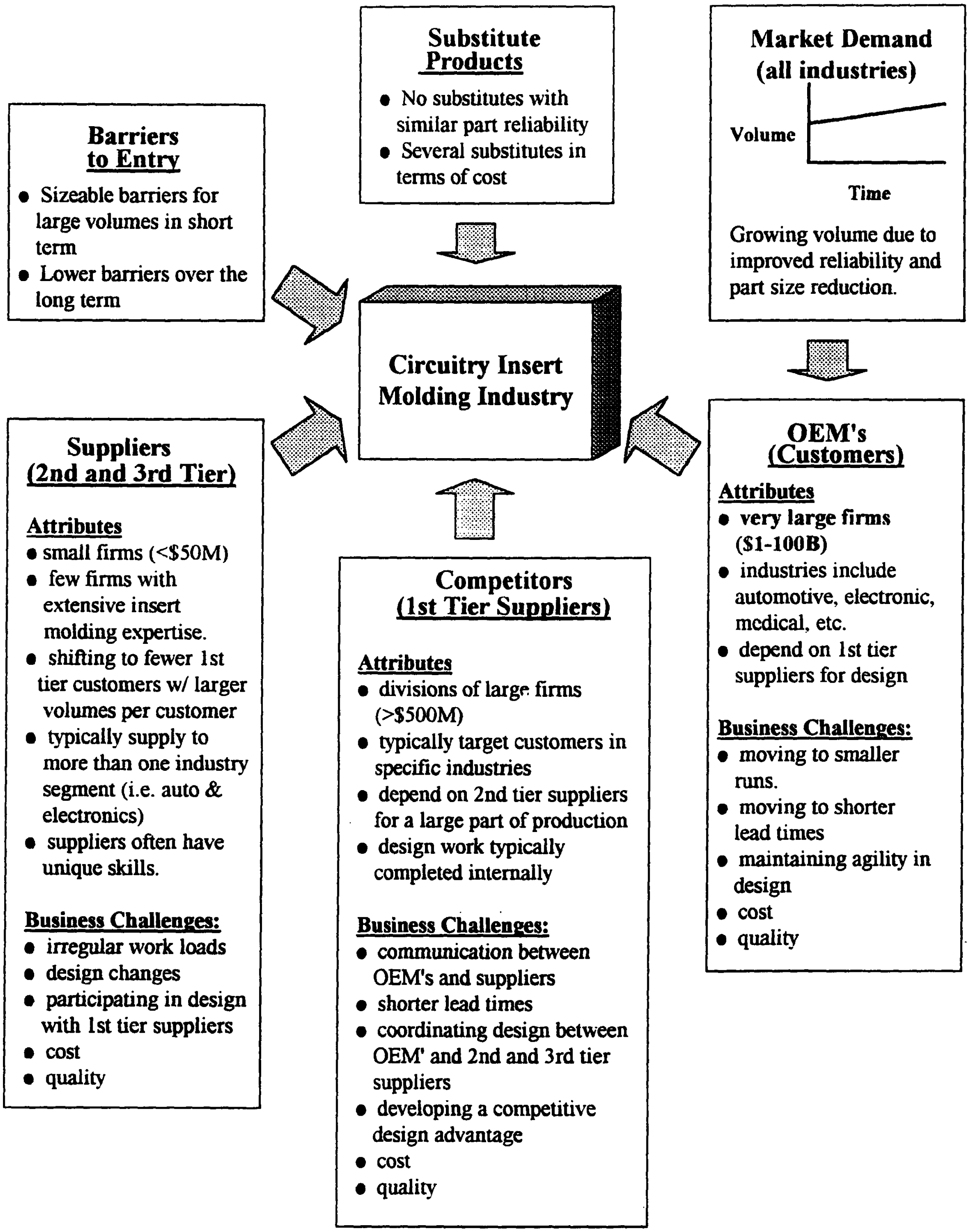
Due to time constraints, the intensity of competition was not evaluated for automotive circuitry insert molding suppliers. It is worthwhile, none the less, to mention the key the competitive driver -- time to market. Products and their functionality are not easily differentiated from one first tier supplier to the next; however, first tier development capabilities are. The most obvious being time to prototype and time to market. Time will increasingly become a competitive advantage or a stumbling block for first tier suppliers as the automakers move to shorter lead times and smaller product runs in response to their markets.

Barriers to Entry

Developing technological expertise is the largest barrier to entry in circuitry insert molding. It applies to all the tiers in the supplier chain as the design and manufacture of parts, insert stampings, and molds all require skills above and beyond regular injection molding. Although this barrier is sizable, it is not insurmountable. Firms can start by participating with one part and grow into the business in an evolutionary fashion. However, it would be difficult for a firm to jump into the market quickly with a significant amount of production.

Substitution of Other Products

Competing processes revolve around joining the insert to the plastic base material in secondary operations including ultrasonic insertion, press fits, riveting, etc. These processes can compete on cost, but they can not compete on part reliability as the insert molding process provides an integral joint between the plastic and the metal insert. Since part reliability is the primary reason insert molding volume is growing, substitution of other products is not a serious threat at this time. However, future threats are inevitable from technical advancements such as 3-D circuitry printing and the like.



Substitute Products

- No substitutes with similar part reliability
- Several substitutes in terms of cost

Market Demand (all industries)

Growing volume due to improved reliability and part size reduction.

Barriers to Entry

- Sizeable barriers for large volumes in short term
- Lower barriers over the long term

Circuitry Insert Molding Industry

Suppliers (2nd and 3rd Tier)

Attributes

- small firms (<$50M)
- few firms with extensive insert molding expertise.
- shifting to fewer 1st tier customers w/ larger volumes per customer
- typically supply to more than one industry segment (i.e. auto & electronics)
- suppliers often have unique skills.

Business Challenges:

- irregular work loads
- design changes
- participating in design with 1st tier suppliers
- cost
- quality

OEM's (Customers)

Attributes

- very large firms ($1-100B)
- industries include automotive, electronic, medical, etc.
- depend on 1st tier suppliers for design

Business Challenges:

- moving to smaller runs.
- moving to shorter lead times
- maintaining agility in design
- cost
- quality

Competitors (1st Tier Suppliers)

Attributes

- divisions of large firms (>$500M)
- typically target customers in specific industries
- depend on 2nd tier suppliers for a large part of production
- design work typically completed internally

Business Challenges:

- communication between OEM's and suppliers
- shorter lead times
- coordinating design between OEM' and 2nd and 3rd tier suppliers
- developing a competitive design advantage
- cost
- quality

Figure 4.5.1: Five Forces Model of Circuitry Insert Molding Industry

4.5.2 Strategy

Strategy is the competitive battle plan for a firm. It's vital for a firm to contemplate its overall strategy whenever it is trying to implement change to help focus the effort on the correct issues and to avoid an implementation plan that contradicts part of the core strategy. For example, if Input Controls decided it needed to reduce late shipments from its second tier suppliers, it could choose a variety of paths including increasing inventories, improving communication, or reducing cycle time in the supplier's process. All may work, but if Input Controls is trying to improve quality, increasing the inventory would probably contradict that effort. Similarly, implementing change for this project needs to fit into Input Controls strategic plans. To that end, a simple strategy is developed and presented in this section. This is not intended to be an all encompassing long term strategy, but it does help provide a structure for making recommendations and was used to formulate the project's final recommendations outlined in **Section 4.5.3**.

The market analysis in **Section 4.5.1** provides half of the information required to develop and implement a strategy -- the opportunities and threats in the market place. The other half comes from internal scrutiny -- the strengths and weakness of Input Controls. This half was provided by the benchmarking studies of which the results are summarized at the end of each tier's results in **Section 4.4**. Each of the four issues (opportunities, threats, strengths, and weaknesses) are summarized in **Figure 4.5.2** and are addressed in detail below.

Opportunities in the Market Place

There are several ways for a firm to stand out among its competitors including lower cost, better design, shorter lead time, etc. For Input Controls and its competitors, time will likely be a key competitive driver in the future as the automakers move to shorter lead times and smaller runs. This will push suppliers to design more parts faster and produce smaller volumes of each part. All suppliers will not respond equally well to this challenge, so there is an opportunity to stand out for those firms who can shorten development cycles most while still meeting customer requirements. Therefore, reducing cycle time should be one of the primary concerns for Input Controls over the next few years.

Although cycle time is vital, there is also an opportunity for Input Controls to stand out by being a first tier supplier who can provide better services and integrated products to its customers. As discussed in **Section 4.5.1**, the automotive OEM's have a great deal of buyer power. They will use this power to force the cycle time reduction on their suppliers. Input Controls can counteract buyer leverage by becoming one of the most desirable suppliers for the automotive OEM's. Ideally, if Input Controls could become so desirable that all the automotive OEM's want to work with them before any other supplier, Input Controls could exert power over its buyers.

Becoming the preferred supplier for its customers is one of Input Controls' biggest challenges. It is difficult because customer needs are a moving target to start with and difficult to assess even at a snap shot. It will only come through closer relationships over the long term with the customers and consistent focus on meeting their needs. This study did not focus on the customer relationship, but it can still help improve the customer relationship through building closer relationships with second and third tier suppliers and improving internal performance.

UTA Internal Scrutiny

Strengths

- o Size -- volume is attractive to 2nd and 3rd tier suppliers and capability is attractive to OEM's.
- o Engineering expertise in part design, flow analysis, and manufacturing.
- o In-house production to maintain manufacturing expertise.
- o Materials expertise in metals, resins, and lubricants.

Weaknesses

- o Mold design expertise on the development team.
- o Supplier participation in design.
- o Communication with suppliers in design and changes (EDI, response time, direct contact).
- o Design standards & checklists.
- o Capturing internal & external lessons learned (design and manufacturing).
- o Challenge to improve manufacturing quality.

Industry Environment

Opportunities

- o Being a 1st tier supplier that 2nd and 3rd tier suppliers love to work with.
- o Being a first tier supplier who provide more to OEM's:
  - \+ speed
  - \+ cost
  - \+ quality
- o Leveraging other UTA businesses to become a supplier of integrated products.

Threats

- o Competitors "partnering" with suppliers and customers.
- o Falling from suppliers "preferred customer" status.
- o Falling from OEM's "preferred supplier" status.
- o Variability in market demand and repercussions through supplier chain.

Figure 4.5.2: Strategic Drivers

Threats in the Market Place

Given that customers and suppliers have some leverage in this industry, Input Controls runs the risk of being replaced by one of its competitors if the competitor can better meet the needs of the supplier or the customer. Considering that the circuitry insert molding is growing faster in other industries, this is especially threatening for the second and third tier suppliers as the automotive piece of the pie will likely decline reducing its leverage over the sub suppliers. Therefore, Input Controls needs to be cognizant of its customer and supplier needs and work to meet them.

Strengths of Input Controls

One of Input Controls biggest strengths is its engineering expertise and resources. It has a great deal of part design experience as well as experience in flow analysis and manufacturing considerations. It can leverage a wealth of material and processing expertise from UTRC in metals, resins, and lubricants. Its size is also a strength as suppliers like it because it can provide a significant volume which helps smooth their shop flow. Customers also experience advantages as they can leverage a great deal of engineering skill. Another strength is its in-house production capability. Experiencing the manufacturing phase plays a vital role in Input Controls ability to stay abreast of manufacturing issues that can be addressed in the part design.

Weakness of Input Controls

There are several areas for concern which need to be addressed at Input Controls. First, Input Controls has very little mold design expertise compared to its competitors and compared to its second tier suppliers who design a large volume of parts. Part design sets mold design which, in turn, sets much of the manufacturing process capability. Therefore it's vital to consider mold design issues during part design, and this requires mold design expertise. Second, Input Controls does not extensively solicit the input of its suppliers in the design process which hinders the design and hurts the relationship with the suppliers. Third, Input Controls has not streamlined its communication channels with internal or external suppliers for design EDI or engineering change orders. Fourth, There doesn't appear to be an extensive system to capture lessons learned from the manufacturing and assembly plants or from individual development teams. Finally, the manufacturing organization is struggling to improve quality.

Overall Strategy

A fundamental strategy can be formulated for Input Controls by simultaneously considering its strengths and weaknesses and the industry environment. Obviously, part of the strategy should be to address Input Control's weaknesses; several recommendations do address individual weaknesses. The more important issue is to develop a strategy which improves Input Controls position against its competitors. The results of this study suggest that the best way to accomplish this is to resort to the fundamentals -- focus on the customer and the supplier relationships and leverage strengths and backfill weaknesses.

The industry environment suggests that we need to be better than our competitors at meeting OEM needs. If we don't, our competitors may steal them away through formal or informal alliances. Reducing development time is one of the most important issues to our customers and should be the focus of the effort.

Similarly, the strategic power of our second and third tier suppliers suggest that we need to also be more responsive to their needs to prevent them from defecting to our direct competitors or to first tier suppliers in other industries. This threat will become more severe for Input Controls as circuitry insert molding applications are growing more rapidly outside the automotive industry.

It is important to note that meeting supplier needs is perfectly consistent with Input Control's overall objectives -- especially the goal of reducing the development time. Input Controls' suppliers want to make money from doing the job right the first time and charging a fair price for that expertise rather than making money on change orders and expedited orders.

Input Controls is also well positioned to leverage its strengths to compress cycle time. Through engineering expertise in part design, CAE, DFM, and materials, Input Controls can design better parts faster. Additionally, Input Controls weaknesses can be covered in the short term so as not to slow down improvements. One example is to leverage suppliers through presourcing to gain needed expertise in mold and stamping design during the development process.

Addressing issues to reduce development time is the primary issue for Input Controls. Focusing on time will make implementation easier and should also improve quality and reduce cost. Meeting customer and supplier needs and leveraging strengths to improve weaknesses will all impact development time. The recommendations in **Section 4.5.3** were developed with this in mind.

4.5.3 Recommendations for Improving Input Controls Development Process

The recommendations below are geared toward implementation. Due to timing and location issues, they were developed through with very little interaction with Input Controls and, therefore, need to be taken with a grain of salt. The focus should be the intent and not the procedure of each recommendation. Specific recommendations were made, in part, as illustrations to help explain the issues.

The strategy developed in **Section 4.5.2** was the major driver of these recommendations along with the business challenges of speed, quality, and cost. Development time was the primary focus for recommendations.

By focusing on development time and attacking existing barriers, most of the business challenges and the strategic issues can be addressed. This primary focus will simplify implementation. It is also easier to apply performance measurements (metrics) to development time issues which will help maintain the focus over the long term. Most of the recommendations below are made with this in mind except those designed to address specific weaknesses.

Recommendation 1: Evaluate Suppliers for Strategic Fit

Actions:

1) Consider the capability of existing suppliers and compare it to Input Controls' strategy -- respond accordingly by working with supplier to change, finding a new supplier, or reward the supplier to solidify the relationship.
2) Examine internal needs and work with suppliers to meet those needs through presourcing or other alliances.

Justification:

The second tier suppliers tend to be very strategic in who they pick for their suppliers. Several mentioned that they chose their stamping supplier based on the shape of the insert because each supplier has unique skills. Input Controls needs to be more strategic in how they work with their suppliers. For example, the current stamping supplier for internal production, is probably a great stamping supplier, but they have very little expertise in copper and circuitry insert molding. Input Controls is probably missing something by not using a stamping supplier experienced in circuitry insert molding who can participate in the part design phase.

Recommendation 2: Align Internal Groups With Second Tier Suppliers

Action:

Input Controls should align its second tier suppliers with specific teams within Input Controls to facilitate relationships, and they should develop performance measurements focusing on key issues to help keep the team on track and monitor progress.

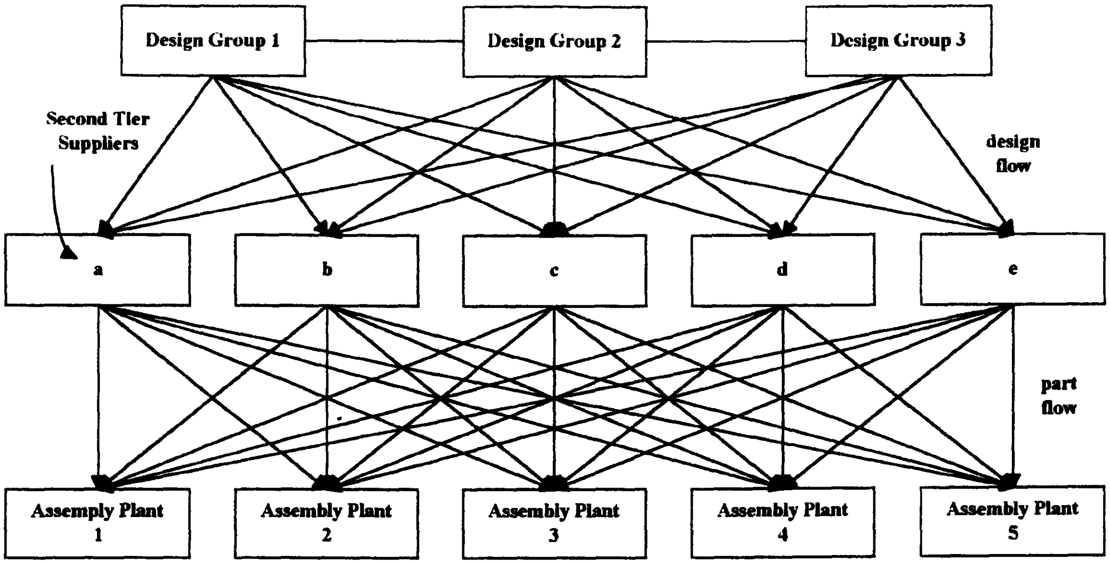
Justification:
Input Controls recently aligned its internal groups so that each engineering group covered one or two specific internal assembly plants. This appears to have helped both the engineer and the assembler as they have more continuity between projects.

This same benefit can be realized by aligning internal groups to second tier suppliers as shown in **Figure 4.5.3**. Aligning into these groups essentially reduces the number of people and procedures everyone has to learn. It also fosters long term working relationships between the development team and creates an informal alliance between the customers, Input Controls, and the second and third tier suppliers. This informal alliance can be very effective, yet it is still a low risk because it isn't legally binding to the participants.

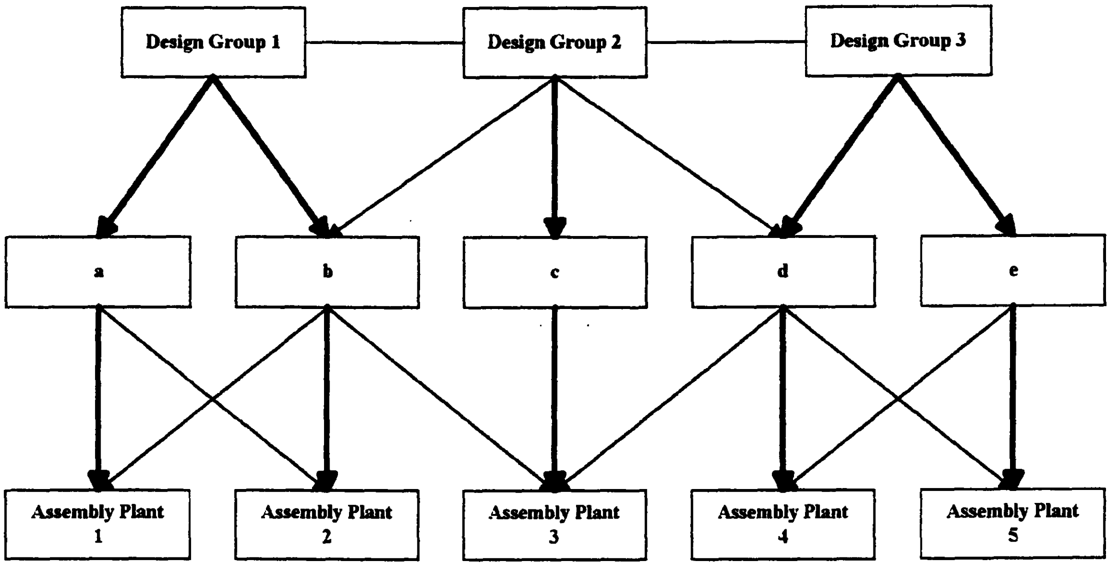
Primary second tier suppliers will be presourced by default as long as their capacity is open, but other suppliers will be available to fill in production gaps and to compare bids for competitiveness. The presourcing will help solicit input during the design stage. Ideally, the mold supplier would be presourced as well to provide the mold design expertise during part design.

The role of each of these teams will be to determine how to reduce cycle time and cost while improving part quality. Every effort should be made to eliminate redundant work, eliminate lag times associated with paper trails, reducing the response time for technical questions, reducing the time and paperwork required for an engineering change, etc. Additionally, team members should spend time determining how they better meet the needs of their customers to help secure future production.

The small size of the teams will allow better focus on the issues impacting each team. It facilitates faster change compared to introducing organization wide procedures which are either too broad to capture critical details or too narrowly focused so that they unnecessarily constrain certain teams.



Existing Design and Part Flow



Design and Part Flow With Alignment of Groups to Suppliers

Figure 4.5.3: Aligning Internal Groups to Second Tier Suppliers

Recommendation 3: Increase the Consideration of Mold Design During Part Design

Action:
Input Controls should ensure mold design expertise is included on each product design team early in the project. This can be accomplished through hiring someone internally to participate on the design team, leveraging the expertise of a presourced second tier supplier, or presourcing the molds and including the mold designer on the team.

Justification:
Part design sets much of the mold design which, in turn, sets much of the manufacturing process capability. Therefore, it is vital to consider mold design during the part design when it can have the most impact.

Recommendation 4: Develop Performance Measures to Focus Improvement Efforts

Action:
Develop metrics to monitor progress of improvement efforts. Time is the most important issue and can be directly and also indirectly measured. Indirect measures may be most valuable to help compare projects since development time will be affected by part complexity. Indirect measures of time performance include:

1) time to quote
2) no. of revisions driven by customer changes
3) no. of revisions driven internally for mistakes
4) no. of revisions driven internally for manufacturability
5) no. of revisions to mold in first year after production start-up
6) start-up time

Other performance metrics include:

1) defect rate in first year of production
2) maintenance downtime for tool in first year
3) project estimated rate of return

Recommendation 5: Establish Purchasing/Engineering Teams

Action:
Input Controls should establish purchasing/engineering teams so there is only one purchasing agent who works with any given engineering group and its supplier pool.

Justification:
By making the purchasing agents part of the aligned teams, they can build long term relationships within Input Controls and the supplier pool. They can help establish the

protocol for when Purchasing should be involved in a decision and when it's not necessary. The contact person for the supplier can reside in engineering and bring Purchasing into issues as required.

Recommendation 6: Presource Suppliers for Internal Production Projects

Actions:

1) Presource molds for mold designer participation on development team and scheduling.
2) Presource stamping inserts for stamping designer participation on development team.

Justification:

Second tier suppliers extensively presource for scheduling and design purposes. First tier suppliers should presource to help get the necessary expertise to improve the manufacturability of their part designs. It may appear more expensive at the outset. However, second tier suppliers are small enough to have a good feel for their costs, and they extensively presource. Therefore, it seems reasonable for Input Controls to follow their lead and presource.

Recommendation 7: Implement Drawing Quality Standards for EDI

Action:

Input Controls should implement a quality standard for its EDI drawings before the design is released to the supplier. The industry surveys indicate that suppliers can normally only use about half of the data they receive through EDI from their upstream customers. To ensure Input Controls' geometry and dimensions are correct, in-house standards should be developed so that a design must meet these requirements before it is released. This can easily be tracked by a post project evaluation of the suppliers who receive the data.

Justification:

Most suppliers felt that high quality EDI files reduced lead time and improved the quality by eliminated human translation errors. Therefore, it is well worth investing time to ensure the data is correct.

Recommendation 8: Create a System to Capture Lessons Learned

Actions:

1) Create a post project evaluation to be completed by the development team to capture lessons learned. The evaluation should include customer feedback, supplier feedback, and internal scrutiny of the project details.
2) Create a regular schedule for updating design checklists and standards using the post project evaluations.

Justification

There is an enormous amount of knowledge within the system, but there are few ways to capture it and communicate it to other people. A post project evaluation would help identify areas which need to be addressed and any lessons learned during the project. The schedule will prompt regular updates. It's worthwhile to note that a system like this is only as good as the use it receives and the priority placed on it by managers under time pressures.

Recommendation 9: Prototype Via Presourced Suppliers Using Pre-production Tools

Action:

If a pre-production prototype tool is to be built in hardened steel, the work should be presourced, if possible, to the shop which will make the final production mold.

Justification:

The industry appears to be moving to pre-production prototypes tools in hardened steel which is consistent with Input Controls' current strategy. The mold suppliers all say that the first tool build is the hardest and subsequent tools are much easier to build using the knowledge and CAD/CAM data from the first build. Therefore, it makes sense to give pre-production prototype work and the final tool work to the same supplier if their production schedule allows.

Recommendation 10: Invest in Rugged Mold Design and Maintainability

Action:

Input Controls should invest in rugged mold design and maintainability.

Justification:

One mold supplier discussed how his "most expert" customer requires him to build molds to gauge dimensions so that replacement parts can be individually fabricated by any mold shop and sent to the plant for installation. It's more expensive to make the molds, but it greatly enhances maintainability. Similarly, cost is often a concern with presourcing. Although the benefits are difficult to quantify, they are significant. If Input Controls is to presource its suppliers to get their involvement in the design, it will be necessary to commit to the process without being able to see the rewards until the project is over.

4.6 Lessons Learned About Benchmarking

This section outlines the lessons learned about benchmarking during this study.

4.6.1 Lessons From Related Work

There has been a great deal of work and research done in industry and universities on the subject of benchmarking. There are a number of books dedicated solely to the subject and there are probably thousands of articles covering the topic. Benchmarking is not universally defined. The articles range from describing benchmarking as a sacred quality technique for every employee to those which describe it as only one of many tools and which warn against pushing it too far.[1] Some companies define it formally while others speak about it in general terms.

Benchmarking Can Lead to Negative Impacts

Although positive benchmarking experiences abound in the literature, negative experiences have also surfaced. The "Best Practices Report," an international study of 580 service and manufacturing businesses published in October 1992 by Ernst & Young and the American Quality Foundation found that benchmarking can actually have negative impacts on firms. The report found that benchmarking was demonstrably helpful only to top-performing companies, defined in the study as those with a return on assets higher than 6.9 percent.[2] Medium performers did not show significant positive impact, and low performers, with an ROA below 2 percent, actually show negative results from benchmarking their marketing and sales systems.

The study suggested that the low performers don't have an infrastructure ready to support the change and suffer when they try to implement the practices of the high performers. Instead of focusing on benchmarking, the study recommends that these firms should focus on building infrastructure that can support change across the organization. This infrastructure includes cross functional teaming, training and empowering workers, and just getting better at what they already do.[3]

Keys to Successful Benchmarking

Assuming a firm has an adequate infrastructure to support benchmarking and to implement best practices, there are several key factors to consider. These keys are summarized in The Benchmarking Book as:[4]

1) *Seek change and be action-oriented.* Benchmarking is not a passive exercise suited to those who are fishing for ideas and have not made up their minds about their desire to change.

2) *Be open to new ideas.* Benchmarking is a seeking of new ideas outside the traditional box. You must be prepared to consider alternative ways of doing business and be cast off the dogma which often binds decisions.

3) *Know yourself before you attempt to know others.* You need to understand yourself in order to compare yourself to others and in order to ask the right questions.

4) *Focus on the improvement of practices.* Don't focus on things like efficiency which tend to result from other factors. Instead concentrate on processes like communication channels which tend to drive results. Note, it is critical to evaluate performance to determine who you want to emulate, but you must also learn why they are different.

5) *Introduce and maintain discipline.* Structure your benchmarking process and provide adequate facilitation to benchmarking teams.

6) *Put the resources in place to get the job done right.* Get senior managers involved, allow sufficient time, provide an adequate budget, etc. Benchmarking is not trivial and should not be undertaken without considering the cost.

Previous Benchmarking Studies in Injection Molding

An article by Matthew Naitove in *Plastics Technology* reported the results of a benchmarking study with 380 customer molders. Naitove identified the world class firms by asking a sample group to list who they felt were world class molders.

The study's results were interesting. The aggregate results showed strong trends, but unfortunately most of the data was averaged which limited the conclusions one could draw. For example, 77 percent of the world class molders had fully implemented quality programs, but only 69 percent had remote process monitoring. Obviously, the firms' quality strategies were not all the same. It would be more valuable to be able to look at the world class molders one at a time and try to understand their strategy. It is possible to achieve world class standards in different ways, and some of these may be more applicable for one firm than another. However, from the results, we can not decide how to pursue a quality program. The data merely confirms that quality is important.

The conclusion I drew from the article is that averages and trends are useful to determine the importance of any given issue, but they are often not very insightful as far as determining how a firm should change. Rather, it is important to look at firms one a time to discover their strategy, practices, and relative performance.

4.6.2 Lessons Learned From The Study

I learned several valuable lessons during the benchmarking study. Each of these lessons is discussed briefly below.

Benchmarking Can Be a Powerful Tool Even in Less Than Perfect Situations

I had several concerns when I started this effort. First, I was an outsider to UTA and Input Controls. Second, I did not have extensive experience in the custom molding industry. Third, I only had four months to complete the work where most benchmarking studies require one man-year of effort at minimum. Finally, I knew I would not be around for implementation of any recommendations that I might make at the end of the study. There were also a couple positives for the project which helped offset the negatives. First and foremost was strong support from UTC and Input Controls management. I also had a reasonable budget in which to complete the study and to visit plants and experts as I deemed necessary.

The situation certainly was less than perfect at the start, but the study did result in a great deal of valuable information which will help Input Controls improve their development cycle.

Focus on Specific Groups for Specific Practices

When we developed the idea of completing a comprehensive benchmarking study, we intended to look at the direct competition. However, we soon realized that second and third tier suppliers rather than our competitors had mastered many of the processes which we needed to address within Input Controls. Therefore, we decided to target specific processes within different supplier tiers to benchmark. For example, in second tier suppliers, we looked at how much they presourced their suppliers and why. Alternatively, in the third tier suppliers, we looked at how they received EDI and what advantage it provided if any.

Its standard benchmarking practice to look at firms who do something very well regardless of the industry. For instance, Hewlett Packard, a computer company, may benchmark L.L. Bean, a successful clothing direct marketer, to determine how they should develop a personal computer direct marketing program. However, this study was somewhat novel in that we focused on extracting the best practices as appropriate from either our competitors or suppliers.

You Can Learn A Lot from Your Suppliers

The suppliers I interacted with for this study were extremely helpful. They desired to improve the effectiveness of the development process as much as we did. They provided a great deal of insight in several ways other than just completing the benchmarking surveys.

First, they often discussed their best customers (in terms of effectiveness), what they did, and why it was so effective. They did not divulge the names of these customers, but they did give specific examples of how their relationship had evolved and how they had overcome obstacles. These examples provided valuable anecdotal information which we could use to improve our process.

The suppliers proved invaluable in helping us compare ourselves to our competitors by filling out formal surveys comparing Input Controls to their other customers. Although these surveys were subjective by nature, they helped identify areas that Input Controls clearly needed to address.

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[1] Marc Hequet, "The Limits of Benchmarking," Training, February 1993, p. 36.

[2] Marc Hequet, "The Limits of Benchmarking," Training, February 1993, p. 36.

[3] Marc Hequet, "The Limits of Benchmarking," Training, February 1993, p. 36.

[4] Michael J. Spendolini, The Benchmarking Book (New York: American Management Association, 1992), pp.201-202.

5.1 Introduction

This chapter discusses the purpose, implementation, and format for checklists for design and drawings for circuitry insert molded parts and their associated molds and insert stampings. Much of the content of this chapter was taken directly from a report previously issued to Input Controls for implementation within their firm. Since the checklists resulting from this study contained information proprietary to United Technologies, the actual checklists could not be included in this chapter. However, the final format and implementation procedures are presented.

5.1.1 Purpose of the Design Checklists

There were two primary purposes for this project:

1) To provide a checklist to be used <u>during</u> the design process to ensure manufacturing issues are considered. This will save time and resources as it should reduce rework caused by latent problems, deadline pressures, or inexperience.

2) To provide a practical procedure to implement the checklists in a team environment.

Our intent for the checklists is not to provide design specifications or standards, nor have we provided hard and fast rules that will guarantee a good design. Rather, the checklists should help provide a structure to force thought and interaction within the development team.

5.1.2 Background of Design for Manufacturability

The attached checklists are part of an effort at Input Controls to improve design for manufacturability (DFM). They were developed through design case studies at UTA and through available literature on insert molding. Their primary purpose is to drive interaction between the part, insert, and mold designers so as to improve manufacturing performance in the broadest sense -- reduced time, lower cost, and higher quality.

DFM is desirable because it brings manufacturing issues into the design process earlier often resulting in lower costs, higher quality, and shorter time to market. For example, you may alter the proposed design of an injection molded part in a way that doesn't impact product function but in a manner which makes it easier to fabricate the mold. This will result in a shorter lead time and lower tooling cost. It is worthwhile to note that structured DFM does not take the place of having development team members who understand the constraints of their functional counterparts. It is, at best, a tool designed to assist technically competent team members. It is not a substitute for experience.

The goal of implementing DFM is not to do the same old things better, but rather to provide a structure that ensures we do the right things right the first time. This structure has several purposes[1]:

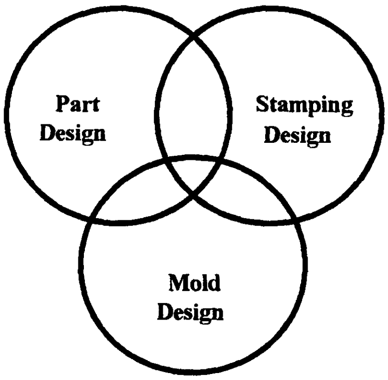
1) It raises the important tradeoff conflicts early in the process saving time and resources.
2) It makes the problem solving more effective by allowing team members to discuss these tradeoffs before the design is fixed.
3) It makes holes in the organizational knowledge about critical relationships readily apparent.
4) It provides a basis to capture knowledge important to design.

Although there isn't one single right way to implement design for manufacturability, the effort generally revolves around setting up a development team and process that structure the thinking and establish critical relationships.[2] This facilitates integration of the process and product design and brings issues of producibility to the center of the development effort.

The checklists represent only a small part of an implementation plan for improving DFM at Input Controls. Design checklists are not a new concept, but they can prove to be valuable DFM tools. Checklists were chosen for this project because they are simple and can be readily implemented without requiring significant investment or changes to the organization. Input Controls is moving toward concurrent engineering, and as it evolves, other DFM principles should be incorporated.

The attached design checklists are a loose form of design rules. Design rules generally set boundaries within which a manufacturing process can operate in terms that a product designer can understand. For example, by limiting designers to certain wall thickness transitions in a molded part, we can minimize warpage of the final product. In a similar way, anyone can a send a message through a design rule to the product designer saying, "If you do this, I can meet the final requirement for cost, time, and quality."[3]

The design checklists perform a similar function. Although they don't present any hard, fast rules, they do force the part, insert, and mold designers to consider how their designs interact. For example, the part design can determine the mold design. If the part designer places a rib in the wrong place, it may prevent the mold designer from placing a core-out in the bottom half of the mold which is the desirable orientation. However, since the checklist asks the part designer if they have placed bottom ribs outside core-out areas, this could be avoided from the start.



The design checklists bring the design realms together to interact.

Figure 5.1.1

The attached checklists are not intended to be all encompassing, nor are they rules which can not be broken. They address the major issues associated with circuitry insert molding and are meant to facilitate thoughtful design of the parts, inserts, and molds. As these only represent issues surrounding insert molding, all design "best" practices for molded parts, molds, and stampings need to be referenced in addition to following through the checklist items. As stated before, these checklists are merely process tools and can not be effective without technical competence in the various development functions.

5.1.3 Implementing the Design Checklists

We recommend implementing the checklists in several phases. First, the checklists should be implemented within one engineering group as test. This group can use the lists on several projects and evaluate the impact along with the areas of the checklist and the process which need improvement. After the first cycle of use, the checklists and procedures should be improved by the team. At that point, they can be phased into other groups with the first group acting as internal consultants.

Choosing the right first group is critical. The checklists will not make any difference if they aren't used during the design phase. If they are used in an "after the fact" manner, they will not impact the design and will be deemed a failure by the organization destined to collect dust on the shelf along with 99 percent of the other three ring binders. The goal is to change the design up front! This, of course, is easier said than done. Given the entrenched culture and thought process, implementation will require a team that wants to be successful with a champion as a manager that can remove organizational roadblocks and that will force the team to adhere to the checklists even when it hurts. The recommended development team members are shown below in **Figure 5.1.2**.

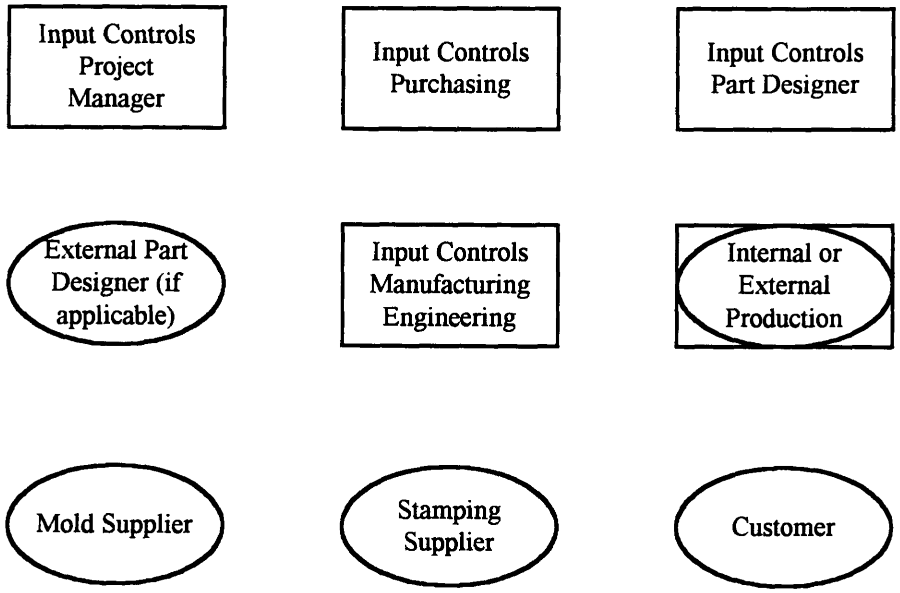
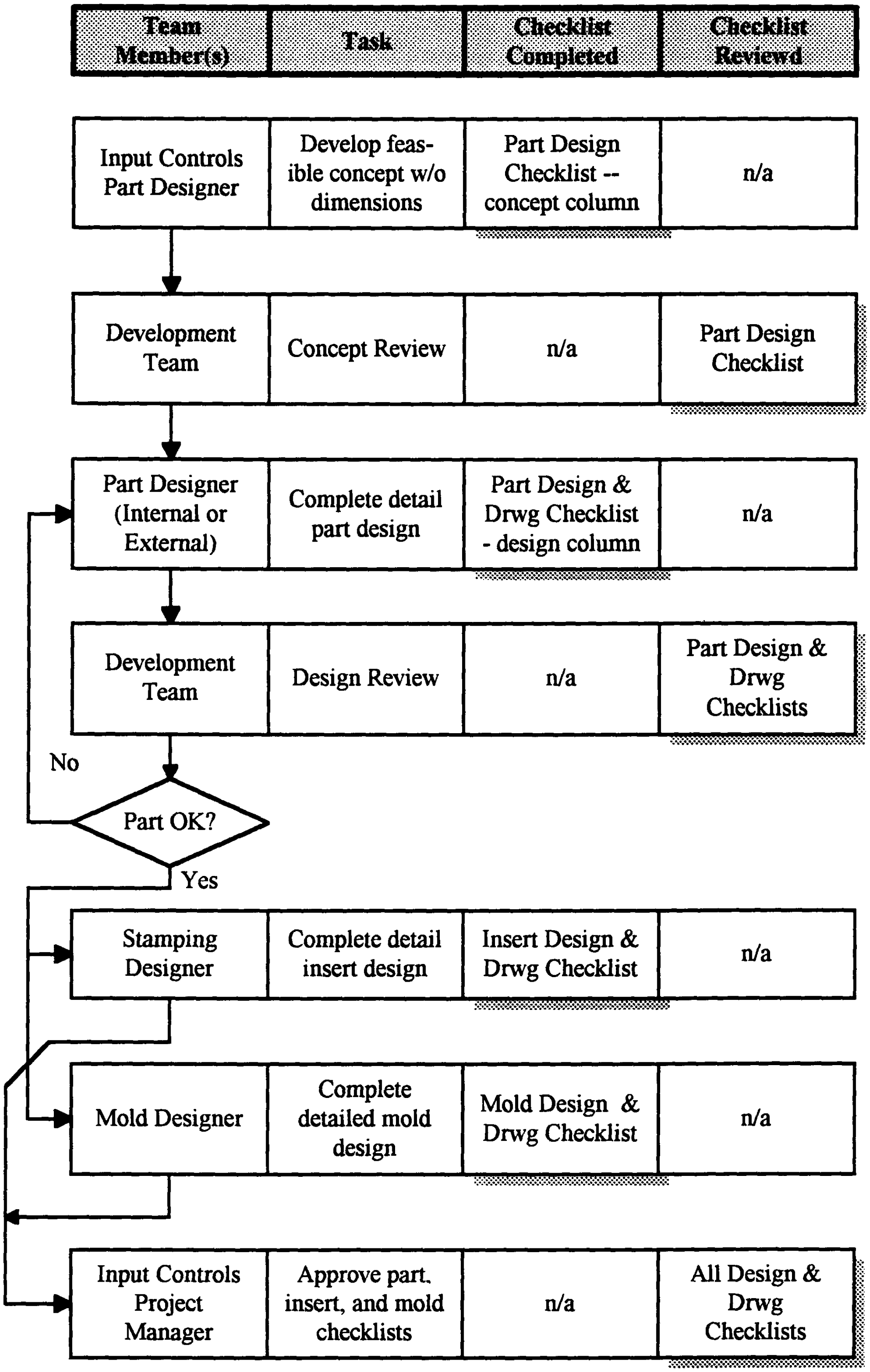


Figure 5.1.2: Recommended Development Team

The recommended procedure for using the checklists during the development cycle are summarized in **Figure 5.1.3**. The steps are generic so that they will apply whether the part design is done internally or externally through a second tier supplier.



Team Member(s)	Task	Checklist Completed	Checklist Reviewd
Input Controls Part Designer	Develop feasible concept w/o dimensions	Part Design Checklist -- concept column	n/a
Development Team	Concept Review	n/a	Part Design Checklist
Part Designer (Internal or External)	Complete detail part design	Part Design & Drwg Checklist - design column	n/a
Development Team	Design Review	n/a	Part Design & Drwg Checklists
Stamping Designer	Complete detail insert design	Insert Design & Drwg Checklist	n/a
Mold Designer	Complete detailed mold design	Mold Design & Drwg Checklist	n/a
Input Controls Project Manager	Approve part, insert, and mold checklists	n/a	All Design & Drwg Checklists

Figure 5.1.3: Using the Design Checklists within the Development Cycle

5.2 Results of Design Checklist Study

Six individual checklists were developed through this effort. There were three areas of concern: parts, inserts, and molds. Two checklists were developed for each of the three areas resulting in six total checklists.. The first checklist type was for design and the other was for drawings. For example, the part designer would complete one checklist to ensure he/she had considered all the critical issues for any given part design. Another checklist would be completed to ensure that the final drawing contained the right information for the designer's downstream customer.

5.2.1 Checklist Format

The format of the checklist is shown in **Figure 5.2.1**. The checklist concept is that the part, insert, and mold designers fill out a design checklist for each part they design. In this way, the checklist will help ensure that design for manufacturability issues are addressed for each part.

The format was deliberately designed so that the justification for any specification was documented immediately beside the requirement. In this way, the designer can evaluate if the specification applies for the given reason. If it did not, the designer does not have to comply and should document the reason why on the checklist.

The person responsible for maintaining the checklists is listed at the bottom of each checklist, so anyone who has a suggestion will be able to find the right contact person.

5.2.2 Checklist Communication Medium

The initial intent was to have the designers use paper copies of the checklists. However, since the checklist is simply a word process document, it can be easily integrated into computer networks. Input Controls will implement the checklists on their PC network which is available to all designers. This will make the checklists much easier to update and distribute. The designers may even be able to complete the checklists inside their terminal and print out the completed form for documentation purposes.

Insert Molded Part Design Checklist

#	Item	Justification	Concept Phase	Detailed Design Phase	Comments *(comment for "No" or "N/A")*
1.			☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	
2.			☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	
3.			☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	
4.			☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	☐ Yes Initials: ____ ☐ No ☐ N/A Date: _____	

Project Title: ____________________

I certify this checklist has been completed fully and accurately:
Project Manager: ________________

Project No.: ____________________

Notes:

1) The project manager should sign-off on all checklists after designs are complete. However, designers should fill out the checklists <u>during</u> the design phase.
2) Any recommendations to improve this checklist should be forwarded to Rick Ratke at Input Controls.

Figure 5.2.1: Example of Checklist Format

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[1] Wheelwright, Steven C.; Clark, Kim B.; Revolutionizing Product Development; New York, Free Press.

2 Wheelwright, Steven C.; Clark, Kim B.; Revolutionizing Product Development; New York, Free Press; p. 234.

[3] Wheelwright, Steven C.; Clark, Kim B.; Revolutionizing Product Development; New York, Free Press; p. 235.

6.1 Introduction

This chapter discusses the purpose, procedure, results for the insert molding experimental work completed at the Taylor Molding facility. Recommendations for improving Taylor's operations are also included. Much of the contrent of this chapter was taken directly from a report previously issued to Input Controls for implementation within their firm.

6.1.1 Purpose of Taylor Processing Study

The primary goals for the project were to determine how Taylor can reduce defects and decrease cycle time for insert molded parts. The secondary goals were to make specific recommendations that could be incorporated into Taylor's operating procedure and to address implementation issues. Although part and mold design strongly impact processing, they were not addressed in this project. They were, however, addressed in a separate project for the Input Controls Design and Manufacturing Engineering Groups.

The required experiments and research for this project were completed on the most problematic insert molded part at Taylor, a terminal block for a multi-function switch, which is produced on the D4 machine. It has an irratic defect rate and secondary operations which strongly affect the cycle time. Our hope was that by focusing on one single process, we could better isolate the defect contributors and cycle time bottlenecks. Once understood for the D4 machine, these same issues could be address for other insert molding machines at Taylor.

6.1.2 Production Equipment

The terminal block is produced on a vertical 150 ton Newbury shuttle table insert molding machine. In the shuttle type machines, the core is held by the clamp and two identical cavities are fixtured to the ends of the shuttle table with each side being used on alternating shots. The mold has two cavities. Unfortunately, it was redesigned several times during and after development. Consequently, a significant amount of its surface is weld build-up from the rework. Generally, weld build-up reduces a tool's durability which has been observed for this tool through a higher than normal tool failure rate.

6.1.3 The Terminal Block Part

The terminal block part is a circuitry insert molded part. It is comprised of 30 percent glass filled nylon molded around one large flat copper stamping. The part forms the base of a switch assembly used in the control panel of an automobile. The part and mold were designed under extremely short timing constraints and were not optimal at the tool's start-up. Consequently, the design for each has been revised several times to improve manufacturability.

6.1.4 Production Performance

Production has frequently been plagued with high defect rates since the tool was first brought into production. It is likely that tool and part design had a significant impact on the defect rate; however, it was unclear why it was so irratic and why so high. Despite part and tool design changes and concentrated effort by the operations team before this project, the process could not be brought into control below a 5 percent defect rate over a sustained period.

The production and defect rates for August 1993 are shown in **Figure 6.1.1**.

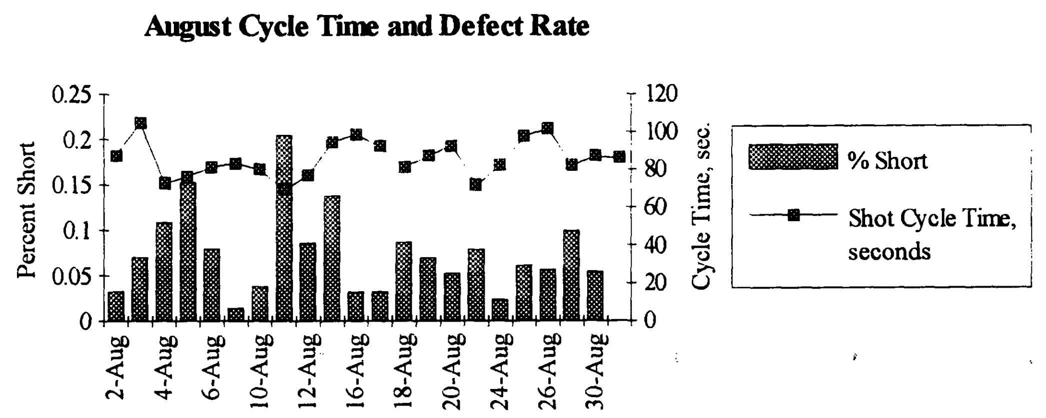


Figure 6.1.1 August 1993 Terminal Block Production and Defect Rates

6.2 Results of Experiments

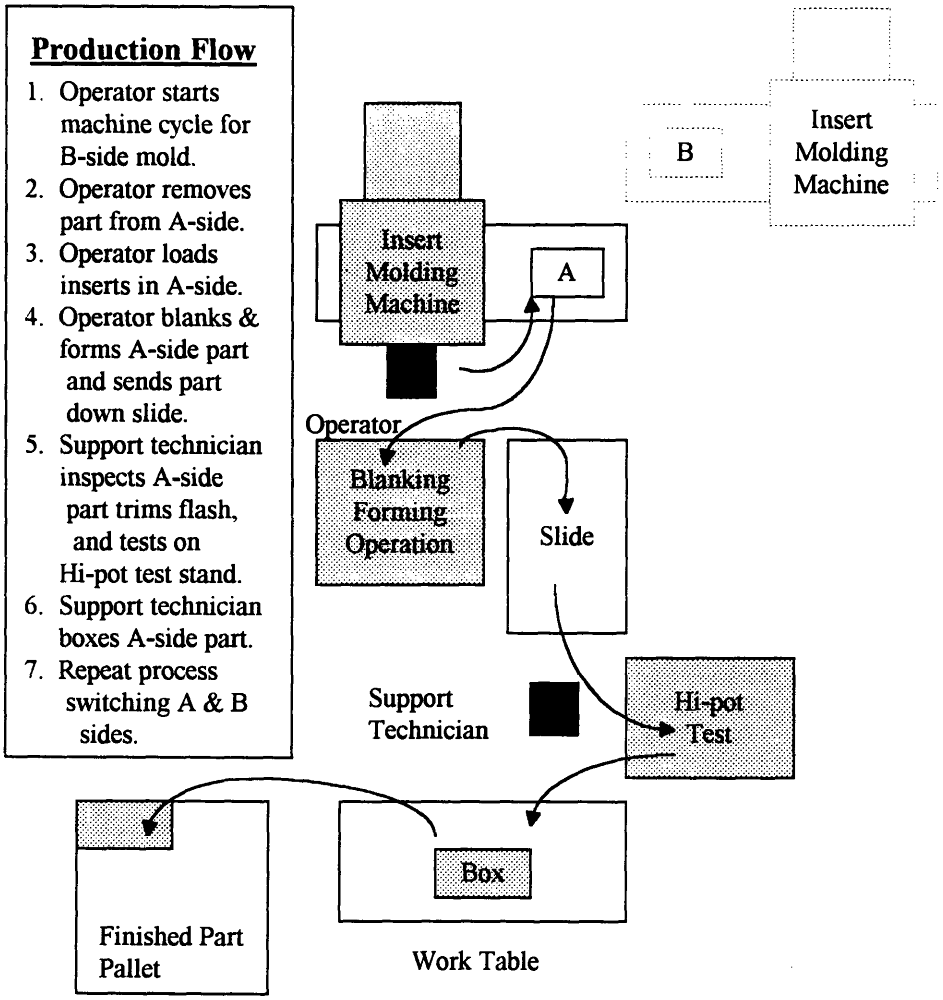
Results for Experiments 1 and 2 are summarized under the appropriate headings below. We had planned a third experiment but could not schedule it into the production window before the end of the project. This experiment along with recommended follow-up work is summarized in the third section titled "Recommended Follow-up Experiments."

6.2.1 Results: Experiment 1 -- Initial Screening Study

In the first experiment we strictly monitored the process and did not perturb it in anyway. We had three goals: 1) to correlate part defects to specific processing conditions, 2) to establish a baseline performance in terms of clamp-to-clamp cycle time and defect rate, and 3) to understand the human factors of the process.

Defective parts were either short shots or parts with inadequate voltage breakdown resistance. Short shots were identified by a visual inspection. Voltage breakdown failures were identified by an electrical potentiometer test. The potentiometer or "hi-pot" test identified if any of the circuit paths were shorted out by attempting to pass a current through each open circuit. If an electrical potential could be developed, the circuit was not open and the part was defective. Both inspection tests were part of the normal procedure and were done at the machine by the support technician.

Two operators worked together to make the part -- a machine operator who operated the injection machine and secondary blanking equipment and a support technician to inspect, test, and package the parts. The equipment layout and part flow for the experiment are shown in **Figure 6.2.1**.



Production Flow

1. Operator starts machine cycle for B-side mold.
2. Operator removes part from A-side.
3. Operator loads inserts in A-side.
4. Operator blanks & forms A-side part and sends part down slide.
5. Support technician inspects A-side part trims flash, and tests on Hi-pot test stand.
6. Support technician boxes A-side part.
7. Repeat process switching A & B sides.

Figure 6.2.1 Equipment Layout and Process Flow

Two types of data were collected during the experiment. First, high speed profile data (20 Hz sample time) was collected for hydraulic pressure, nozzle pressure, cavity pressure, and nozzle temperature. These parameters identified anomolies which occurred during each injection cycle. The expected high speed profiles are shown in **Figure 6.2.2**. The second type of data was summary data for each shot. Summary data included peak pressures, temperatures, and overall cycle times. This data was used to compare one shot versus another on a numerical basis. It should be noted that the high speed data also was used to identify differences between shots, but no formal analysis was completed to compare profile shapes or area under the pressure curves. The parameters that were monitored and the sampling frequency are listed in **Table 6.2.1**.

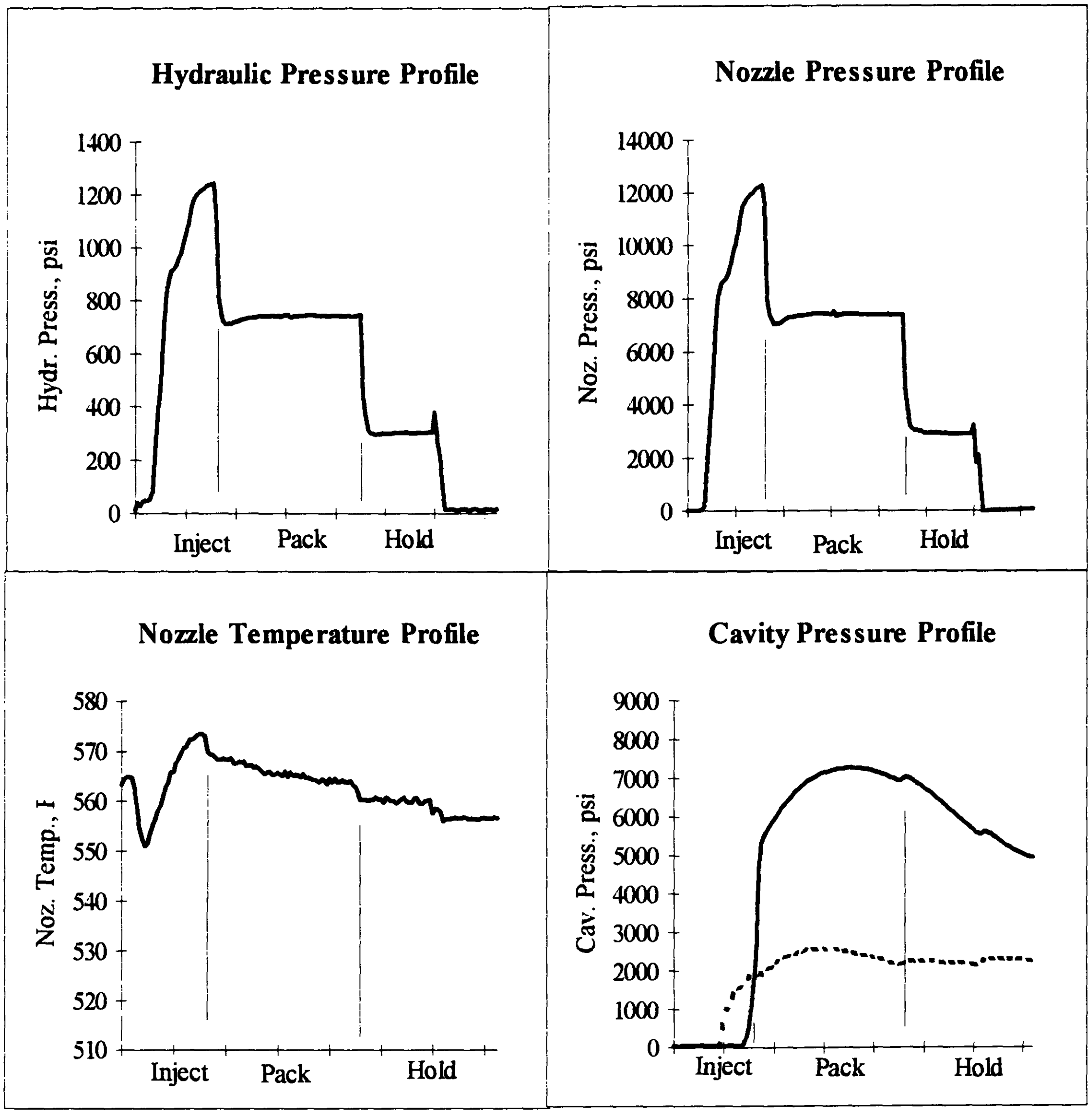


Figure 6.2.2 Typical Injection Cycle Profiles

Process Parameter	Frequency	Process Parameter	Frequency
Hydraulic Pressure	20 Hz	Max. Hydraulic Pressure	1/Cycle
Nozzle Pressure	20 Hz	Max. Nozzle Pressure	1/Cycle
B1 Gate Pressure	20 Hz	A-side Cavity Temp.	1/Cycle
B1 Cavity Pressure	20 Hz	B-side Cavity Temp.	1/Cycle
Max. Screw Position	1/Cycle	Core Temp.	1/Cycle
Min. Screw Position	1/Cycle	Clamp-to Clamp Cycle Time	1/Cycle

Table 6.2.1 Parameters Monitored in Experiment 1

Experiment 1 -- Results and Analysis

The experiment captured 702 shots of data over a continuous 20 hour period. Approximately the last four hours of data, or 103 shots, were not included in the analysis because they had abnormal profiles. These profiles occurred after the machine controller set-points were changed at the 16 hour point in order to reduce the short shot defect rate. The new set-points resulted in marginally unstable control and resulted in inconsistent pressure profiles which could not be compared to each other or the shots from the first 16 hours of the experiment.

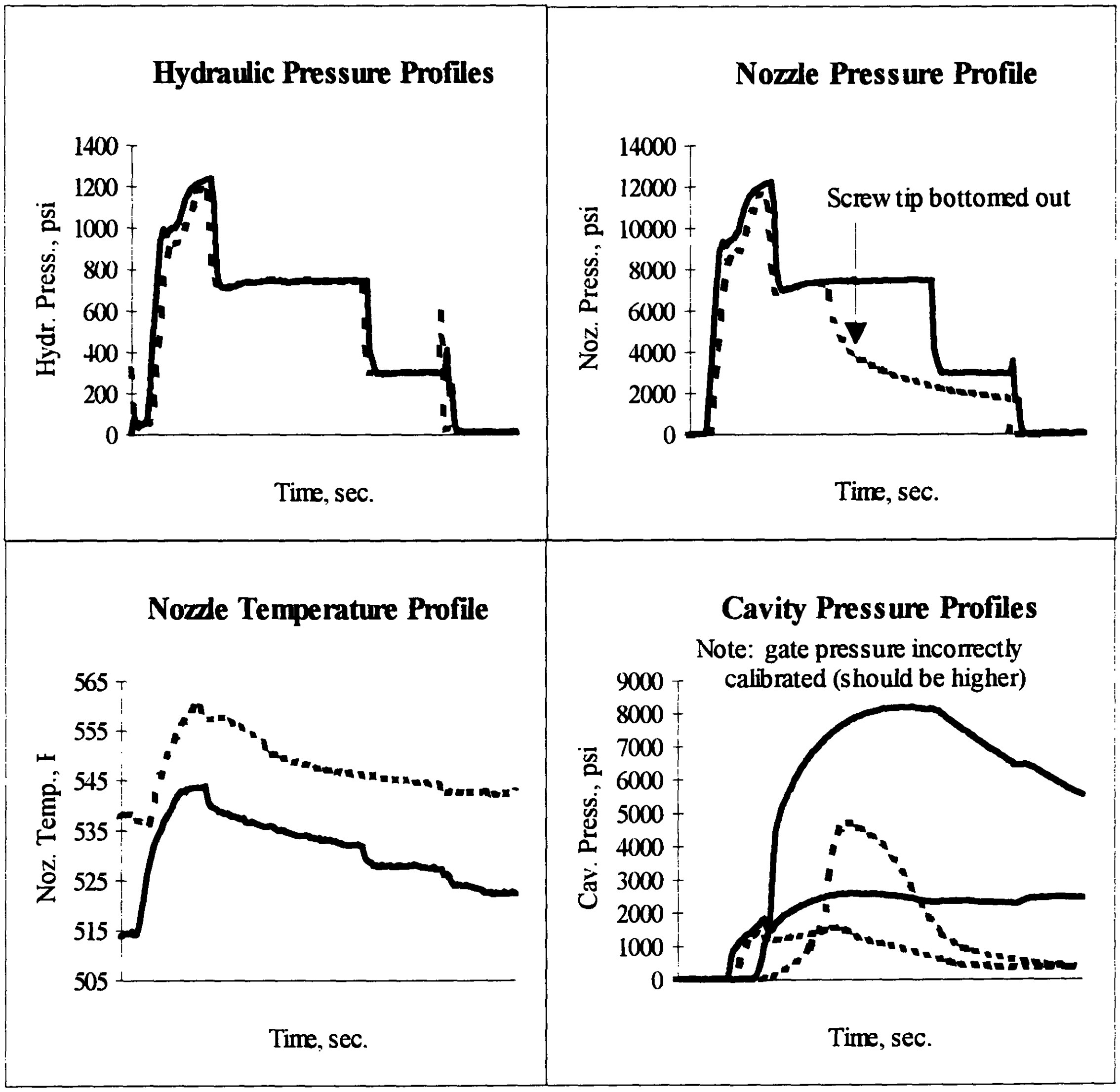
Our analysis included the remaining 599 shots of data. The results are summarized in **Table6.2.2**. There were 95 shots which produced at least one defective part in the two cavity molds. Of these, 90 could be correlated to a zero custion condition where the screw bottomed out against the screw tip. The remaining 5 shots had ample cushion and were not found to correlate with any other parameters. As shown in **Table 6.2.2**, the mold was balanced in terms of producing equal number of defects on each side.

Defect Breakdown

	A-side	B-side	Total	Percent of Shots With Zero Cushion
Single Part Defects	14	14	28	85.7%
Double Part Defects	32	35	67	98.5%
Total Defect Shots	46	49	95	94.7%
Good Shots	253	251	504	68.3%
Total Shots	299	300	599	72.5%

Table 6.2.2 Experiment 1 Results Summary

Although it may seem obvious, it was not a simple matter to determine the screw was bottoming out against the screw tip. As shown in **Figure 6.2.3** for a "zero cushion" shot, the hydraulic profile is normal, while the nozzle and cavity pressure profiles show a loss of pressure during the shot. All the zero cushion defect shots exhibited this loss of nozzle and cavity pressure during injection. The hydraulic pressure is usually the only available pressure to use in troubleshooting, so it did not identify the problem. Additionally, it was impossible to tell that the screw was bottoming out by visually inspecting the machine's operation. The position indicator isn't calibrated physically or in the controller to bottom out at zero on the physical or controller scale.



The dashed line represents the profile of the shot where the screw bottomed out. The solid line is a normal profile for comparison. Note that it isn't possible to determine that the screw bottomed out from the hydraulic pressure profile.

Figure 6.2.3 Pressure Profiles for a Zero Cushion Shot

It is worthwhile to note that a process monitoring program would have identified the problem as the final screw position did shift over time.

The physical cause for the screw bottoming out during injection is that the screw runs out of plastic during the packing or holding phases of the shot leaving no material in front of the screw to hold the resin under pressure. In the absense of the hydraulic resistance, the screw advances forward all the way to the screw tip trying to meet the pack or hold pressure setpoints. The fishbone diagram of the causes of running out of plastic during the shot is shown below in **Figure 6.2.4**.

Since many of the shots during the experiment did not run out of plastic, we assumed the machine shot size setting was adequate. This left two potential causes. First, there could have been an inconsistent charge in the barrel leaving insufficient material to fill the mold for many of the shots. Second, it could have resulted from leakage past the check-ring inside the barrel.

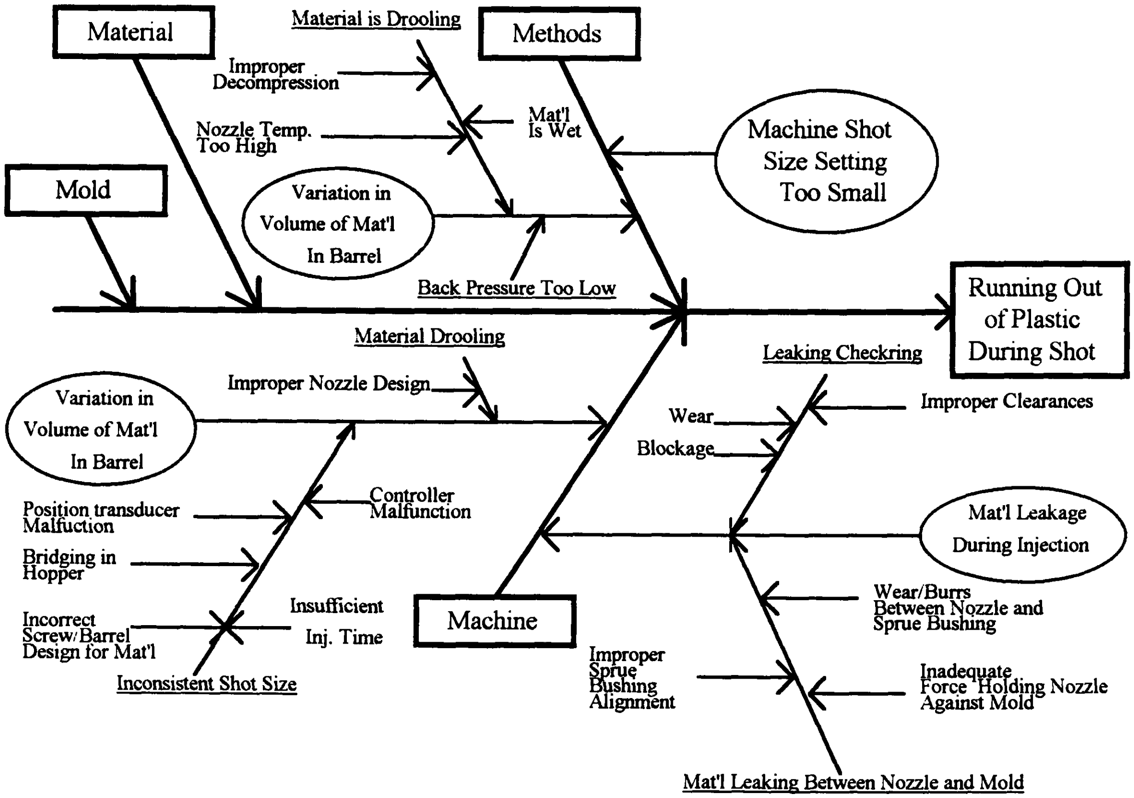
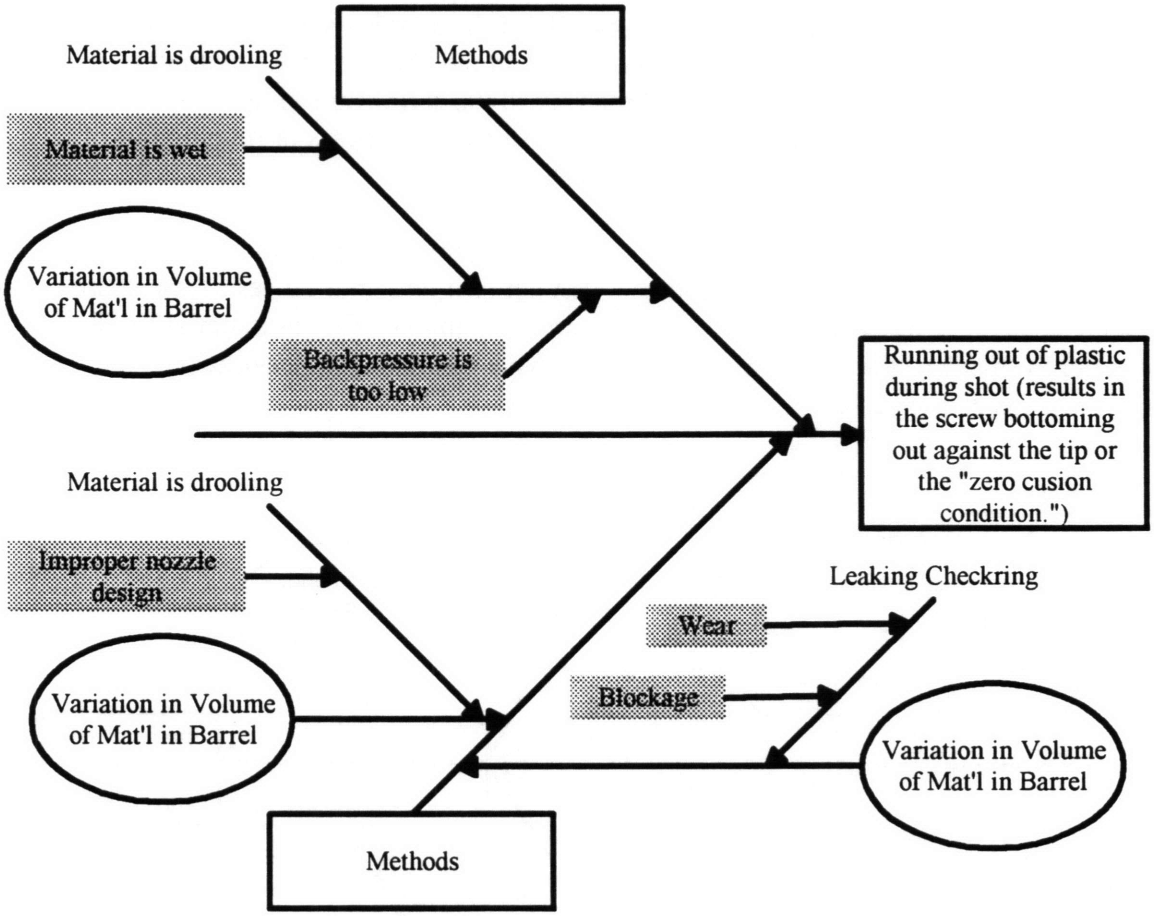


Figure 6.2.4: Fishbone Diagram for Running Out of Plastic During Injection Cycle

As indicated in **Figure 6.2.4**, there are a number of machine and methodology issues that can contribute to the two potential causes identified. However, we narrowed the field down to the most likely contributors shown in the diagram in **Figure 6.2.5**.

addressed in attempt to eliminate the zero cushion condition causing 95 percent of the defects in Experiment 1.



Note: shaded areas were the items identified in the experiment which needed to be addressed.

Figure 6.2.5 Potential Defect Contributors Identified Experiment 1

Experiment 1 -- Actual Defect Contributors

After further investigation and follow-up work, several items were isolated as the actual defect contributors. The most obvious and pervasive problem identified was drool out of the nozzle between shots which added to shot size variation. We believed that drool was particularly critical because the machine was set up to transfer from injection to pack based on screw position. For each shot with a sizable volume of drool, the machine would transfer to the pack phase before the mold was filled contributing to short shots. We found that it could not be controlled by changing operating conditions (decompression, nozzle temperature, backpressure, etc.) and that it was not a result of wet material. This was singled out as the biggest contributor to short shots and as the factor to be addressed in experiment 2 by the installation and testing of a shut-off nozzle.

Several other issues were also found to be problematic but not to the degree of drool. All of these were addressed shortly after the experiment, yet the short shot rate did not fall significantly. The first of these was backpressure. The setting was extremely low (10-20 psi) during the experiment which could have contributed to inconsistent material volume inside the barrel. Second, the screw and check ring were due for replacement and were likely worn contributing to leakage past the check ring during injection. Finally, the machine's hydraulic system integrity was questionable. Although the injection profile was adequate during the experiment, the hydraulic pump failed a few weeks later. The replacement pump appeared to provide a higher system pressure and flow rate which was observed by the plant personnel as a shift in the clamping system dynamics (for the better) which can impact flash.

Experiment 1 -- Additional Observations

In addition to gathering processing data, several other observations were made during Experiment 1 in regard to processing. First, whereas consistency is normally the standard in computer controlled molding operations, the human element of this operation added to cycle variation. The cycle time variation for the entirety of Experiment 1 is shown in **Figure 6.2.6**. Although the defects could not be correlated with cycle time in any way for the experiment, we believed that the variation in cycle time significantly impacted process variability and, therefore, should be addressed in future work.

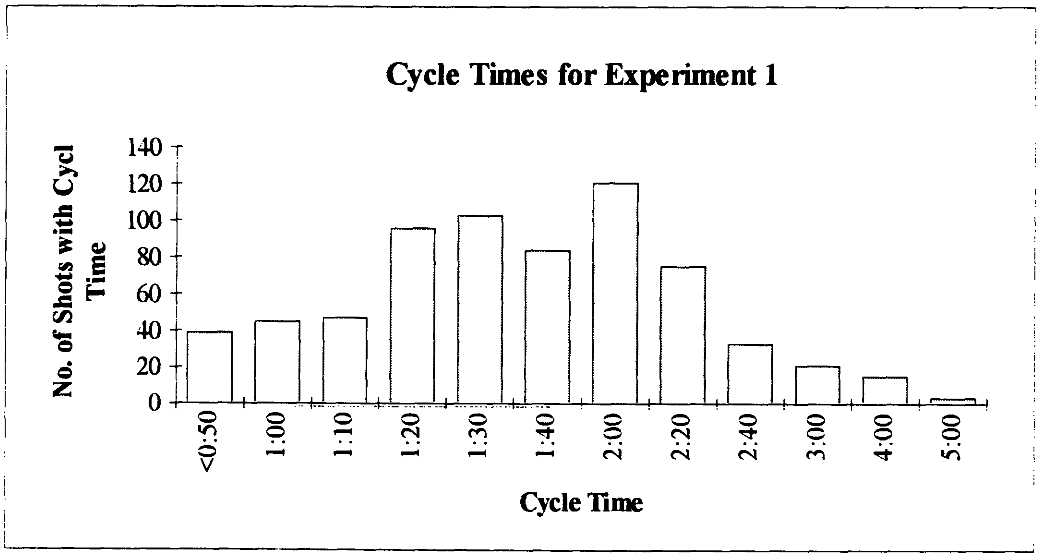


Figure 6.2.6

Second, we observed significant variation in the flash at the mold parting line during the experiment. We also observed that flash strongly impacts throughput as it is normally trimmed manually with a razor blade by the support technician. The current operating strategy appears to focus on the operation of the molding machine as the governor of throughput. However, it was evident during the experiment that the secondary support technician could bottleneck production as flash increased. It appeared that it was a vicious cycle because if flash increased suddenly, the machine operator would slow down to help the support technician to trim flash. The resulting increase in cycle time aggravated the problem by contributing to even more flash.

The last observation during Experiment 1 was that the troubleshooting methods used by the plant personnel were often inconsistent with proven injection molding troubleshooting techniques as well as process troubleshooting standards in general. The methods observed and their potential impacts are listed in **Table 6.2.4**.

Table 6.2.4 Troubleshooting Methods Observed During Experiment 1

No.	Observation	Process Impact	Comments
1.	Troubleshooters did not wait for the process to come to equilibrium between set-point adjustments.	Until the process lines out and temperatures come to an equilibrium, it is impossible to determine if the setpoints are satisfactory.	An industry rule of thumb is to wait 10 cycles between adjustments. This was rarely provided. The most common problem observed was not waiting for 10 or more cycles before the next adjustment. The other problem observed was when the troubleshooter adjusted the machine and walking away assuming the problem was fixed. Even though the problem may disappear initially, it would often reappear as the machine came to equilibrium.
2.	Troubleshooters did not document process setpoints adequately.	Documenting what works provides a baseline you can always return to.	I did not observe any formal documentation of process setpoints. There is an unformatted log book, but it doesn't appear to be used. At one point during the experiment, a process technician asked me if I had written the setpoints down for the previous day. When I said "no," the technician resorted to a set-up sheet dated in May (the experiment was in August).
3.	Troubleshooters changed more than one thing at a time.	It is impossible to determine the process impact if you change more than one thing at a time (one move may counteract another).	During one troubleshooting episode during the experiment, three people were troubleshooting the machine. Several times, two of them changed things independently at the same time without discussing it. We then waited to see the net effect of the two changes in the next cycle. I am confident that this added to process variability.

No.	Observation	Process Impact	Comments
4.	Troubleshooters (on the same shift or on different shifts) rarely worked or communicated as a team.	Unless everyone works in a concerted effort, process changes by different technicians (on the same or different shifts) can work against each other and add to process variability.	On one shift during the experiment, the two process technicians disagreed on how the machine should be adjusted to reduce short shots. Instead of agreeing to disagree and letting one person work the problem, they both periodically adjusted the machine over the shift often reversing the other person's adjustment. My guess is that this is a rare occurence on the same shift, but that it is fairly common between shifts. Shift-to-shift "optimization" is a prevalent problem in manufacturing and adds to process variability.
5.	Troubleshooters did not use a structured troubleshooting methodology.	Increased process variability.	An associate of Rodney J. Groleau, a guru in injection molding, recently taught a class at the Peru, Indiana plant. His number one rule for systematic injection molding was "*Always have a logical reason for doing everything.*" I am not convinced that technicians were consistently using the same rules of logic as a structure to troubleshoot the D4 machine.

Experiment 1 -- Conclusions

The major conclusions drawn from Experiment 1 and the subsequent follow-up activities are summarized below.

Drool is the largest contributor to short shots. To address this, we decided to install and test a shut-off nozzle on the machine during experiment 2. Wet material was not found to be a cause of the drool.

Cycle time variation needs to be addressed. Although the impact on process variability could not be addressed, processing experience suggests that it strongly impacts flash which in turn was found to significantly impact throughput.

A troubleshooting structure is needed at Taylor. Much of their process variability could be removed by a better troubleshooting methodology.

6.2.2 Results: Experiment 2 -- Reducing Short Shot Defects

The second experiment focused on eliminating drool with the installation of a shut-off nozzle. Our primary objective was to install the shut-off nozzle and determine its impact on drool and the process. Our hope was that by eliminating drool, we could isolate other defect contributors that were previously masked by the drool. Our secondary objective was to complete a design of experiments to minimize flash and defects with the shut-off nozzle installed. Unfortunately, we were only able to meet the first objective as a special order heater band failed on the new nozzle on the third day of operation preventing us from completing the optimization work to further reduce short shots and to improve flash.

As in the first experiment, short shot and voltage breakdown defects were identified through the normal inspection procedure. The data acquisition and the experimental methodology were also similar to those used in Experiment 1.

Experiment 2 -- Initial Results of the Experiment

The production and defect rates for Experiment 2 are shown in **Figure 6.2.7**. As shown by the plot, the defect rate dropped significantly while the shut-off nozzle being used (November 12-13). There were 22 defects out of 4260 parts produced. This equates to a defect rate of one half of one percent compared to an average of over five percent during the four month period of August through November.

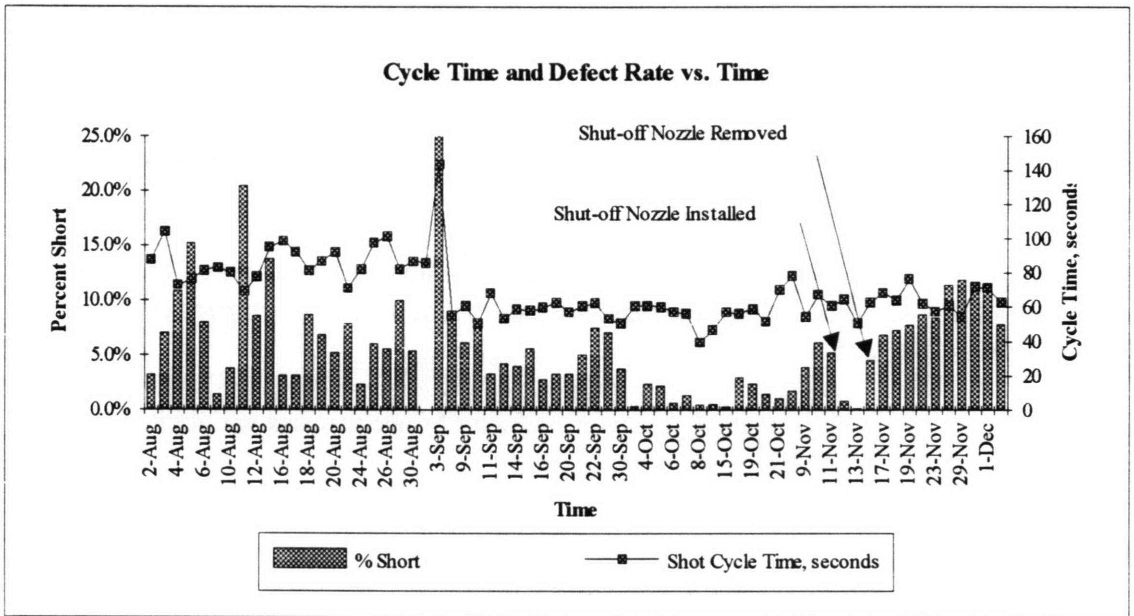


Figure 6.2.7

The impact of the shut-off nozzle on short shots exceeded all expectations. It is worthwhile to note that Taylor did have one period with a very low defect rate in October. However, it was not sustained, and we were unable to acertain why it was so low. Our belief has been that this process can be run with a very low defect rate if all the operating conditions are perfect. We surmise that the process set-points, the operator methods, and the material were ideal during the October window. Given that it was not sustained and that it can not be explained, we are not using it as a baseline for comparison of the shut-off nozzle. Instead, we consider the nozzle to be a success compared to the average defect rate demonstrated by Taylor. Additionally, we saw step changes in the defect rate over 5 percent when the nozzle was installed and then removed three days later.

The results were particularly encouraging when you look at the production data during the experiment shown in **Figure 6.2.8**. The nozzle worked across a fairly wide range of production rates demonstrating that it is a robust solution not requiring special operating procedures. It does appear that the defects could correlate with very long cycle times as three out of five of the defect spikes occurred during periods with very long cycle times, but it is impossible to make any firm conclusions from the available data.

Repeatability was also improved with the shut-off nozzle. Part weight variability decreased slightly supporting this fact, but it was more evident during process tuning. When we first started the machine up with the shut-off nozzle, the shots were all short because we hadn't tuned the process yet. The "degree of shortness" was extremely consistent. This constrasts the large variation observed in the typical short shots without the shut-off nozzle (during start-up or normal operation).

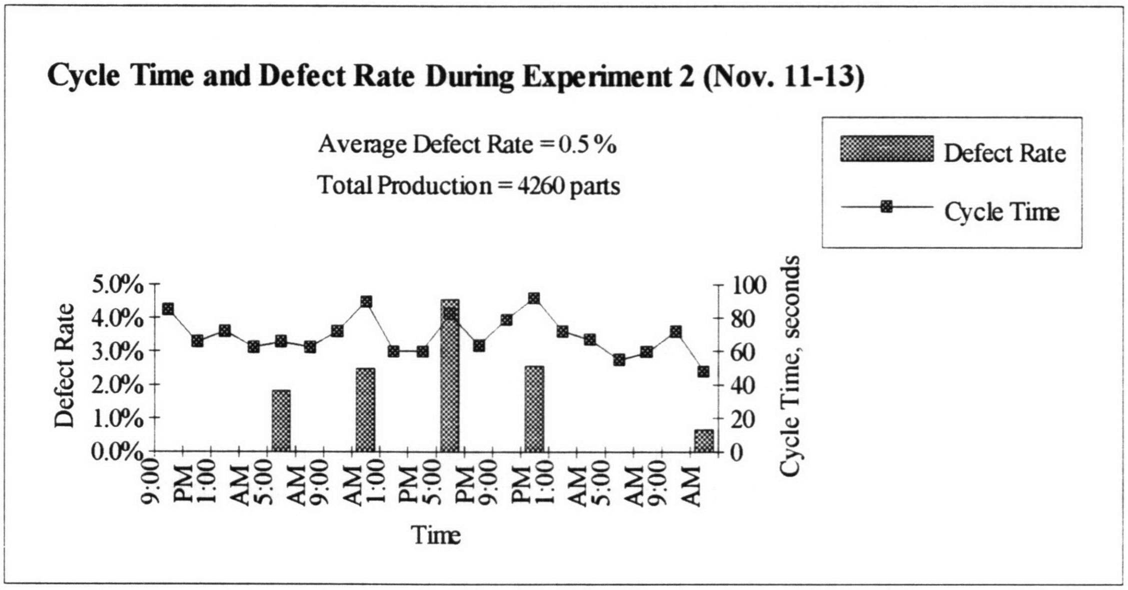


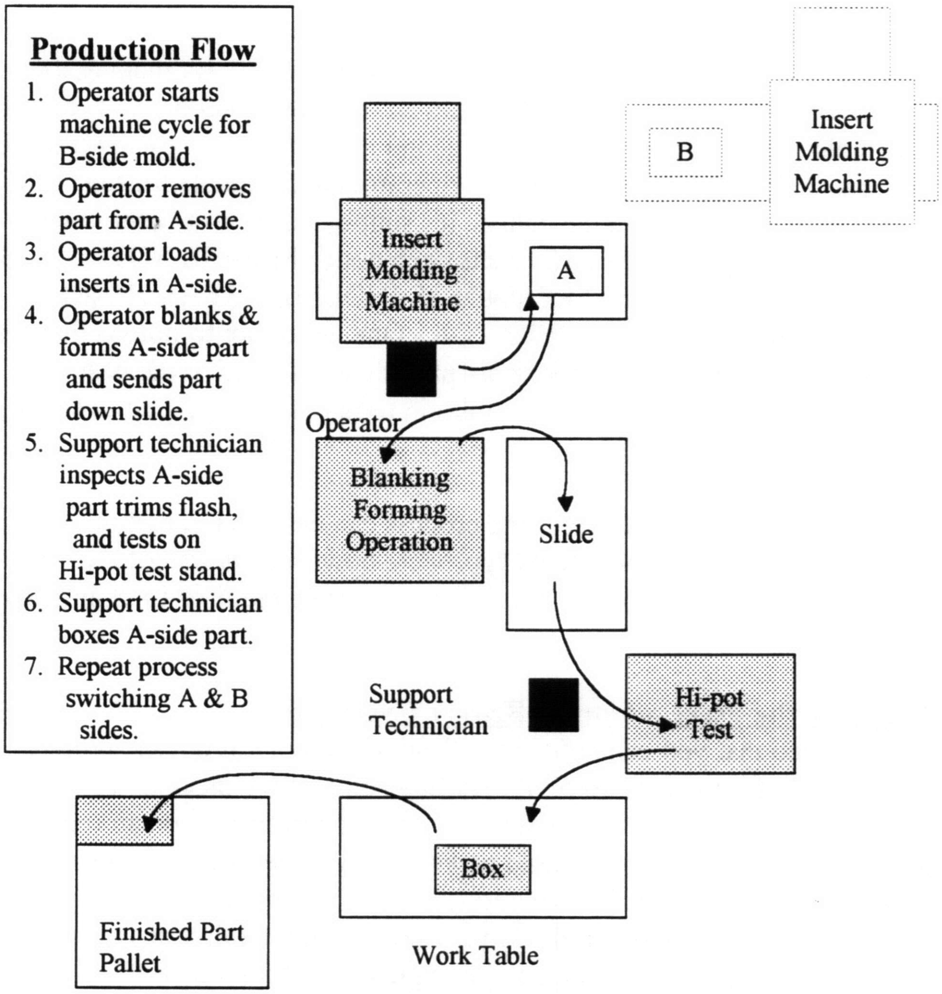
Figure 6.2.8

The economic returns of the shut-off nozzle were significant. A very conservative savings estimate for the experiment window are included below in **Figure 6.2.9**. These economics are conservative because they are based on the transfer cost and do not

6.2.3 Results: Recommended Follow-up Experiments to Reduce Flash and Cycle Time

This section summarizes the recommended follow-up work for the terminal block part at Taylor. The next step is to eliminate flash, the current bottleneck, from the process. If flash is eliminated, the support technician who currently trims the flash will be free to take over the blanking operation from the machine operator (see **Figure 6.2.10** for the equipment layout and part flow). This in turn will allow the operator to reduce the overall cycle time of the process.

The initial work for this effort was planned for Experiment 3 in December but was not completed due to equipment and scheduling problems. The procedures for this work are outlined in this section in hope that the work is carried forward. A two phase approach is presented: First, we should verify that flash can be eliminated at the current cycle time. Second, shift the blanking operation to the support technician and reduce the cycle time.



Production Flow

1. Operator starts machine cycle for B-side mold.
2. Operator removes part from A-side.
3. Operator loads inserts in A-side.
4. Operator blanks & forms A-side part and sends part down slide.
5. Support technician inspects A-side part trims flash, and tests on Hi-pot test stand.
6. Support technician boxes A-side part.
7. Repeat process switching A & B sides.

Figure 6.2.10 Process Flow and Equipment Layout

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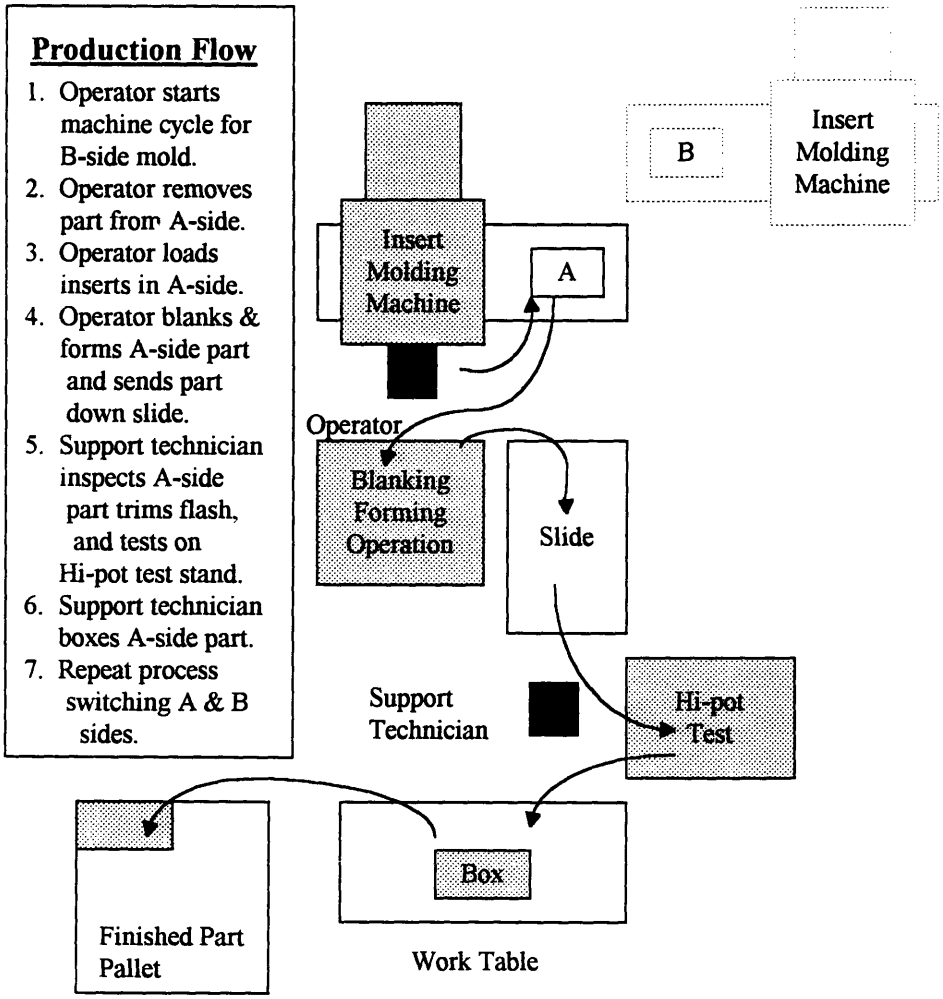

Production Flow

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6. Support technician boxes A-side part.
7. Repeat process switching A & B sides.

Figure 6.2.10 Process Flow and Equipment Layout

Phase 1: Eliminating Flash at the Current Cycle Time

To address flash, we first need to realize that shot consistency is a critical factor -- this is provided by the shut-off nozzle. Second, we need to standardize all the other variables in the process which primarily is accomplished through standardizing the cycle time for every shot. To do this, we need to run the same cycle time consistently every minute of every hour of every day. This is the first and most important hurdle.

Currently, the machine clamp-closed-to-clamp-open cycle time is set at about 45 seconds. However, overall process (clamp-closed-to-clamp-closed) runs at approximately a 60 second cycle time. Most operators can't run the machine consistently at the 45 second cycle time. They can do it for a while, but not all day every day. My guess is that most operators know they can't meet the cycle time, so they don't put a lot of effort into trying. In their mind, if they miss it by 5 seconds, they may as well miss it by 10, 20, or even 30 or more seconds (that's the way my mind works anyway).

I propose to set the clamp-closed-to-clamp-open cycle time to 60 seconds by changing the mold open delay so that the mold opens at the 60 second mark. By making it 60 seconds, the operators will have a realistic pace and an obvious signal of the cycle time -- as soon as the mold finishes opening at the 60 second mark, the operator should start the next cycle. It will also make it easier to hold operators accountable for the cycle time without resorting to a watchdog mentality. It's simply a matter of determining whether they have made approximately 120 parts each hour. PLEASE NOTE THAT WE NEED TO CONFIRM THAT 60 SECONDS IS INDEED A REASONABLE CYCLE TIME FOR THE TYPICAL OPERATOR. One good fact to note is that a 60 second cycle time is about the best the operators have demonstrated in the past. Therefore, it should be reasonable, but not harmful in terms of meeting past production rates.

Once the cycle time has been standardized, the process can be tuned to minimize flash. Our plan was to use a design of experiments approach; however, this is not the only and not necessarily the best approach. Mold modifications may be required to eliminate all the flash.

Phase 2: Modifying the Process Flow to Reduce Cycle Time

Once you are convinced that you can reduce the flash to the point it doesn't require trimming, you are ready for the next step. By shifting some of the machine operator's work to the support technician, the blanking and forming operation, you can reduce the cycle time further. The final cycle time could be limited by either the machine operator or the support technician. It may be possible to split the blanking operation by having the machine operator place the parts on the fixture and cycling the first phase and having the support technician flip the parts and complete the second phase.

Once the work flow is balanced and the cycle time is reduced to a manageable level for all the operators, the process should again be tuned to minimize flash.

6.2.4 Potential Economic Returns

The two main levers in the cost equation for the Taylor machine we examined are the defect rate and the cycle time. These in turn are impacted by other factors such as flash, machine downtime, the condition of the mold, etc. To help prioritize different issues, a cost sensitivity analysis was completed for defect rate and cycle time. If something is impacting either of these, one can quickly evaluate the approximate credits for eliminating the problem and make the right trade-offs depending on those credits.

My analysis along with my assumptions are attached in the **Appendix**. There is one issue about these economics which needs to be clear from the start. I am not confident about the absolute cost of the parts (they depend on machine cost rates, utilization, etc.). However, I am confident that these numbers do approximate the marginal impact. In other words, I would not base the absolute part price on my calculations, but I would base a price change on my calculations. The results are shown in plots included in the **Appendix** and can be generalized as follows:

Defect Rate's Impact on Cost

Each 5 percent increase in the defect rate results in a \$0.10/part cost increase across all good parts. For example:

> 5% defect rate at 60 second cycle time ==> \$0.10 x 960 parts/shift x 3 shifts => \$288/day

This rule is applied below in **Figure 6.2.11** to the same scenario (8/2-11/30) presented earlier using the transfer price (see **Figure 6.2.9**).

Operating Savings

Average Daily Production (Aug. 2 - Nov. 30)....................................\$2,010
Average No. of Defects (Aug. 2 - Nov. 30)..109 (5.4%)
No. of Production Days (Aug. 2 - Nov. 30)..64
Average Daily Loss Without Shut-off Nozzle @ 0.10/part x production....210
Estimated Annual Savings With Shut-off Nozzle (@ 32,000 parts/month
production rate, 0.5% short shot rate).......................................\$38,400

Required Investment

The shut-off nozzle and installation cost approximately \$3,000.

Note: See **Appendix** for assumptions used to develop economics.

Figure 6.2.11 Economic Returns of Nozzle Using Cost Accounting Techniques

Cycle Time's Impact on Cost

Each 3 second increase in cycle time results in a \$0.02/part increase across all good parts. For example:

> 3 second increase of cycle time @ 3000 parts/day ==> \$0.02/part x 3000 ==> \$60/day.

Note, the cycle time credits assume that the operators and machine can be used for different products if freed up from the terminal block.

6.2.5 Results: Conclusions

This section summarizes the conclusions we can draw from the work completed at Taylor. Specific recommendations for action are included in **Section 6.3**.

Drool was by far the single largest contributor to short shots for the terminal block part. Even on shots where the drool doesn't cause the screw to bottom out, it can significantly change the injection profile as the machine switches to the pack phase based on position irregardless whether the mold is full or not. The pneumatic shut-off nozzle installed during Experiment 2 effectively stopped the drool and, consequently, significantly reduced the short shots. Although the D4 machine clearly had the worst drool problem, a shut-off nozzle may prove a wise investment on the other insert molding machines.

Cycle time variation needs to be addressed in the insert molding operations. Although the impact on process variability could not be quantified in the experiments, industry best practices clearly show that cycle time should be held constant. In the D4 case, the variation in cycle time aggravates the flash problem which in turn can bottleneck production. By addressing the flash problem on D4, it is likely that the cycle time can be reduced by another 25 percent. In order to accomplish this, process variation must be brought under control. The two major drivers are the shut-off nozzle to control shot size and a consistent cycle time to reduce variation in other process variables.

A troubleshooting structure is needed at Taylor. As Rodney J. Groleau, a guru in injection molding, says, "Always have a logical reason for doing everything." When troubleshooting a process, this is especially important along with, working as a team, communicating process adjustments across shifts, and only changing one process parameter at a time. I observed several inconsistent and substandard practices (outlined in **Table 6.2.4**). It appeared that many adjustments were made as if "shooting from the hip." Even though they may work 95 percent of the time, they weren't working when I saw them, and they cost a lot of money.

The potential financial returns are significant for addressing drool, cycle time, and troubleshooting methods. Potential credits, along with sample calculations and my assumptions, are included in the **Section 6.2.4, Potential Economic Returns**.

6.3 Recommendations

6.3.1 Use Shut-off Nozzles to Control Drool When Other Means Fail

The drool on the D4 machine was effectively controlled by the shut-off nozzle. Shut-off nozzles should be considered for any machine meeting the following criteria:

1) The machine has visible drool that cannot be eliminated by manipulating the machine and process parameters.
2) The machine has a defect rate high enough to pay for the nozzle in one year.

Drool was the single largest contributor to defects for the terminal block part. On the D4 machine, the shut-off nozzle will easily pay for itself within a few months. The benefits are likely to extend beyond the defect improvement into areas such as reducing dimensional variation.

6.3.2 Improve Process Capability by Standardizing Cycle Time

Standardizing the cycle time is the second area which needs to be addressed for the insert molding machines. This should increase process repeatability and reduce part variability across the board, but it should be most evident in reducing flash. Given a well maintained mold, the improved repeatability combined with process tuning should allow flash to be reduced to the point where trimming is no longer required. Once the trimming is eliminated, the process cycle time can be reduced. I estimate that the D4 cycle time on the LH part could be reduced by 25 percent by eliminated flash. Unfortunately, we weren't able to verify this during the project because the third and final experiment could not be scheduled in the project window due to production schedule constraints. The recommended procedure for this work is outlined in **Section 6.2.3**.

6.3.3 Establish Troubleshooting Protocol

Two issues need to be addressed in the troubleshooting methodology at Taylor. First, a standardized methodology needs to be adopted. There is a number of good troubleshooting guidelines available. These guidelines need to be combined with a discipline to follow the guidelines and document all adjustments. Most guidelines don't recommend changing control parameters until all other factors have been ruled out. My general observation at Taylor was that the process was changed too frequently and often without considering factors like material changes, dryer operation, etc.

Teamwork is the second issue which needs to be addressed. Process adjustments and the reasons why they were made must be communicated between technicians on the same shifts and across different shifts. If technicians disagree on what to do, they should discuss it rather than optimizing machines in their own personal way on their own shifts. I recommend enforcing the use of log books and explicitly monitoring the number of times each machine's control parameters are adjusted on any given shift. In this way, technicians will be encouraged not to change the process settings unless they have a very good reason and are willing to explain that reason later.

6.3.4 Develop and Apply Metrics -- Measure What Counts When It Counts

Metrics are probably impact more in business than almost any other one item, yet they are often overlooked. Metrics drive behavior. If you have the wrong metric, you will find the wrong behavior. If you don't have a necessary metric, it's likely that you won't have a necessary behavior. Taylor should revive existing metrics or consider developing and applying new metrics for its operations in several areas.

A few examples of areas to address along with possible metrics or standards are listed below.

1) Process troubleshooting should be driven toward technicians making the right adjustment the first time.

   Possible metric: The number of times each machine is adjusted per shift should be tracked along with the machine's defect rate. Management's expectation should be that both should get smaller over time -- for each product (mold) and for the plant as a whole.

2) Operators should be expected to maintain a constant cycle time and maintain the appropriate production rate over the entire shift. THE CYCLE TIME MUST BE ACHIEVABLE FOR ALL THE OPERATORS ALL-DAY-EVERYDAY. MOLD OPEN SHOULD BE SET AT THE CYCLE TIME AS A SIGNAL TO THE OPERATOR. THE PRODUCTION RATE MUST CONSIDER BREAKS.

   Possible metric: The production for each 2 hour period for each shift, and a written explanation of why the cycle time or production rate wasn't met. This data is already collected, but it needs to formally be reported for each operator group. Note, this needs to be viewed as a tool, not as a part of a watchdog mentality.

3) The maintenance group should be rewarded for being proactive and maintaining the equipment in a way that prevents equipment downtime due to machine failure.

   Possible metric: The number of hours per month each machine is out of service due to machine failure, mold failure, or auxiliary equipment failure. The number of cycles since last maintenance, screw replacement, etc.

Please note that this is not a plug for collecting numbers for the sake of collecting numbers. I would rather not collect any data than spend time collecting worthless data. However, there are always a few numbers that can be used to monitor performance and drive behavior in a strategic direction. It's a two step process. First, decide where you want to go. Second, define performance standards that lead in that direction.

Base Case Economics

Fixed Costs

	Hours/Day	Days/Month	$/hour	$/Month
Machine Usage Cost	24	20	$16.66	$7,996.80
Overhead/Burden Cost	24	20	$20.00	$9,600.00

Variable Costs

Part Resin Cost	$0.26
Insert Cost	$0.52
Total Part Mat'l Cost	$0.78
Labor Cost/Hr	$15.00

Assumptions

1) Production demand (parts/month)		32000		
2) Production rate (parts/shift)	min ==>	500	max ==>	1000
3) No. of operators required		2		

4) D4 machine dedicated to LH part (i.e. all overhead and machine costs are absorbed by LH parts)
5) Inventory costs are static and not considered in the analysis
6) Operating scenario provides adequate time for maintenance

7) Available Production Time (hrs/mo.)	480

Economics

$$\text{Part Cost} = \frac{\text{(Machine Cost)+(Overhead Cost)+(Production Time)(\$Labor Rate)(No. of Operators)+(Production Rate)(Production Time)(Material Cost)}}{\text{(Production Rate)(Production Time)(Yield)}}$$

Sample Calculation for Average Part Cost for One Month of Production at 95% Yield at 600 parts/shift Production Rate

$$\text{Part Cost} = \frac{\text{(\$7997) + (\$9600) + (427)hrs(15)\$/hr(2)workers +(600)parts/shift(427)hrs(1/8)shifts/hour(0.78)\$/part}}{\text{(600)parts/shift(427)hrs(1/8)shifts/hr(0.95)}} = \text{\$1.82/part}$$

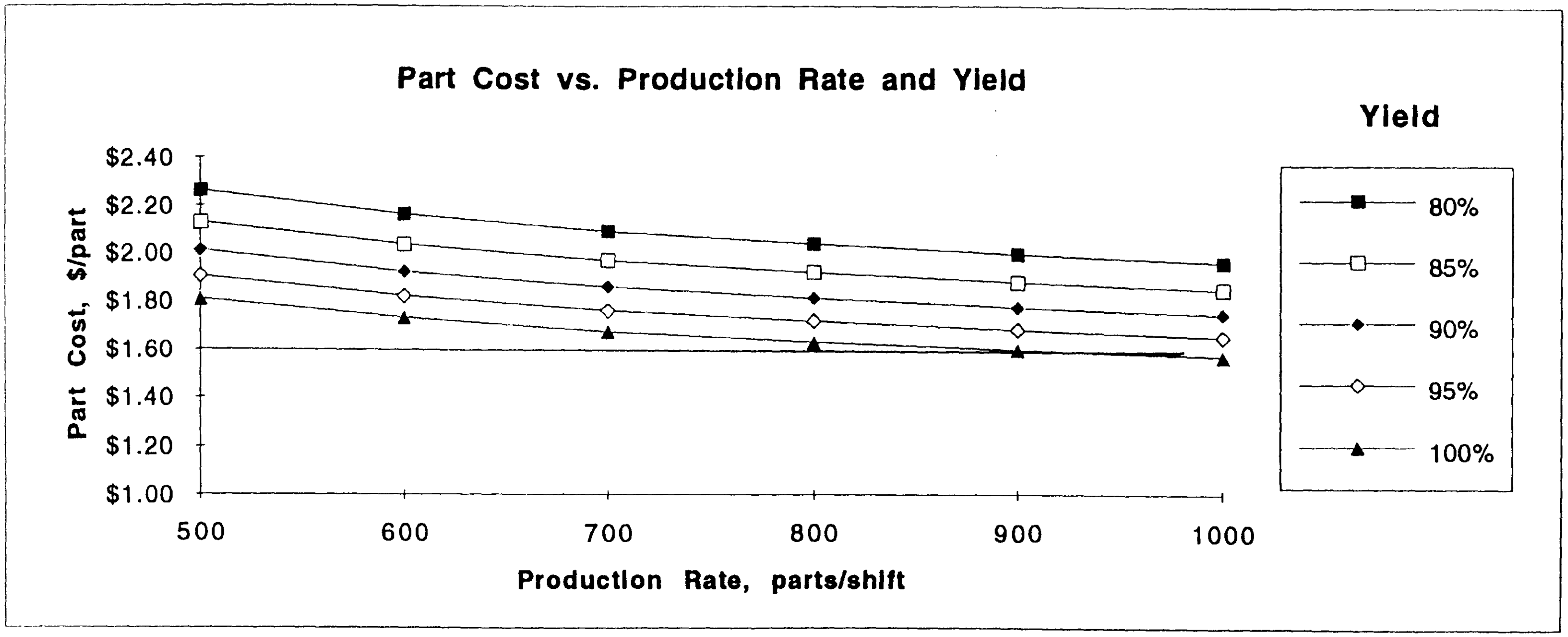
Appendix

Base Case Economics

Monthly Production Demand ==> 32000 No. of Operators==> 2

Part Cost at Different Scenarios

Yield ==>	80%	85%	90%	95%	100%	Monthly Production Hrs	Monthly Idle Machine Hrs
Production Rate (parts/shift)							
500	$2.26	$2.13	$2.01	$1.91	$1.81	512	-32
600	$2.16	$2.04	$1.92	$1.82	$1.73	427	53
700	$2.09	$1.97	$1.86	$1.76	$1.67	366	114
800	$2.04	$1.92	$1.81	$1.72	$1.63	320	160
900	$2.00	$1.88	$1.77	$1.68	$1.60	284	196
1000	$1.96	$1.85	$1.74	$1.65	$1.57	256	224



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