Design of a Process Improvement Methodology for Die Construction

by
Derrick Clarence Walker

B.S. Manufacturing Engineering
Central State University
(1991)

Submitted to the Department of Mechanical Engineering
and the Sloan School of Management
in Partial Fulfillment of
the Requirements for the Degrees of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING
and
MASTER OF SCIENCE IN MANAGEMENT
at the
Massachusetts Institute of Technology
June, 1993

Signature of Author____________________
Department of Mechanical Engineering
and Sloan School of Management
May 7, 1993

Certified by____________________
Stanley Gershwin
Senior Research Scientist, Department of Mechanical Engineering
Thesis Supervisor

Certified by____________________
Donald Rosenfield
Senior Lecturer,Sloan School of Management & Director, LFM Fellows Program
Thesis Supervisor

Accepted by____________________
Ain Sonin
Chairman, Departmental Graduate Committee
Department of Mechanical Engineering

Design of a Process Improvement Methodology for Die Construction

by
Derrick Clarence Walker

Submitted to the Department of Mechanical Engineering
and the Sloan School of Management
in Partial Fulfillment of
the Requirements for the Degrees of

Abstract

The process of building dies for automotive panels is essential to the success of any new car development program. Additionally, this process has historically been the longest lead time element in the development program. However, the process affects more than just the lead time. It also impacts the quality and cost of the development program. As a result, companies are seeking to improve the construction process as a means of gaining a competitive advantage. To accomplish this, they are examining their operations to better predict, control, and improve the overall performance of the process .

This thesis outlines the steps in a process improvement methodology, and provides a structured and systematic approach to the examination of any processes. This methodology allows the user to gain a more profound and extensive understanding of the process.

The heart of this methodology is a probabilistic simulation. It is used to identify problem areas in the process, and to test the feasibility of process or technological alternatives without affecting the actual process.

Lastly, the thesis compares and contrasts the various die construction process used in the industry, and describes emerging technologies.

Thesis supervisors: Donald Rosenfield
Senior Lecturer, Sloan School of Management, and Director, Leaders For Manufacturing Fellows Program

Stanley Gershwin
Senior Research Scientist, Department of Mechanical Engineering

Acknowledgments

The author gratefully acknowledges the support and resources made available to him through the Leaders for Manufacturing Program.

I would also like to thank:

The many people at the study company who supported this effort in some way. Specifically, I would like to thank those who provided data, taught me about the automotive industry, answered my questions, and expressed interest and support in my work.

My advisors, Don Rosenfield and Stan Gershwin for giving me support and advice in my school and internship related endeavors. Their advice has been beneficial in enhancing my overall knowledge of manufacturing from an operations management perspective.

Dan VandenBossche, Al Shephard, Dick Dow, Frank Pitonyak, and Tonya Hoard for befriending me, supporting my work, providing constant feedback, and helping me to understand my true potential.

Dedication

I would like to dedicate this thesis to Loretta Walker, my mother, and Charles Walker Jr., my brother. Their encouragement and support has helped to make all of my educational endeavors successful.

Table of Contents

Chapter 5

Chapter 6

Chapter 7

Chapter 8

List of Figures

List of Tables

Chapter 1

Introduction to the Die Construction Industry

1.1 Introduction

The die construction industry is very competitive. Although every major automotive company has a die shop that is somewhat shielded from this competition, there are thousands of independently owned die shops that are struggling to compete in this globally expanding market. For all die shops in the industry, competitive advantage is achieved through lowering cost, improving quality, and shortening lead times. To accomplish this, many companies actively seek new technologies and new construction methods. This thesis will address both of these issues. It will also provide a process improvement methodology that will enable companies to gain a better grasp of their operations. Additionally, this thesis will examine the activities at an American automotive die facility, and apply the improvement methodology to their processes. Finally, technology-driven and process-driven alternatives will be discussed.

1.2 Dies for Automotive Panels

Automotive dies are used to transform sheets of flat metal into defined contours. These dies create the shape of the inner and outer body panels of the automobile. To achieve the desired shape of the body panels, a multitude of dies is required. This set of dies is referred to as a line. The most common types of line dies are the blank, draw, form, pierce, and trim. Each type is defined below.

Body panels are formed by sending the sheet metal through the series of line dies in the order mentioned previously. The blanking operation usually occurs first. This operation cuts the sheet metal into a desired size. The drawing operation then shapes the metal into some defined configuration. In the forming operation, the sheet metal is bent or folded. The piercing operation then punches holes into the metal. Finally, the trim operation removes any excess material from the sheet metal. While these operations can vary in sequence, they usually occur in the previously mentioned order to ensure proper development and formation of the sheet metal.

1.3 Overview of the Die Construction Industry

There are a multitude of die shops in the United States geared towards building dies for the automotive industry. Some of these die shops are captive internal suppliers to an automotive company. These internal suppliers reside in-house for one main reason. Automotive companies view die construction as an essential element to their competitiveness. It is essential because the lead time, quality, and cost of new car development are affected by the supplier of the dies. Although many of the automotive companies outsource a portion of their dies, they still maintain the ability to build dies in-house because of the importance of the die construction capability.

1.4 Die Construction in a Job Shop

The majority of die shops build dies in a job shop environment. This is due in part to the high product mix, variable volumes, and specialized skills required. As is typical in a job shop, product and material flow often vary from part to part, and there is little standardization of the process. Some of the problems inherent in many die shops are as follows:

- High work-in-process inventories
- High setup times
- High costs
- Long lead times
- Poor product tracking

Despite these problems, a die shop is very flexible, and capable of adapting to changes in customer demand.

1.4.1 Workforce required in a die shop

The process of die construction requires experienced and skilled workers. Specialized skills can only be developed over long periods of time. Historically, companies have had to pay a premium for these specialized workers. Consequently, they tended to hire only when the work force had deteriorated due to attrition. To keep labor cost low, companies did not usually hire as many die makers as had been lost. This has led to a reduction of skilled die makers in most companies.

1.4.2 Technology used in a die shop

Technology is changing the way dies are being built. Computers are being used to transfer CAD data to CNC machines in ways never used before. CAD/CAM is taking on new roles in reducing the work time from design to machining. It automates the burdensome and tedious tasks such as die finishing. Employing such technology has been noted to improve throughput drastically. Moreover, in this changing industry, technology can be seen as a true source of competitive advantage.

Although computers are making more headway in the die making industry, the majority of the operations are still performed without the assistance of numeric or computer control. The trade of die making is complicated and requires years of experience to become proficient. One of the primary reasons why the die shop has been so difficult to automate is the experience and skill level needed to make judgments and decisions concerning a part. This decision-making ability has not yet lent itself to automation.

Another reason why automation is difficult to implement is because of the high product mix. Enabling automation to adapt and adjust to different types, sizes, and shapes of dies is a time consuming and troublesome task. For this reason, it is not common practice to automate.

Finally, automation is not being used extensively in the die construction process because demand in most die shops is often uncertain. In fact, only one die maker in the industry has totally automated its processes. The uncertainty of recuperating technological investments quickly is hence making many die shops hesitant to upgrade technology in their facilities.

Chapter 2

Competitive Elements in Die Construction

In the automotive industry, companies have historically focused on building dies that would last approximately six to ten years. This was done in attempts to amortize the costs of new car development over as many vehicles as possible. Consequently, die designer's and constructor's main concern was reliability and maintainability. Lead time, cost, and quality were all secondary concerns. Because the dies would be used for long periods of time, die shops had sufficient time to construct new dies while the old ones were still being used. Cost was not a major issue because most of the die development cost would be amortized over the life of the die. As for quality, dies were maintained and repaired at the stamping plant. In fact, many stamping facilities had die repair personnel in-house. This was done because the stamping facilities anticipated some type of quality problems over the life of the die. One example of this is when an engineering change requires that material be welded on the die to compensate for previous metal removal operations. By adding material to the die, its strength, durability, accuracy, and reliability are compromised. Consequently, the life of the die is much shorter. While U.S. companies focused on reliability, the Japanese companies were more concerned with cost, lead time, and quality. With this focus, they were able to improve their competitive position in the industry. As a result, U.S. companies were forced to re-evaluate their focus in attempts to better compete.

2.1 Reasons for reducing lead time

Die shops' emphasis on reliability was challenged as overseas automotive companies began gaining a competitive advantage in the U.S. market. This advantage was achieved mainly by reducing new car development time. Many Japanese automotive companies were able to introduce entirely new vehicles in a two to three year time span. In the United States, the three major automotive companies were introducing cars every four to five years (Roodvoets, 1991). Japanese automotive companies were able to reduce lead times on new car developments by shortening the lead time of die development.

Clark and Fujimoto state that the major gap between the Japanese and the United States die makers occurs in the die construction phase. They continue by stating that Japanese die shops require approximately six months to build a line of dies. In strong contrast, it takes United States die makers up to fourteen months to complete the same line of dies (Clark, 1991). Moreover, this eight month difference in die development lead time is significant considering that it takes approximately four years to design and manufacture a new automobile in the U.S.

Figure 2.1 shows that the highest lead time element in a die development program is die construction. This re-affirms the fact that the die construction process is an important competitive element. Narrowing the gap in die construction will bring most U.S. automotive companies closer to a three year product development cycle time.

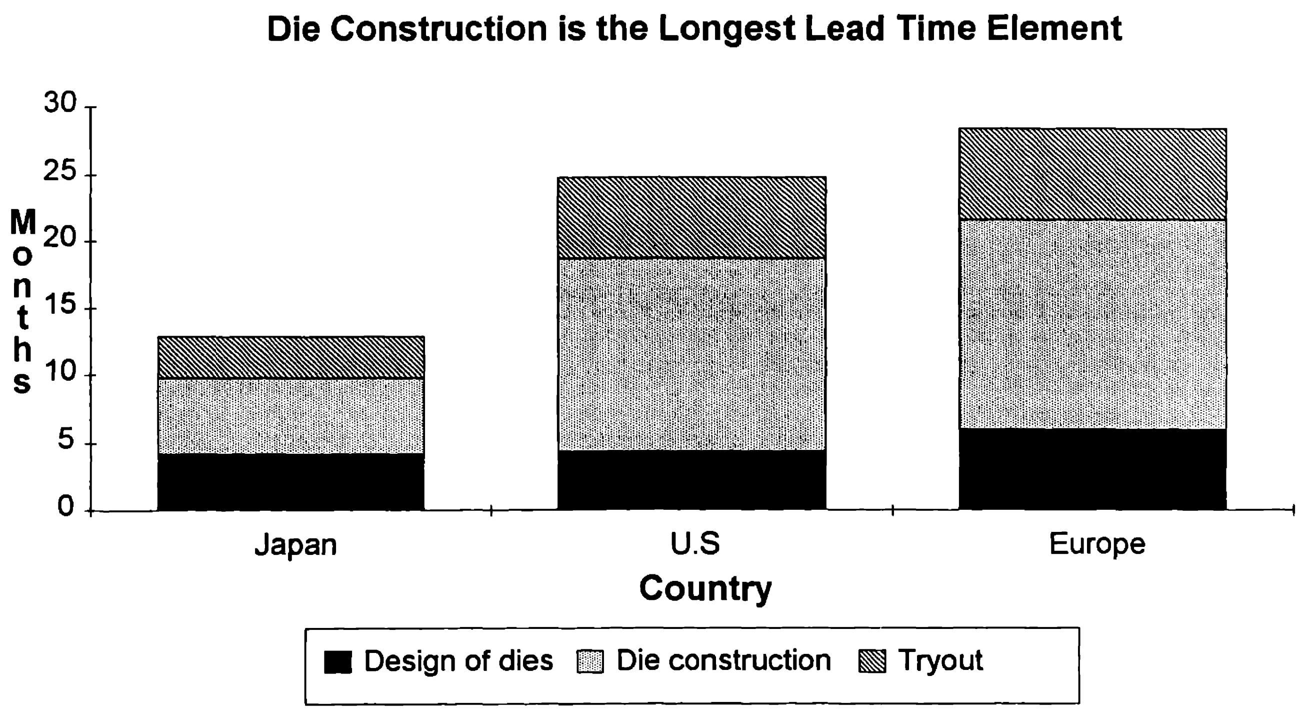


Figure 2.1 (Clark, 1991)

2.1.1 Lead times are competitive elements

Focusing on shortening the lead times enabled most Japanese companies to react faster to customer demand and minimize rework. Each of these benefits will be examined closer.

Shortened lead time increases a company's responsiveness

Shortened lead times allow automotive manufacturers to better predict the styles and preferences of its customers. New car development lead time of two years places a company in a better position to forecast customer trends. These trends might include fuel economy, shape, or styling. Conversely, when companies require four to five years to produce new vehicles, they must predict customer demands much further into the future. This is a more difficult task.

Minimize the amount of rework required

The Japanese approach to die construction is to structure the start of construction so that the plant has just enough time to complete the dies. In essence, the die is started as late as possible. This is feasible because the die construction plant has an understanding of the process and the variations that might impact the process. This understanding allows the plant to incorporate as many engineering changes into the design as possible before the start of construction. Consequently, this reduces the amount of rework required due to engineering changes.

2.2 Japanese approach to die construction

Many Japanese automotive companies view short lead times, low costs, and quality as measurements of a successful new car development program. Moreover, to meet these measurements, many Japanese companies concentrate first on shorter lead times for die construction projects. Reductions in lead time occur by increasing the capacity of the bottlenecks in the system, identifying critical lead time operations, and reducing non-value added tasks. As a result, one Japanese firm has found that placing more die construction operations in parallel has reduced its lead time dramatically. This will be revisited later in the thesis.

In Figure 2.2, Clark graphically depicts the typical scheduling of dies relative to the product engineering work. From this chart, it can be seen that from preliminary design to pilot run requires about 26 months to complete. This is in direct contrast to the 37 months needed in the United States as shown in Figure 2.3. As a result, Japanese firms can bring a new car to market almost a year earlier than its American counterparts. This difference is based only on die development. It does not take into account the other competitive advantages obtained by the Japanese in other areas of new car development.

Timing Chart of Die Development in Japan

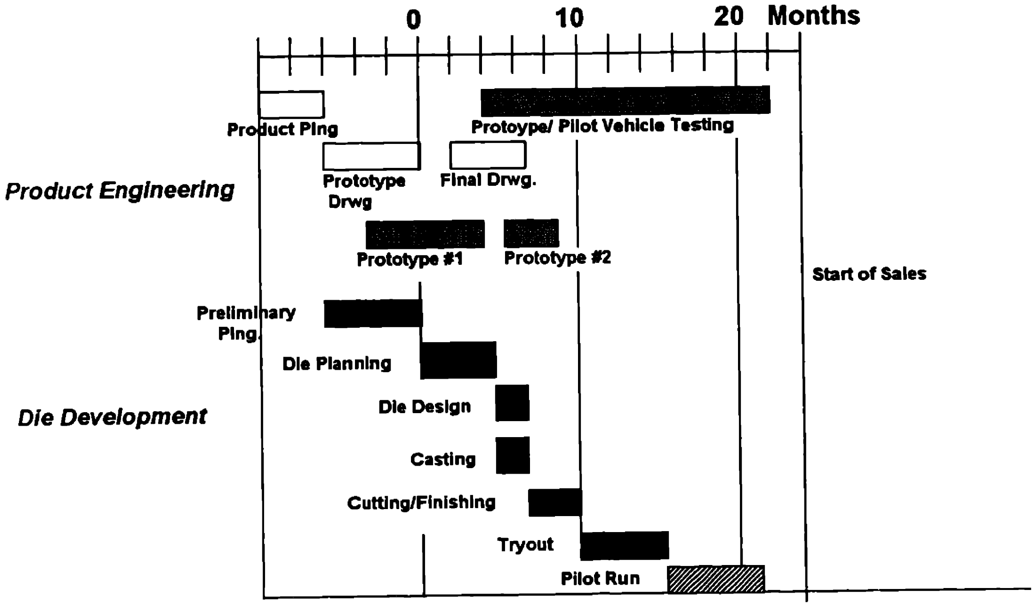


Figure 2.2 (Clark, 1991)

2.3 United States approach to die construction

In contrast to the Japanese approach, most U.S. die shops start dies as soon as possible. This is done in attempts to ensure that the dies are completed on time. However, starting the dies early has increased the amount of rework due to engineering changes that must be incorporated into the design and construction. In Figure 2.3, it can be seen that most U.S. die makers require more time to cut and finish dies than in the Japan. In fact, it takes about 10 months to cut and finish a line of dies as opposed to only 3 months in Japan.

Timing Chart of Die Development in the U.S.

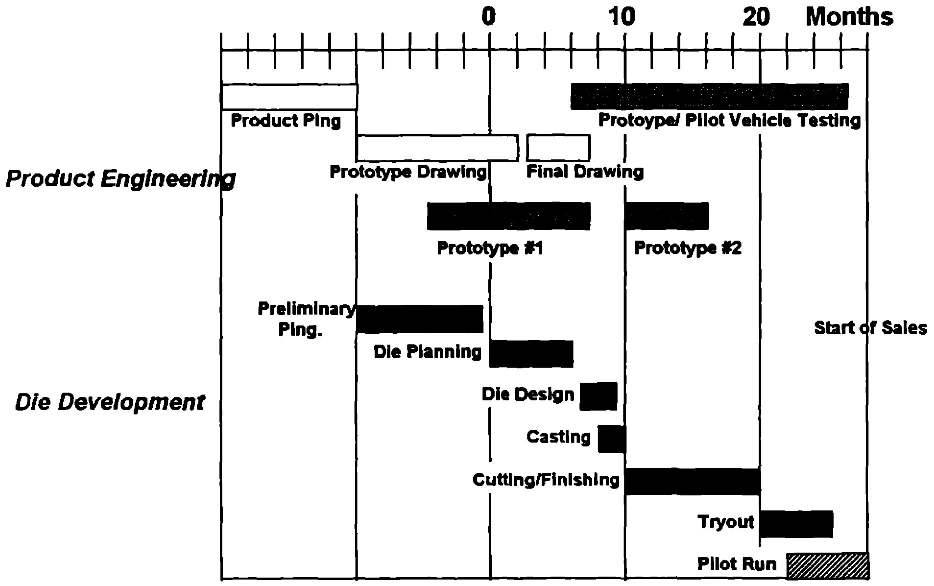


Figure 2.3 (Clark, 1991)

Not only is rework a problem for ensuring quality of the die, but it also adds significantly to the cost of the overall die. Moreover, Clark and Fujimoto mention that engineering changes account for 30-50% of the cost of a die in the U.S. This is because rework may be required for those dies that are close to completion. The need for rework causes the die to repeat several labor and resource intensive steps in the process. This adds considerably to the overall cost of the die.

The quality of a die suffers due to rework because additional operations usually have to performed. For example, if a certain surface contour is required, but the die has already been cut, die makers have to weld material to the surface. This compensates for the loss of metal in the cutting operation, but compromises the strength, reliability, and subsequent quality of the die.

As seen in Figures 2.2 and 2.3, the most striking difference between the American and Japanese approach to die making is in the cut and finish time. Clark states that this difference resides in the organization of the production process (Clark, 1989). In American die shops, production is based on job shop processing methods. With this type of process, machines are grouped in areas in the plant, and the dies move back and forth from each machining area (Clark, 1989). Moreover, the dies move to the machining areas in a "jumbled flow jumbled flow depending on the set of operations required" (Clark, 1989). As a result of improper scheduling, dies spend an inordinate amount of time waiting in queues in front of operations or waiting to be transported to different machining areas. As a result of these long wait times, the lead time of dies in the process is increased.

In contrasts to the American approach, the Japanese approach to die making is based on "just in time" manufacturing principles (Clark, 1989). Clark cites that the low work-in-process inventory and multifunctional workers are among the reasons why Japanese die makers are able to reduce wait times and reduce lead times (Clark, 1989). However, standardized work flows, reduced variance within operations, and increased understanding of the process, also contributes to the Japanese advantage in lead time.

Research performed by Drees supports Clark's hypothesis which states that the Japanese advantage in die development resides mostly in the construction process. However, Drees' views differ from Clark's concerning the reasons for the Japanese advantage in die construction lead time. Drees states that high inventory and poor scheduling are not among the major issues affecting lead times at American die facilities (Drees, 1990). Instead, the differences in machine rates, cusp heights on machined castings, and die design are the important differentiating factors that give Japanese die makers a distinct lead time advantage (Drees, 1990). Although Drees and Clark differ on the determinant factors of the lead time advantage, both identify that the die construction process is an area where American die shops can improve their competitiveness.

2.4 Modes of Competition

Because most automotive companies have captive die facilities in-house, competition in the industry only exists for those companies that are independently owned. These companies rely heavily on the automotive companies for business. Captive automotive die shops that have reached their maximum capacity will outsource dies to foreign or domestic die facilities.

These foreign or domestic die facilities are usually independent, and compete on a host of issues. First, these shops compete on lead time. The ability to construct dies in short time periods give many of shops a distinct advantage. The primary reason is their ability to significantly reduce the time required to cut and finish dies. This advantage is due to a thorough and in-depth understanding of the process of die construction. In doing so, Japanese die makers are able to identify areas in the process where inventory can be reduced, non-value added operations can be eliminated, and work flows can be simplified. Overall, Japanese die facilities have a better grasp of the process and its capabilities than their American counterparts. As a result, lead time is reduced.

Another reason for shorter lead times in Japanese die facilities is the simultaneous development of dies (Winter 65). This requires die makers to work closely with die designers in the both the design and construction phase. Additionally, it allows small changes to be made with minimal confusion and difficulty. It also allows information concerning these changes to filter down into the process even before construction begins. Lastly, simultaneous die development allows the die maker to make changes impacting feasibility to the die before the die leaves the designing phase. Furthermore, simultaneous die development reduces the lead time by improving communication.

Next, independent die shops compete on cost. Many Japanese companies have a decided cost advantage. In general, many overseas die makers were able to quote lower cost for dies (Sharf, 1992). These lower cost lured many of the American automobile companies from domestic to foreign suppliers . One reason for the lower costs quoted by overseas competitors was the Japanese government subsidies given to various die shops (Sharf, 1992). These subsidies supported many ailing Japanese die shops, and gave them time to improve their processes and gain customers. As a result of the lower overseas quotes, American die shops had to lower their prices. Consequently, they were unable to make a profit. In fact, more than half of the die shops present in 1975 are no longer in business due to large financial losses (Sharf, 1992).

Another source of competitive advantage is in technology. While most companies are on par with each other in terms of technology, many companies seek to use technology as a means to reduce lead time and increase overall competitiveness. One industry official said, "Sharpening the sword of technology is critical in keeping foreign competitors at bay" (Amber, 1992).

While there is great emphasis on staying abreast with technology, many American die makers find this a difficult task. As a result of the Japanese cost advantage, many independent American die makers were in trouble financially. Consequently, these die makers did not have the money to invest in upgraded equipment or new technology (Sharf, 1992). Moreover, these independent die shops were unable to obtain long-term commitments that would justify purchasing equipment that was technologically current. As a result, many of these die shops went out of business . For the remaining independent American die facilities, the tremendous cost of keeping up with technology to support the automotive industry is their biggest challenge (Amber, 1992).

Chapter 3

Process Analysis For Die Construction

This chapter has a dual purpose. First, it is intended to introduce the reader to a methodology used in analyzing processes. While the methodology is applicable to any process, this chapter will focus on die construction. Second, this chapter is intended to expose the reader to some of the tools used to identify areas for improving the process.

Process analysis is the thorough an in-depth examination of a sequence of operations using production, process, and scheduling tools. It allows one to look at individual steps in the process, and to examine their relevance in the total process. These tools assist in visualizing, monitoring, and evaluating any process given a series of inputs and desired outputs. Examples of these tools are the Critical Path Method, operation sheets, process flow charts, and simulations.

Additionally, process analysis is a method of scrutinizing any process, and examining the relevance of operations or tasks within the process. It provides a deeper understanding of the overall system. Furthermore, it leads to "a different and potentially more penetrating, comprehensive, and insightful grasp of the process. This can lead to significant improvement and innovation of the process" (Zuboff, 1993).

Process analysis can accomplish one of two objectives. First, it can increase control of the operation (Zuboff, 1993). Specifically, it can increase the predictability and consistency of the process. By developing a deeper understanding of the process, underlying assumptions can be uncovered, standards can be developed, and shop floor procedures can be evaluated. The development of standards will improve the consistency and predictability of the process. As a part of standardization, the best procedures for performing a task are incorporated into the process. For a given operation, these procedures allow the die maker to perform each task according to standards. Thus, worker to worker variation is reduced. Additionally, the process is more consistent and predictable because an operation is repeatedly performed in the same manner.

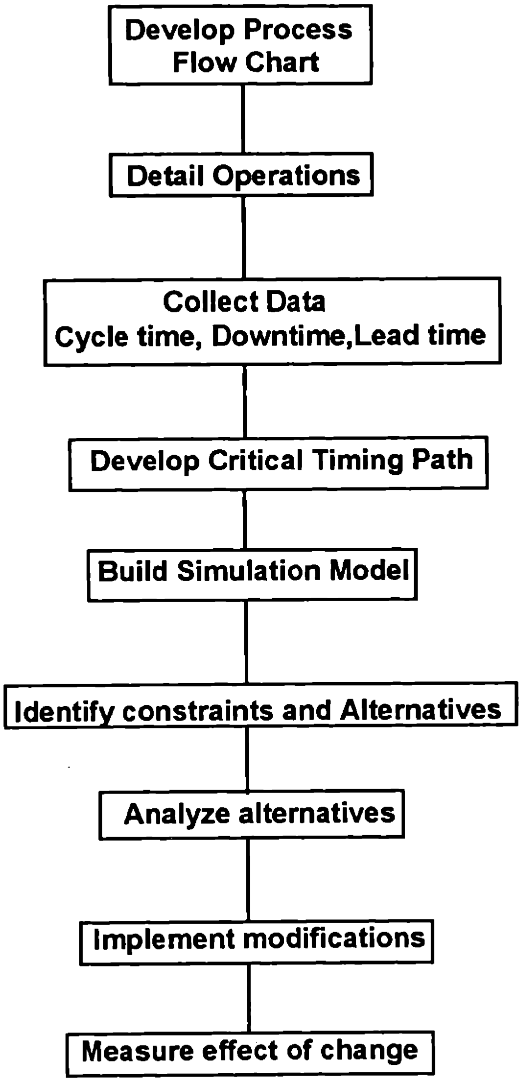
Process analysis can also increase the comprehensibility of the process (Zuboff, 1993). Because analysis requires the process to first be broken down into its smallest components, a greater understanding of the function and relevance of each operation can be developed. Moreover, the analysis requires the collection of information concerning the process such as cycle times, lead times, downtimes, and work-in-process. This information gives the die maker a greater understanding of the operations and subsequently the process.

Examples of possible uses for process analysis are cited below. Two possible uses for process analysis are to minimize lead time and reduce cost. However, there are other uses for this type of analysis. For instance, it allows the user to examine work flows, congestion, scheduling policies, and resource constraints. This is accomplished first by examining the process under close scrutiny. This requires the use of several of the tools such as the process flow charts, critical path methods, and simulations. For example, by developing a simulated model of the process, the user can identify areas in the process where congestion of work loads is high. Additionally, the user can graphically display the flow of work in the plant, and make corrective suggestions based on the observations made. This will not only increase a die shop's competitiveness, but it will also improve the competitiveness of the automotive company.

However, before any tool can be used or any analysis can be performed, a methodology must be outlined. To achieve success using process analysis, it is imperative to use a structured and disciplined approach. Figure 3.1 is an example of one such approach. While there are several ways of approaching the analysis of a process, this methodology takes the user through the most important steps required to analyze the process. Moreover, the steps in this methodology are listed in order of precedence. For example, one cannot determine which operations have the largest effect on lead time without first knowing the sequence in which operations occur.

Before this methodology can be implemented, it is important to first define the process that will be analyzed. Moreover, only one process should be analyzed at a time. This will ensure that all members involved in the analysis are focused on improving the same process. It will also serve as a way of harnessing the energy and expertise of all members so that the best process improvement ideas emerge.

After defining the process, the process improvement methodology should be implemented. The remainder of this chapter will discuss each of the steps in the methodology in greater detail.



Process Improvement Methodology

Figure 3.1

3.1 Detail Operations

Detailing the operations is the first step in implementing the process improvement methodology. However, it is often the step that most companies seem to overlook. In the minds of the plant's employees, the process and operations are not changing. When working, employees try to apply the same knowledge and decision making rules to the current process as they did five or ten years ago. However, the process is periodically changing. These changes can occur by simply purchasing a new machine, or adding some new technology to the process. Both of these changes alter the path of materials through the plant, and necessitate different decision making rules as well as process knowledge. For this reason, it is important that the process first be outlined, and then evaluated periodically for any change.

Also, by outlining the process, one is graphically depicting the flow of material from operation to operation. This is helpful in standardizing the work flow and operator tasks. Standardization is not the objective. Instead, it should serve as a foundation upon which future improvements can be made. In keeping with the continuous improvement ideology, the standard should evolve as changes occur. This would ensure that the process is current.

The process can be outlined by using several sources. First, it can be outlined by questioning those workers on the plant floor. They have information based on experience that is essential to a better overall understanding of the process. This is accomplished in the form of surveys or interviews. As is typical in a job shop environment, each worker has the autonomy to forward a part in any reasonable sequence. For example, a part might go from drilling to machining to finishing as opposed to machining to drilling to machining. While this may only be a subtle difference, it can often have a serious impact on the overall quality, lead time, and cost. For this reason, those individuals using process analysis should try to identify the variation, and uncover the reasons for these variations. All of this is done with the intent of finding the best process.

The next step in the process of detailing the operation is to walk the process to ensure validity. In a semi- or fully automated factory this is a simple task. However, in a job shop, this is much more difficult. More specifically, in the die construction industry, dies are built over a period of months. So, to follow a die through a sequence of operations is a much more time consuming process. However, to assist in verifying the accuracy of the model created, it is an important task.

The last step in detailing the process is to gain consensus of the process. This is often the most difficult step because it requires all workers to consent that the process chart created is the best representation of product flow through the plant.

3.2 Operation Sheets

Operation sheets are used to enumerate the tasks that make up an operation. These sheets are also used to place time standards on tasks. Caution should be exercised in using time standards. These times should be used to assist in forecasting lead times. The times are not meant to be used as a strict standard to gauge worker performance. Additionally, standard times should be used as a piece of data that facilitates macro-management of projects, not micro-management. Often managers use time standards to gauge performance by the minute or hour. Rating performance over such short intervals is a micro-management approach. Managers should use time standards to improve forecasts for lead times or to create project schedules. This is the macro-management approach, and is preferred.

The operation sheet allows for process analyst to determine the significance of a task. For example, if the sheet states that tool retrieval consumes half an hour, this tasks would be a prime candidate for examination. High tool retrieval times would make the process analyst question that task, and would prompt the analyst to find ways to reduce the time required to perform that task.

Operation sheets also facilitate the location of non-value added activities. These are activities that do not improve quality, reduce lead time, or increase throughput. More specifically, these are tasks or operations that do not increase the value of the product. Value can be defined as the worth of a product as perceive by the customer. In a die facility, the customer is the stamping plant.

Examples of value added operations are described below. As mentioned previously, a value added activity can be one that reduces lead time. This is a value added activity because it fulfills customer demand faster. This type of activity follows the 'Time Value of Money' theory. This theory states that the sooner value can be received, the greater its worth. Therefore, operations that reduce the lead time are value added.

Operations that increase throughput add value only if these operations allow the plant to fill excess customer demand. However, if these operations produce more goods than the customers' demand, the operations do not add value (Goldratt, 1986). Instead, they produce inventory which loses value through depreciation.

As for quality, a higher quality product is valued higher than a lower quality product. So, an operation that increases the quality of the product is also a value added activity. The preferred process would have all operations increasing the quality of the product. Moreover, operation sheets are an essential tool to achieve this preferred process. However, only a detailed operation sheet can be beneficial in detecting these non-value added operations.

Operation sheets are especially useful for defining the machines or pieces of equipment that should be used to complete an operation. Moreover, it provides a standard for workers to conform to. Once standards are made, they can be continuously altered and improved. This will also facilitate workers understanding of the steps required at a given operation. Because operation sheets assist in standardizing the process, worker variability is reduced.

As mentioned in the section on detailing the process, the information on the specific task that make up an operation should be acquired from those workers closest to the operation. Verification can come from interviewing several workers performing the same operation on different shifts, or through observation.

3.3 Data collection

The process of data collection can be the most time consuming, but is by far one of the most important steps in the process improvement methodology. Data is the essential ingredient that converts intuition into fact. For example, workers may claim that downtime is dramatically affecting inventory and throughput. However, without information on mean time to failure and mean time to repair, the workers' intuition remains a hunch. The data supports the workers' hunch, and provides a basis for fact.

Data can be acquired from several sources. One of the most important sources for data are the workers closest to the manufacturing process. This data is more qualitative than quantitative. However, it can provide keen insight into material release policies or priority rules. Other sources of data are current databases, time studies, past estimates, or machine tolerances.

It is difficult to determine the different types of data that might be required to better analyze the process. However, some of the most essential pieces of data are as follows:

- Operational cycle time
- Downtime on machines
- Process lead time
- Amount of variations in cycle time

The type of process being analyzed will determine the sort of data required. However, in the die construction industry, the above data is among the most important pieces of information needed to be gathered.

3.4 Develop Critical Timing Path

The critical timing path consists of those operations that most impact the overall lead time. It is those operations that must be monitored closely to keep the project on schedule. For those operations on the critical path, any variation in their cycle times will directly impact the lead time of the project.

The critical timing path determines the earliest time an operation can start based on cycle times. Moreover, it can also determine the latest time an operation must be completed to keep the project on schedule. Lastly, it can determine the lead time of a product given the time it takes to complete a series of operations.

3.4.1 Identify precedence relationships

The critical path requires knowledge of the precedence relationships of the process. By building the process flow chart in the first step of the process improvement methodology, operations can be linked in the order in which they occur. Once these relations are identified and cycle times noted, the earliest start and finish dates can be calculated.

Below in Figure 3.2 is a process flow chart for a simple system. The chart shows two branches of the process with different inputs feeding into an assembly operation E. The part being built has two components. One component enters the process at operation A, and the other component enters the process at operation D. For the first component, upon completion of operation A, the component moves to operation B then operation C. After operation C is complete, the component then moves into operation E. Also, for the second component, upon completing operation D, the component waits to be assembled with the other component. Once both components are ready, they are assembled in operation E. The assembled product then exits the process.

Example of operations in a process

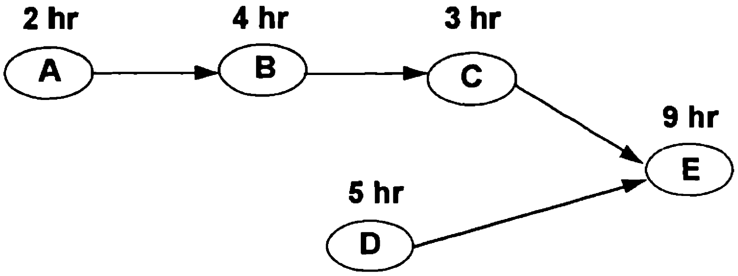


Figure 3.2

3.4.2 Define earliest start and finish times

The next step in determining the critical path is to determine the earliest start and finishing times. The earliest start time is defined as the earliest time an operation can begin. Usually, the earliest time the first operation in a process can begin is at time 0. This implies that the operation can begin immediately. Similarly, the earliest finish time is defined as the earliest time an operation requires to finish a series of tasks. From Equation 3.1, the earliest finish time (EF) is defined as the sum of the earliest start time (ES) and the cycle time of the operation (CT).

$$EF = ES + CT \qquad \text{Eqn 3.1}$$

Given the earliest finish time of an operation is known. The preceding operation's earliest start time is equal to the prior operation's earliest finish time.

For the process created in Figure 3.2, we can determine the earliest start time for operation A. Because operation A is the first operation on its branch of the process, it can begin immediately. So, time 0 is its earliest starting time. Because operation A requires 2 hours to complete, the earliest finishing time is time 2. The earliest start and finish times for the other operations can be calculated in the same manner as mentioned above. The result of this calculation is shown in Figure 3.3. The first row in each box shows the earliest and latest finishing time.

Start and Finish Times for Operations

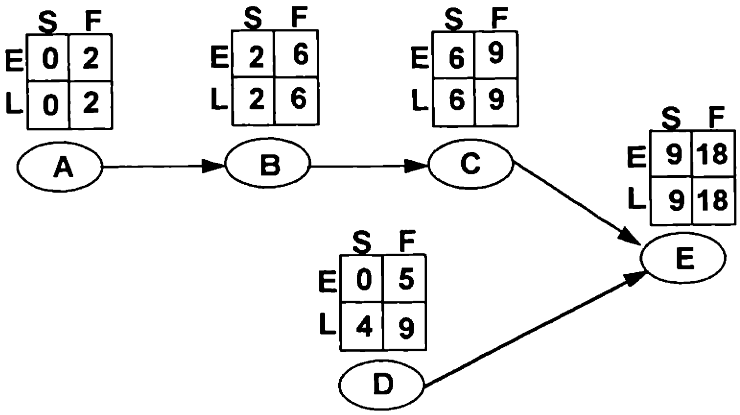


Figure 3.3

(Source Vonderembse, 1991)

3.4.3 Define latest finish and start times

The next step in determining the critical timing path is to determine the latest start times and finishing times. These times represent the latest time a project can start and still be completed on time, and the latest time a project can be completed by and still stay on schedule.

The latest finish time is based on specifics of the project. Depending on when a project requires completion, the latest finish time is set. The latest finish time is defined as the latest time an operation must be finished without affecting the preceding operation's start time. In the form of an equation, the latest start time (LS) is the difference between the latest finish time (LF) and the cycle time of the operation (CT). This is shown as follows:

$$LS = LF - CT \qquad \text{Eqn 3.2}$$

In the model created in Figure 3.2, it is arbitrarily assumed that the finish time is at time equal 18 or in the 18th hour of production. Now, working backwards from the last operation, E, we can determine the latest start time. Since time 18 is the latest finish time, operation E must be completed by time 18. Additionally, the cycle time of operation E is 9 hours. So, the latest start time is time 9. Setting time equal to 9 as the latest finish time for operations D and C, the latest start times for operations D and C can be calculated. Using equation 3.1, the latest start time for operation D is time equal to 4. Moreover, for operation C, the latest start time would be time equal to 6. This can be performed for all of the operations in the process.

3.4.4 Calculate slack times

Upon defining the earliest start and finish times and the latest start and finish times, the slack times can now be determined. The slack time is the amount of time allotted for variations in the cycle time of an operation. If the slack time is greater than 0, then that operation is not on the critical path. However, those operations with 0 slack times are on the critical path. These operations must be monitored closely to ensure on time completion. Any variation in these operation's cycle time will impact the overall lead time of the project.

To find the slack time (ST) take the difference between the latest (LF) and earliest finish time (EF). It can also be calculated by taking the difference between the latest (LS) and earliest (ES) start time. So, written in the form of an equation, the slack time can be defined as follows:

$$ST = LF - EF \qquad \text{Eqn 3.3}$$

$$= LS - ES \qquad \text{Eqn 3.4}$$

Transferring the information in Figure 3.3 and adding the calculated slack times, Table 3.1 can be constructed. According to Table 3.1, operations A,B,C, and E are on the critical path because their slack times are 0. These are the operations that must be monitored closely to ensure on time completion. Because operation D is not on the critical path, its cycle time can vary up to 9 hours without impacting the overall lead time of the project.

Calculation of slack times and critical path operations

		Start		Finish			
Op	***Cycle Time***	***Earliest***	***Latest***	***Earliest***	***Latest***	***Slack***	***Critical Path***
A	2	0	0	2	2	0	Y
B	4	2	2	6	6	0	Y
C	3	6	6	9	9	0	Y
D	5	0	9	5	14	9	N
E	9	9	9	14	14	0	Y

Table 3.1

With the identification of the critical path, a powerful tool for improving the process has been identified. The critical path now tells us which operations must be improved to shorten the overall lead time.

3.4.5 Bottleneck is on the critical timing path

The bottleneck of the operation can now be located. The bottleneck of a process is located on the critical timing path. It is the operation that has the highest cycle time of any operation on the critical path and has zero slack time (Goldratt, 1986). The bottleneck has to reside on the critical path because those operations on the path have zero slack times. Operations with zero slack times have their capacity equal or less than demand . This refers to operations whose cycle times cannot keep up with the required cycle times needed to fulfill customer orders in the time period allotted (Goldratt, 1986). Referring to the process defined in Figure 3.2, it can be seen that the bottleneck of the process is operation E. It has zero slack time, and has the largest cycle time of any operation on the critical path.

The remainder of this section will recap the definitions of a bottleneck operation. If the sum of the cycle times (CT) on a given path are less than the required lead time (RLT) of a project then the operations on the path have excess capacity.

$$\Sigma CT < RLT \qquad \text{Eqn 3.5}$$

Moreover, if the sum of the cycle times(CT) on any given path are equal to the required lead time(RLT) of a project the path is critical.

$$\Sigma CT = RLT \qquad \text{Eqn 3.6}$$

Lastly, if the sum of the cycle times (CT) is greater than the required lead time, the path is critical. However, the project will not be completed on schedule because the operations on the path do not have enough capacity.

$$\Sigma CT > RLT \qquad \text{Eqn 3.7}$$

3.5 Build Simulation Model

The next step in the process improvement methodology is to build a simulation. This is a simulated depiction of the actual process. This simulation should be based on the process flow chart and the data collected in previous steps. With the simulation, a computer is used to evaluate a model numerically over a time period (Law, 1982). Data is gathered to estimate the actual characteristics of the process The more accurate the data and process flow chart are the more accurate the simulated model will be. So, it is imperative that the model be created using information that truly depicts behavior on the plant floor.

Often, it is desired to study a process to enhance the understanding of the relationships between operations, or to predict performance of the process under new operating policies. However, actual experimentation with the system may be unfeasible, cost-ineffective, or disruptive to the current process (Law, 1982). Because of the unfeasibility of experimenting with the process, the simulation is used to draw inferences about the operations of the actual system.

There are several advantages to using the simulation. First, the simulation can be used to model a real-world stochastic process (Law, 1982). Because most processes have randomness, it is important to find a tool that incorporates a level of uncertainty. Although the critical path can convey important information about the process, it does not handle uncertainty. Therefore, the use of the critical path is limited, and the simulation should be used to obtain a more accurate depiction of the real process.

Second, it can estimate the performance of an existing process under some set of operating conditions. Given the current system dynamics, predictions can be made concerning the process. For example, given the current sequence of operations in the process, the effect of increased loads in the system, or extensive downtime can be examined. With the simulation, the effect of these changes in operating conditions can be predicted.

Third, the simulation allows the user to analyze alternatives concerning process design or operating policy. These scenarios are geared to testing hypotheses or improvement alternatives. The simulation thus provides a method of testing alternatives without tampering with the actual process.

Fourth, the simulation allows the user to study a process with a long time frame in compressed time (Law, 1982). Because the die construction process can take up to nine months, it is difficult to see trends and their causes on the shop floor. With the help of the simulation, it is easier to see trends such as increases in inventory or areas where inventory has high wait times.

There are several commercial simulation programs available. The size and the complexity of the process will assist in determining which package to use. In general, those programs that require some type of programming allow the user to add more complexity than those packages that are only menu driven.

Before advancing to the next step in the methodology, the process must be validated. This is essential in maintaining the credibility of the simulation. To ensure validity, the results of the simulation should be checked against actual data. If the results from the simulation are similar, then the analyst should proceed to the next step of the process. However, if substantial discrepancies exist, the analyst must re-evaluate the simulated model, and correct any error made before advancing to the next step.

3.6 Identify Constraints and Alternatives

Upon completion of the simulation and the critical timing path, several alternatives can be developed. For example, knowing which operation is the bottleneck will allow the process analyst to develop a series of alternatives that can increase the capacity of the bottleneck. Other types of alternatives can be changes in technology, material flow, or scheduling. An in-depth discussion of these alternatives will be made in Chapter 7 and 8. The analyst is encouraged to develop as many alternatives as possible. The number of alternatives will be reduced as they are tested in the simulation. Based on the results from the simulation, the viable alternatives will be implemented and the others will be discarded.

3.7 Analyze Alternatives

The alternatives can be evaluated by testing them in the simulation. This provides a safe and effective way of testing alternatives without unnecessarily altering the manufacturing process. This step in the process methodology will reduce the number of alternatives created in the previous step. Based on the results from the simulation, alternatives will either be selected for the next step of the methodology or discarded. In essence, this is the step that filters the number of alternatives down into viable options.

3.8 Implement Modifications and Measure the Effect of the Change

The viable options selected in the previous step should now be implemented on the plant floor. To verify that the anticipated results has been acquired, measurements should be taken. This will not only show whether an alternative has been successful, but will also assist in validating the simulated model. Because most processes are complex, some amount of discrepancy is expected. However, the inconsistencies should be noted and used to improve the model.

Chapter 4

Model for Die Construction

This chapter is intended to apply the methodology discussed in Chapter 2 to identify problematic areas of the die construction process in an American automotive company. Specifically, this chapter will develop a process flow chart, detail the operations in the process, and collect data pertaining to die construction.

4.1 Description of die shop

Research was conducted in the die shop of an American automobile company. This facility is a captive supplier of an American automotive company. They produce a large percentage of the dies for the company. However, due to capacity constraints, they are only able to produce between 10 and 20% of the dies for new car development. The remaining dies are outsourced to domestic and foreign suppliers.

4.1.1 Job Shop

In the facility where research was conducted, dies are produced in a job shop environment. This die facility suffers from some of the common problems associated with many job shops. These ailments are long lead times, high cost, high inventory, and high rework. The scheduling of work is a difficult task because the dies do not follow the same process flow. Instead, each die is constructed based on a worker's experience. For example, after a die has been machined, it then can either be drilled for vent holes or finished. The decision to choose one of these options is made by the die maker. This choice can vary from worker to worker. Moreover, it is often made independent of the other constraints placed on the process such as machine availability.

The dies vary by size and complexity, and the demand for dies is often uncertain. The demand is dependent upon the automotive company's new car development program and subsequent resource availability. However, since most operations in a die shop are manual operations. The capacity of many of the operations are worker constrained.

The company does not track the flow of material in the plant on an operation to operation basis. Instead, they aggregate the construction process into generalized groups such as machining, mastering, and tryout. Additionally, die lead times are estimated using a formula that was a function of the die's surface area.

4.1.2 Description of the workforce

The workers in this automotive facility are unionized. The average age of a worker is approximately 48 years. Despite most preconceptions of unionized facilities, the workers in this plant are very cooperative, and willing to gather and share information pertaining to their jobs. An observer would not know that the workers on in the plant were unionized except for the distinct blue uniforms that most of them wore.

Overall, most of the unionized workers in the plant are excited about the opportunities to improve the process. However, based on conversations with many of the employees, they believe that the plant is slow to respond to their suggestions. Despite the worker's beliefs, change is taking place.

4.1.3 Approach to die construction

This die facility took the usual American die construction approach that is to start die construction as early as possible. This approach will be analyzed further in Chapter 7. At this die facility, they started dies as early as possible with the belief that this would ensure sufficient time to build the die. However, this approach created several problems for the plant. First, by starting a die too early, it would sit in work-in-process because other parts needed to be mated with it were not complete. Second, when dies are started early, they sit in finished goods inventory waiting to be used by the plant. Third, starting dies too early causes resources to be used unnecessarily. Because the die construction process is so labor intensive, starting a die too early causes these valuable resources to work on a die that does not have a high priority. Lastly, the earlier a die is started, the higher the cost of engineering changes made later.

4.2 Development of process flow chart

As mentioned in the previous chapter, the first step in the methodology is to develop a process flow chart. This chart is intended to show the flow of materials through the plant using a precedence relationship. It is a graphical representation of operations in sequence or parallel that make up a process. In most fully automated or batch flow facilities, mapping out the process is a relatively simple process. However, in a job shop environment where the process flow is not as obvious, creating a flow chart is more difficult, but can still be developed.

4.2.1 Commonalties in Draw Die Development

Although it is difficult to develop a process flow chart for a die shop, it can still be accomplished. This can be done by finding the commonalties within certain die types. Commonalties can be defined as those aspects of an assembly or construction process that are shared by more than one part or component. Examples of these commonalties are parts that follow similar process flows, or parts that have similar components. Because most die facilities have a high product mix, many people conclude that each die is so different that commonalties among various dies cannot exploited. The approach towards grouping commonalties should be changed from one of 'how different' the parts are to 'how similar' they are (Knight, 1971). For the research conducted, the commonalties in the draw die construction process were examined. A description of the draw die construction process is provided in Appendix A. These commonalties were identified as follows:

- Operations
- Sequence of operations
- Components
- Resources

Draw dies were selected for four reasons. First, they share the most obvious and identifiable commonalties. The only real difference is in the cycle time of the operations. Depending on the size and complexity of the surface contour, cycle times can fluctuate greatly. Nevertheless, these fluctuations do not impact the process flow charts. Second, the draw dies is an essential die needed to shape most body panels. For example, the curves and styling lines of exterior body panels are produced using the drawing process (Internal

Document).Third, air draw dies make up a significant portion of dies built in the plant. Table 4.2 shows that the air draw die has the fourth highest volume of dies built in the plant. Fourth, they consume a significant amount of time in the overall construction of dies. Table 4.1 shows that construction of the air draw die requires approximately 24% of the time required to build a line of dies. A line of dies is the set dies needed to bring a flat piece of metal to a desired size and shape.

% Construction time by Die Type

Die Type	% of Construction Time
Draw	24%
Trim	29%
Form	26%
Pierce	22%

Table 4.1

Types of Dies in the Schedule

Die Type	# of Dies Scheduled
Restrike	4
Cut-off	10
Blank	20
Draw	36
Pierce	37
Trim	49
Form	83

Table 4.2

Source: Internal New Car Development Program Schedule

4.2.2 Mapping the operations in the process

The next step in the improvement methodology is to create a process flow chart. Because building a die requires experience and training, mapping out the operations in the process mandates die maker participation. Appendix A describes in detail the components that make up the die, and the steps in the construction of the air draw die. After gathering information concerning the various operations, the analyst defines the precedence relationships. This determines which operations feed others, and ultimately determines which operations are in parallel and series. Figure 4.1 shows the process flow chart based on the description of the die construction process in Appendix A.

4.2.3 Examining the process using flow charts

The process flow chart identifies potential areas for improvement. One way to improve lead time is to place more operations in parallel instead of series. This requires moving some operation further upstream, and subsequently performing some operation earlier.

Another area for improvement is the movement of material through the process. In most job shops, the time to move material, wait times, and set-ups contribute to a significant portion of the overall lead time of a product (Clark, 1991). Although the process flow chart currently does not allow for the examination of set-up or wait times, it does allow one to examine the amount of movement a product undergoes. Analysis of these move operations requires the process improvement analyst to ask questions such as "are these move operations necessary" and "can workers move to the material as opposed to the material moving to the worker?" The goal of these questions is to get the analyst to examine the reasons for the movement of materials.

Another area for improvement is in the assembly and disassembly of parts. From the process flow chart shown in Figure 4.1, it can be seen that the die is often assembled and disassembled. Whether these operations are necessary is an important question that should be posed. In this case, these operations are necessary to achieve a quality die.

Process Flow Chart for the Die Construction Process

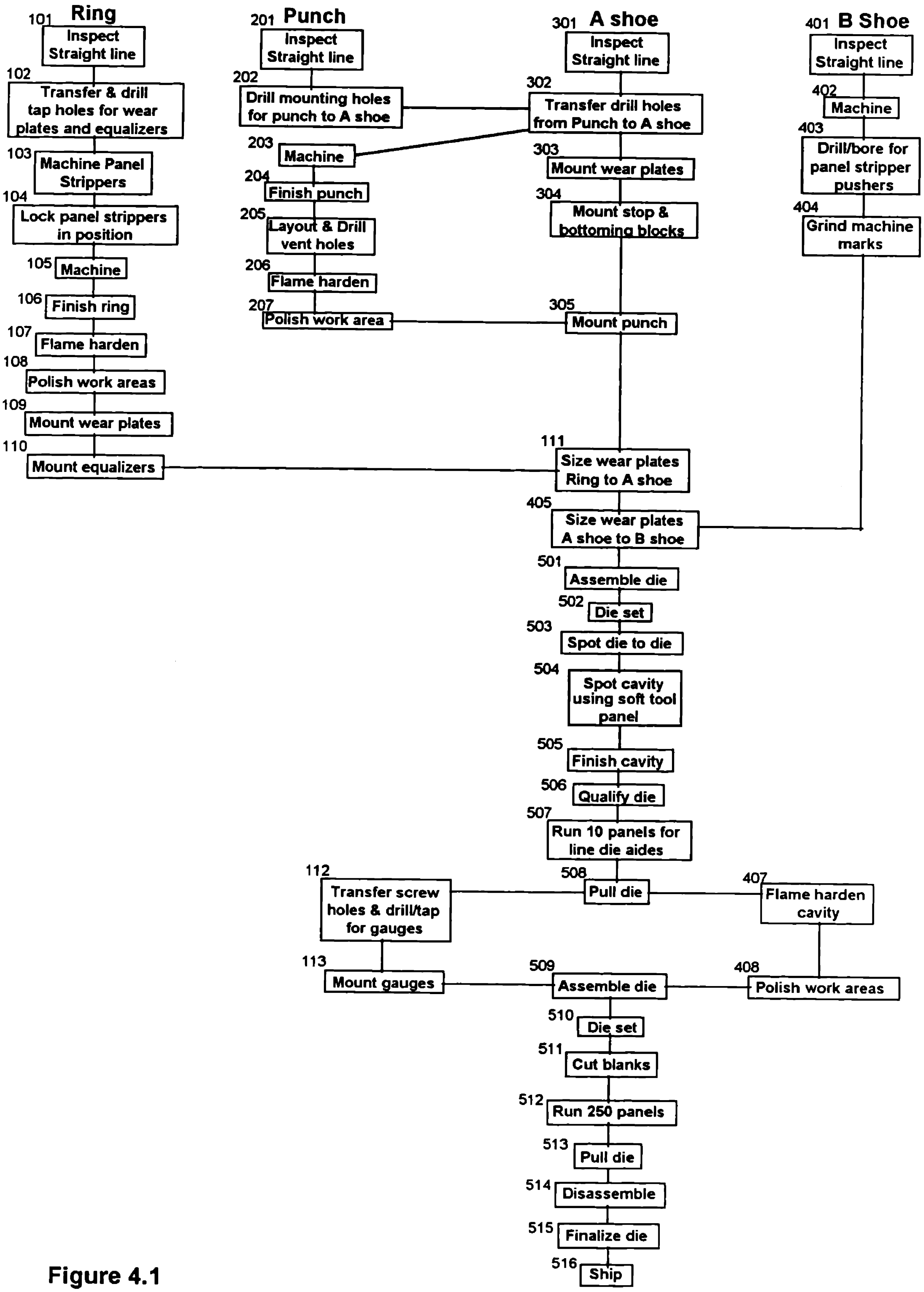


Figure 4.1

In examining the process, it is essential to define the importance of all operations. This will assist in uncovering the overlooked areas. Although these areas may seem to be irrelevant, they still contribute to the process, and require examination. Examining every operation will allow one to determine that operation's relevance in the overall process.

4.2.4 Periodically update process flow chart

The process flow chart should be updated periodically so that changes to the operations can be incorporated. Surprisingly, when a process chart has not been updated frequently, operations are added and deleted from the process through process improvements but are never noted. Changes in technology also place into question the importance of certain operations. Consequently, the process should be updated to reflect changes in technology as well as process improvement.

4.3 Detailing operations

The next step in the process improvement methodology is to detail the various operations. This requires the process improvement analyst to define the various tasks that make up each operation. This is done in attempts to pinpoint non-value added operations as well as assist in standardizing the operation. Moreover, it is a way of improving the proficiency of workers unfamiliar with the process. While these operations are standardized, they should be changed frequently to represent improvements in the process or technology.

Operation sheets for all of the operations in the draw die process have to be developed. Examples of these sheets are shown in Appendix B. As seen in the appendix, each operation sheet has an operation number. This number matches the number and operation on the process flow chart. It allows for easy identification on the process flow chart. The operation sheet also has a brief description of the operation, and the machines needed. Additionally, the sheet lists the tools that are needed for the operation. Moreover, on the operation sheet, the operation routine is defined. These are the sequence of tasks required to complete the operation. Finally, each chart has some type of graphical representation of the operation. This helps to facilitate location of the areas where work is performed.

After operation sheets have been completed for all operations in the process, the next step is to examine each of these sheets for non-value added tasks.

4.4 Data collection

The next step in the process improvement methodology is the collection of data. This is an essential step in improving the process. It is the step that transforms worker's intuition into fact by supporting that intuition with data. There are several pieces of data that are essential to a thorough analysis. They are the cycle time, downtime, and lead time.

4.4.1 Adding cycle times to the operations

Now that the operations of the process are outlined as in Figure 4.1, the cycle times can be added. These times represent the average amount of time that it would take to complete an operation given no complications. Figure 4.2 displays the various cycle times corresponding to the size of casting. The number in the left column represents cycle times for small castings. The number in the middle column represents cycle times for medium sized castings. Finally, the right column represents cycle times for the large castings. Figure 4.2 lists the same operations as seen in Figure 4.1.

Most die shops do not have data on cycle times, because they can vary from part to part. However, an estimate of the cycle times can be made for the die shop by creating three categories based on size. Dies can be categorized as being small, medium, and large. A small die might be a die for an extended side front fender or a reinforced door frame. A medium sized die might be a die for an upper dash panel or a lower deck opening. Finally, an example of a large die would be a door panel or an outer hood panel.

Because the die shop did not keep a listing of the cycle times for operations, they had to be obtained from the employees through interviews. Another method for gathering cycle times is through actual measurement. However, this is requires more time than conducting interviews, but it does yield greater accuracy. It was essential that input from several employees be obtained to collect the best estimate of the cycle times. Gathering data from multiple sources reduces the bias in the data.

For proprietary reasons, the cycle times shown in Figure 4.2 are severely altered using a linear equation as seen in Equation 4.1.

$$Y = mX + b \qquad \text{Eqn 4.1}$$

In equation 4.1, 'X' is the actual cycle time. The 'm' is the multiplier or slope, and 'b' is an arbitrarily chosen constant. The constant is small in comparison to 'X'.

Figure 4.2

Cycle times by die size

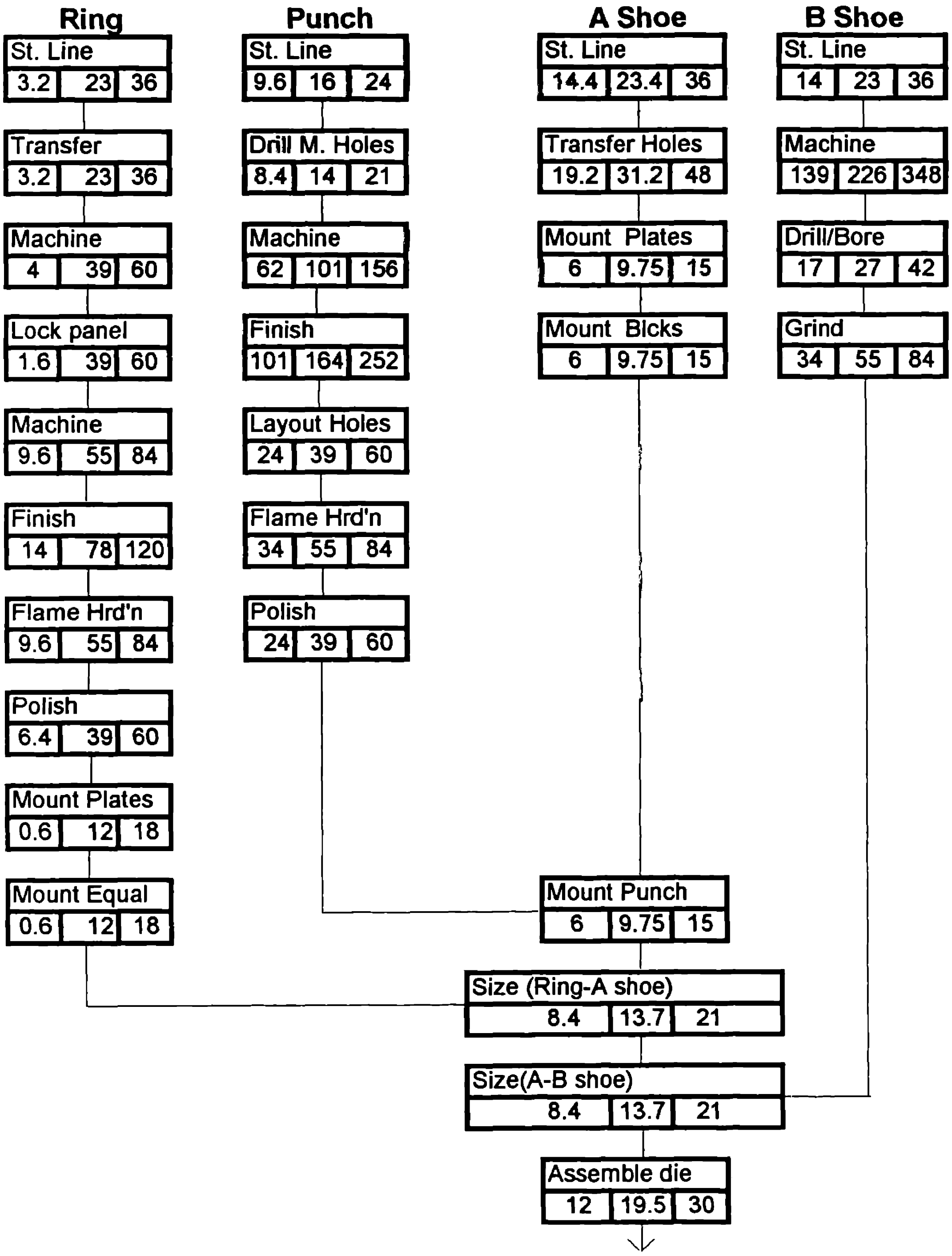


Figure 4.2 cont....

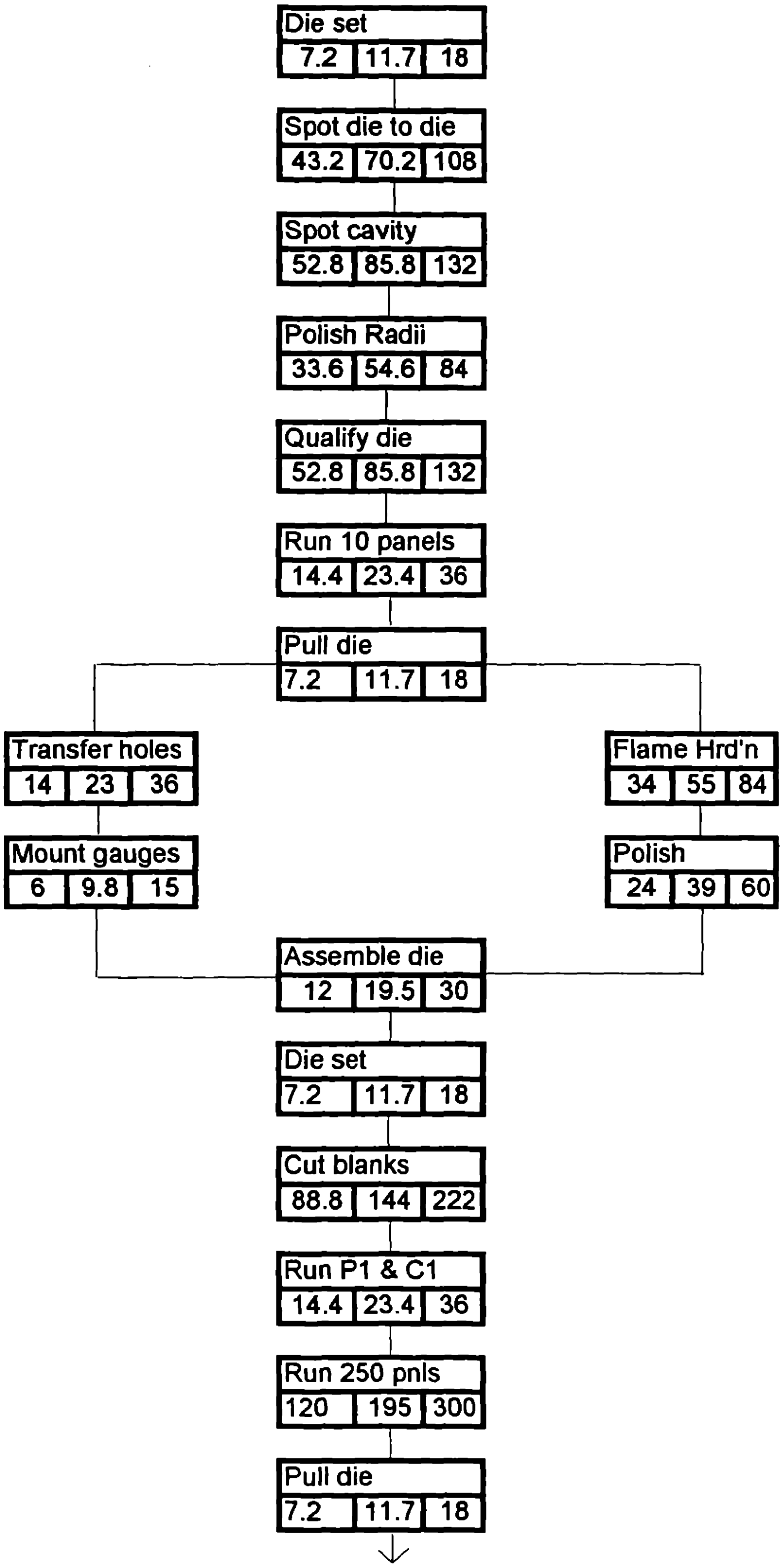
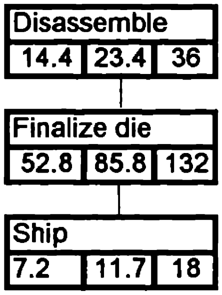


Figure 4.2 cont ...



With every operation there is some variation or statistical fluctuation (Goldratt, 1986). These fluctuations either lengthen or decrease the cycle time of an operation. Due to the difficulty in measuring fluctuations, any analysis of cycle time must account for the variations that occur in the manufacturing environment. For this reason, the author conducted interviews with die makers to get an approximation of how much their operations vary. Based on their responses, the author determined that the operations in the process vary an average of 10%. The 10% represents the range at which the cycle times vary about the mean. When the simulation is built, it will account for these variations.

4.4.2 Collect downtime information

Because almost all die shops use modern machines for drilling, surfacing, or polishing of dies, the collection of downtime data is important in understanding the effect of downtime on the cycle time and availability of a machine. It also affects resource allocation decisions. For example, if a part is scheduled to go to one of three machines, and all machines are available, the operator will probably select the machine that has the lowest amount downtime. Although the operator probably will not have any data to support the assumption that one machine has a higher downtime than another, the die maker still has an intuitive feeling of which machine is the most reliable. The die maker will choose the most reliable and accurate machine. It is the job of the process improvement analyst to look at the distribution of downtime, to validate or invalidate the die maker's hunch, and then to measure the impact of the machine on the whole process. Then, the analyst should look for ways to improve the downtime of that machine. This includes examining the preventative maintenance program, or checking to ensure that machines are not running beyond their capabilities.

The next step in collecting downtime information is to examine the machine's reliability and maintainability. Although there were a multitude of manual machines used for drilling or cutting small tools, the analysis included only machines that cut the four major castings needed for a complete die. This die facility had 9 machines for surfacing or bottoming the dies[1] . Listed in Table 4.3, are the machines used in the process. Reference to these machines will be made according to their associated numbers as seen in the first column of Table 4.3. Additionally, listed in Table 4.3 is each machine's capability to cut small, medium, or large castings. An 's' represents those machines capable of cutting only small castings. An 'm' represents those machines capable of cutting both medium and small sized castings. Finally, an 'l' represents those machines capable of cutting any sized castings.

---

[1] Bottoming refers to the process of cutting the lower surfaces of some dies in an attempt to level their surface.

Types of Machines Used in the Plant

No.	Size	Description
1	m	Horizontal spindle, traveling column mill
2	l	Horizontal spindle, traveling column mill
3	s	Vertical spindle, open side-mill
4	l	Horizontal spindle, table type mill
5	l	Vertical spindle, adjustable rail mill
6	l	Horizontal spindle, traveling column mill
7	m	Vertical CAM fixed bridge mill
8	l	5 axis vertical ram, adjustable rail mill
9	m	Vertical spindle, openside mill

Table 4.3

4.4.3 Evaluating recorded downtime

At the plant, detailed records of the downtime were not maintained. However, they did keep a record of the downtime on certain machines, but this data was not used proactively to find solutions to common problems. An example of the way data was recorded on the shop floor can be seen in Table 4.4. The layout of the data sheet seen in Table 4.4 was chosen by the plant as an appropriate way of conveying information concerning the status of a machine.

The plant kept track of downtime using tables similar to the one seen in Table 4.4. The top two rows indicated the date and day respectively. The third row indicates the shift. The first column indicates the hours of operation. The third row from the bottom indicates the status of a machine. An 'X' indicates that the machine has run for some determined length of time. A 'D' represents downtime on that machine, and an 'A' indicates a lack of operator availability. The last row indicates the casting being machined.

Machine Utilization Data Sheet

Machine #1 (Horizontal spindle, traveling column mill)

	1/7/1991			1/8/1991			1/9/1991			1/10/1991			1/11/1991		
Hrs	Monday			Tuesday			Wednesday			Thursday			Friday		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
8	X			X	X		X	X	X	X		X	X	X	X
7															
6			X												
5															
4															
3															
2						X									
1															
1															
2															
3															
4															
5															
6						X									
7															
8											X				
						A					D				
	Job			Job			Job			Job			Job		
	497-40B			497-29B			497-29B			497-15B			497-15A		

Table 4.4

The first column indicates the hours of operation and non-operation time. The first eight numbers, listed in descending order, describe the amount of time spent machining a part. The second set of eight numbers, listed in ascending order, describe the amount of time a machine is idle, down for maintenance, or down due to lack of operator availability.

Before continuing the evaluation of downtime, the table will be clarified. The table enables the analyst to measure a machine's uptime and downtime over a desired period. For example, on Monday, 1/7/91, the table indicates that the machine ran for 8 hours for the first shift. For the second shift, the machine idled. For the third shift, the machine ran for only 6 hours. For the other two hours of the shift, the machine once again idled.

Examining Tuesday, third shift, the machine ran for only 2 hours. For the other 6 hours the machine idled because there was no operator available. This occurs when there is no trained person available to operate this machine. Moreover, examining Thursday, second shift, Table 4.4 indicates 8 hours was spent to repair the machine. Because the machine ran on the third shift, downtime was a total of 8 hours between the second and third shift.

For the die shop examined, four of the machines were down for extensive time periods. These time periods ranged from five to seven months. If the mean time to failure and mean time between failures were calculated, they would be relatively high. Instead of using the data for these machines in their entirety, these long downtime periods were excluded from the calculation. This was done with the belief that these extensive downtime occurrences are not typical of most machines, and represent outliers in the data.

4.4.4 Analyzing the downtime

Data for downtime was determined only for the 9 machines over a year time span. So, the data for the machines was collected and compiled over this time period. The following will describe the methodology used to analyze the downtime data recorded.

Using the information supplied in the data, the mean time between failure (MTBF) and the mean time to repair (MTTR) were first calculated. The mean time between failure can be defined as the average amount of time that has elapsed from the time a machine is repaired to the beginning of its next failure. This was calculated by counting the hours of uptime (UT) before each machine failure. Then, the series of uptimes (UT) were summed, and divided by the total number of samples in the series. The following equation captures this where 'S' is the number of samples taken in the series.

$$MTBF=\frac{\Sigma\, UT}{S} \qquad \text{Eqn 4.3}$$

The mean time to repair (MTTR) is defined as the average amount of time a machine is down due to failure. The mean time to repair is calculated using a similar equation. It was calculated by determining the amount of time a machine was down after each failure. These times were then summed, and divided by the number of samples taken. DT is defined as the amount of time a machine is down, and 'S' is the number of samples taken in the series. Written in the form of an equation, the following can be shown:

$$MTTR = \frac{\Sigma\, DT}{S} \qquad \text{Eqn 4.4}$$

The relationship between mean time to failure, mean time to repair, and the mean time between failures are shown in Figure 4.3.

Types of failures that can occur over time

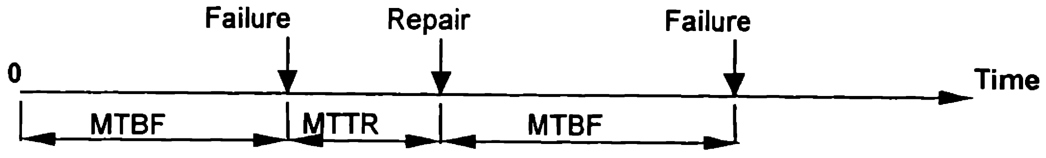


Figure 4.3
(Blanchard, 1969)

Next, the failure rate was calculated. It can be defined as the rate at which failures occur in a given time frame. The failure rate is denoted by the symbol 'λ.' It is equal to the reciprocal of the mean time between failure (Blanchard, 1969). Knowing the failure rate has a unique benefit. It assists in determining when to perform corrective maintenance on a machine. Thus, it is a tool used to enhance the preventive maintenance program.

$$\lambda = 1 / \mathrm{MTBF} \qquad \text{Eqn 4.5}$$

Another piece of data that can be used to evaluate downtime of a machine is reliability. Reliability can be defined as the probability that a machine has not failed over a specified period of time. Under the assumption of an exponential distribution, the following equation is true.

$$R(t) = e^{-\lambda t} \qquad \text{Eqn 4.6}$$

The negative exponential distribution as defined above has several inherent assumptions. First, it assumes that there is no one mechanism which is responsible for most failures (Blanchard, 1969). This implies that each type of failure is random and cannot be consistently traced to the same cause.

The negative exponential distribution also assumes that failures during infant mortality have been eliminated. This presupposes that the machine has been operating long enough to eliminate defects. The infant mortality period consists of failures that occur due to design or manufacturing deficiencies. Once these failures occur, corrective action is taken, and these failures are eliminated.

Another assumption implicit in the negative exponential distribution is that failures due to wear-out do not have a significant impact on the overall failure rate. This implies that the machine has not been running long enough to encounter failures due to wear-out.

Given that the above assumptions, the negative exponential distribution accounts for failures that occur only in the random failure period. This period is shown in Figure 4.4. Moreover, during this duration, the failure rate is assumed to be constant. The rate only changes when the machine's operating conditions change. Additionally, because the negative exponential distribution is a memoryless process, the time until the next failure is independent of the time elapsed since the last failure.

Relative Failure Rates During a Machine's Life

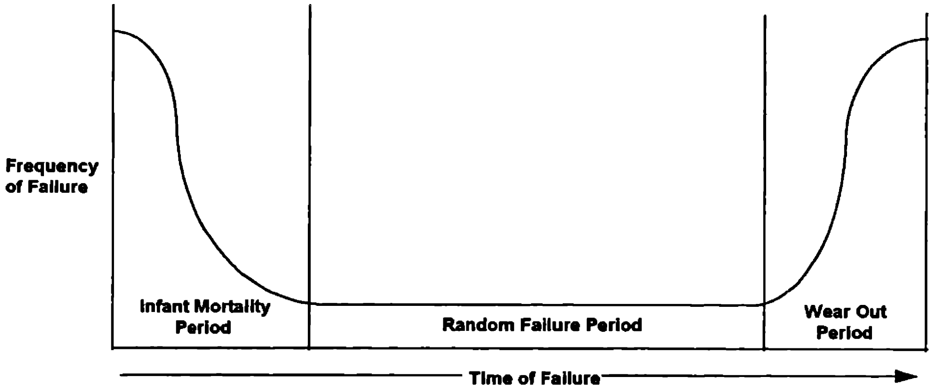


Figure 4.4

(Nahmias, 1989)

Figure 4.5 and 4.6 graphically apply Equation 4.6 to the first two machines listed in Table 4.3. The figures show a decline in the exponential curve. The X axis represents the time period from the first hour of operation to 1114 hour or 46 day of operation. The Y axis represents the reliability of the machine.

In Figures 4.5 and 4.6, it can be seen that Machine #1 has a higher reliability than Machine #2 over the same time period. Thus, if given a choice of which machine to use to perform a given operation based solely on reliability, Machine #1 would be the better of the two choices.

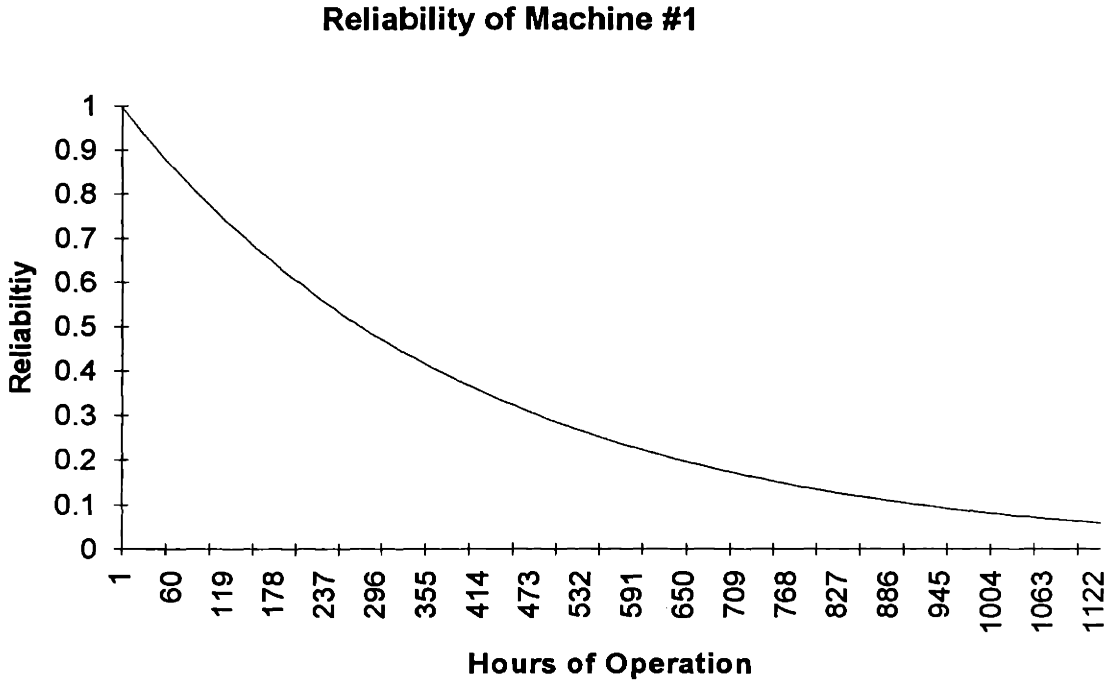

Reliability of Machine #1

Figure 4.5

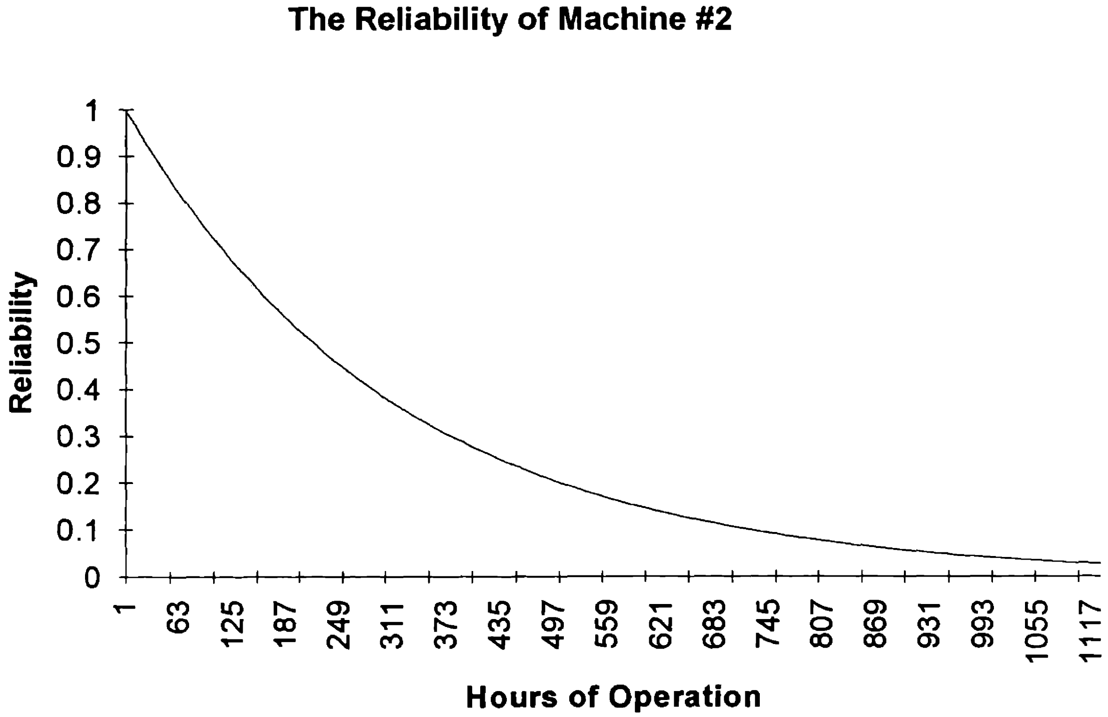

The Reliability of Machine #2

Figure 4.6

Finally, the availability (A) of a machine is calculated. It is defined as the average percent of time that a machine will operate satisfactorily (Blanchard, 1969). It can be calculated by dividing the mean time between failure (MTBF) by the sum of the mean time between failure (MTBF) and mean time to repair (MTTR) (Amstadter, 1971). This can be seen in the following equation:

$$A = \frac{MTBF}{MTBF + MTTR} \qquad \text{Eqn 4.8}$$

Table 4.4 shows the calculations made based on the performance of the machines over a year's time period.

Chart of Machine Reliability Characteristics

No.	Size	MTBF	MTTR	FAILURE RATE	AVAIL.
1	m	355.8	36.4	2.5E-03	0.91
2	l	288	19.8	3.2E-03	0.94
3	s	259.2	30	3.5E-03	0.90
4	l	336.4	24.6	2.8E-03	0.93
5	l	268.5	11.2	3.6E-03	0.96
6	l	135	55.5	5.2E-03	0.71
7	m	288	19.8	3.2E-03	0.94
8	l	288	19.8	3.2E-03	0.94
9	m	288	19.8	3.2E-03	0.94

Table 4.5

The next piece of information that should be collected is the set of historical lead times of the product. The lead times serves as a standard to compare the results of the simulated process to that of the "real world" process. Since one of the objectives for examining the process is to find ways of improving the process, it is important to know the lead time of the loads exiting the process. This allows the analyst to validate the model on the basis of lead time. If the lead time of the simulation and the real process are approximately equal, the simulation still may not mimic the real process. However, having these similar lead times gives greater confidence in the realism of the simulation.

There are several pieces of data that can be acquired. However, cycle time, downtime, and lead time are among the most common. Moreover, any pieces of data that can support an argument for improving the process should also be collected.

Chapter 5

Critical Timing Path For Die Construction

The intent of this chapter is to apply the critical timing path tool introduced in Chapter 3 to the draw die construction process. The goal of applying this tool is to find the series of operations that impacts the overall performance of the process. This includes identifying operations where improvements in cycle time, lead time, or inventory can be made. Additionally, the critical timing path will also assist in the identification of the bottleneck of the process.

5.1 Pre-requisites for the Critical Timing Path

As mentioned in Chapter 3, the prerequisite for developing the critical timing path is the development of the precedence relationships. These relationships were developed in Chapter 4. Specifically, Figure 4.1 gives an accurate representation of the operations needed to be performed to complete a draw die.

The other prerequisite for completion of the critical timing path is the operation cycle times. These cycle times were listed in Figure 4.2, and will be used extensively throughout this chapter.

5.2 Critical Path Software

Due to the number of operations in the die construction process, it was necessary to use a commercially available software package to create the critical path. The underlying principles of the software package are no different from those described in Chapter 3.

Another benefit of using a commercially available software package is the ability to better track and schedule projects. This can be performed by hand, but it is a tedious process. Manual calculation of the critical timing path gets workers more involved in thinking about the process and trying to improve it. In contrast, when a computer churns out the critical path, workers have a tendency to accept it without really understanding the significance of the information.

For larger processes, it is recommended that critical path software be used. This will speed up the process of calculating the critical timing path, as well as assist in the tracking and scheduling of dies in the plant.

The software used to examine the die shop was developed by the Microsoft Corporation. It is entitled Microsoft Project Version 3.0, and is a user-friendly window system. It requires a basic understanding of Windows, and an understanding of the process, cycle times, and resources constraints.

5.3 Determination of the Critical Timing Path

In calculating the critical timing path, the software first computes the earliest start and finish times. It then computes the latest start and finish times. Based on the difference between the earliest start time and the latest start time, the slack times are calculated. This can be seen in Table 5.1.

As seen in the table, there are two different slack times listed. The first is the free slack time. This is the amount of time a task can be delayed before it affects another task. The total slack time column listed in the table refers to the amount of time a task can be delayed before it affects the project finish date. Referring to Table 5.1 again, it can be seen that the total slack time before an assembly operation is 0. The only exception is when an operation immediately precedes the assembly operations.

Table 5.1

Critical Timing Path Table

RING

	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Straight line	1/1/93 6:30am	1/3/93 10:30am	1/10/93 6:30am	1/12/93 10:30am	0d	18days
Transfer holes	1/3/93 10:30am	1/5/93 2:30pm	1/12/93 10:30am	1/14/93 2:30pm	0d	18d
Machine panels	1/5/93 2:31pm	1/9/93 10:30am	1/14/93 2:31pm	1/18/93 10:30am	0d	18d
Lock panels	1/9/93 10:30am	1/12/93 10:31pm	1/18/93 10:30am	1/21/93 10:31pm	0d	18d
Machine	1/13/93 6:30am	1/18/93 10:30am	1/22/93 6:30am	1/27/93 10:30am	0d	18d
Finish Ring	1/18/93 10:30am	1/25/93 6:31pm	1/27/93 10:30am	2/3/93 6:31pm	0d	18d
Flame harden	1/25/93 6:31pm	1/30/93 10:31pm	2/3/93 6:31pm	2/8/93 10:31pm	0d	18d
Polish	1/31/93 6:30am	2/3/93 6:31pm	2/9/93 6:30am	2/12/93 6:31pm	0d	18d
Mount plates	2/3/93 6:31pm	2/4/93 8:31pm	2/12/93 6:31pm	2/13/93 8:31pm	0d	18d
Mount equalizer	2/4/93 8:31pm	2/5/93 10:31pm	2/13/93 8:31pm	2/14/93 10:31pm	18d	18d

A SHOE

	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Straight line	1/1/93 6:30am	1/3/93 10:30am	1/1/93 3:31pm	1/3/93 7:31pm	1d	1d
Transfer holes	1/3/93 7:31pm	1/6/93 7:31pm	1/3/93 7:31pm	1/6/93 7:31pm	0d	0d
Mount plates	1/6/93 7:31pm	1/7/93 6:31pm	2/12/93 9:30am	2/13/93 8:30am	0d	73d
Mount btg blcks.	1/7/93 6:31pm	1/8/93 5:31pm	2/13/93 8:30am	2/14/93 7:30am	73d	73d
Mount punch	2/14/93 7:30am	2/14/93 10:31pm	2/14/93 7:30am	2/14/93 10:31pm	0d	0d
Size wear plates B shoe	2/15/93 6:30am	2/16/93 11:30am	2/15/93 6:30am	2/16/93 11:30am	0d	0d
Size wear plates A shoe	2/16/93 11:30am	2/17/93 4:31pm	2/16/93 11:30am	2/17/93 4:31pm	0d	0d

B SHOE

	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Straight line	1/1/93 6:30am	1/3/93 10:30am	1/15/93 1:30am	1/17/93 5:30pm	0d	29d
Machining	1/3/93 10:30am	1/24/93 10:31pm	1/17/93 5:31pm	2/8/93 1:30pm	0d	29d
Drill strippers	1/25/93 6:30am	1/27/93 4:31pm	2/8/93 1:30pm	2/11/93 7:30am	0d	29d
Grind marks	1/27/93 4:31pm	2/1/93 8:31pm	2/11/93 7:30pm	2/16/93 11:30am	29d	29d

PUNCH

	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Straight line	1/1/93 6:30am	1/2/93 2:30pm	1/1/93 6:30am	1/2/93 2:30pm	0d	0d
Drill mnt. holes	1/2/93 2:31pm	1/3/93 7:31pm	1/2/93 2:31pm	1/3/93 7:31pm	0d	0d
Machine	1/6/93 7:31pm	1/16/93 3:31pm	1/6/93 7:31pm	1/16/93 3:31pm	0d	0d
Finish punch	1/16/93 3:31pm	2/1/93 11:30am	1/16/93 3:31pm	2/1/93 11:30am	0d	0d
Drill vent holes	2/1/93 11:30am	2/5/93 7:30am	2/1/93 11:30am	2/5/93 7:30am	0d	0d
Flame harden	2/5/93 7:30am	2/10/93 11:30am	2/5/93 7:30am	2/10/93 11:30am	0d	0d
Polish	2/10/93 11:30am	2/14/93 7:30am	2/10/93 11:30am	2/14/93 7:30am	0d	0d

Table 5.1 cont.

ASSEMBLY OPERATION	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Assemble die	2/17/93 4:31pm	2/19/93 2:30pm	2/17/93 4:31pm	2/19/93 2:30pm	0d	0d
Die set	2/19/93 2:31pm	2/20/93 4:31pm	2/19/93 2:31pm	2/20/93 4:31pm	0d	0d
Spot die to die	2/20/93 4:31pm	2/27/93 12:30pm	2/20/93 4:31pm	2/27/93 12:30pm	0d	0d
Spot cavity	2/27/93 12:30pm	3/7/93 4:31pm	2/27/93 12:30pm	3/7/93 4:31pm	0d	0d
Polish	3/7/93 4:31pm	3/12/93 8:31pm	3/7/93 4:31pm	3/12/93 8:31pm	0d	0d
Qualify die	3/12/93 8:31pm	3/21/93 8:30am	3/12/93 8:31pm	3/21/93 8:30am	0d	0d
Run 10 panels	3/21/93 8:30am	3/23/93 12:30pm	3/21/93 8:30am	3/23/93 12:30pm	0d	0d
Pull die	3/23/93 12:30pm	3/24/93 2:30pm	3/23/93 12:30pm	3/24/93 2:30pm	0d	0d
B shoe						
Flame hrd'n	3/24/93 2:31pm	3/29/93 6:31pm	3/24/93 2:31pm	3/29/93 6:31pm	0d	0d
Polish	3/29/93 6:31pm	4/2/93 2:30pm	3/29/93 6:31pm	4/2/93 2:30pm	0d	0d
Ring						
Transfer holes	3/24/93 2:31pm	3/26/93 6:31pm	3/30/93 11:30am	4/1/93 3:31pm	0d	11d
Mount gauges	3/26/93 6:31pm	3/27/93 5:31pm	4/1/93 3:31pm	4/2/93 2:30pm	11d	11d
Assemble die	4/2/93 2:31pm	4/4/93 12:30pm	4/2/93 2:31pm	4/4/93 12:30pm	0d	0d
Die set	4/4/93 12:30pm	4/5/93 2:30pm	4/4/93 12:30pm	4/5/93 2:30pm	0d	0d
Cut blanks	4/5/93 2:31pm	4/19/93 12:30pm	4/5/93 2:31pm	4/19/93 12:30pm	0d	0d
Run 250 panels	4/19/93 12:30pm	5/8/93 8:30am	4/19/93 12:30pm	5/8/93 8:30am	0d	0d
Pull die	5/8/93 8:30am	5/9/93 10:30am	5/8/93 8:30am	5/9/93 10:30am	0d	0d
Disassemble	5/9/93 10:30am	5/11/93 2:30pm	5/9/93 10:30am	5/11/93 2:30pm	0d	0d
Finalize die	5/11/93 2:31pm	5/19/93 6:31pm	5/11/93 2:31pm	5/19/93 6:31pm	0d	0d
Ship	5/19/93 6:31pm	5/20/93 8:31pm	5/19/93 6:31pm	5/20/93 8:31pm	0d	0d

Those operations listed in the table with total slack times of 0 are operations that are on the critical timing path. Moreover, they are the operations that most impact the lead time of a part flowing through the process. Based on Table 5.1, the critical path can be identified. However, this can be seen with greater ease in Figure 5.1.

Critical Path for Die Construction

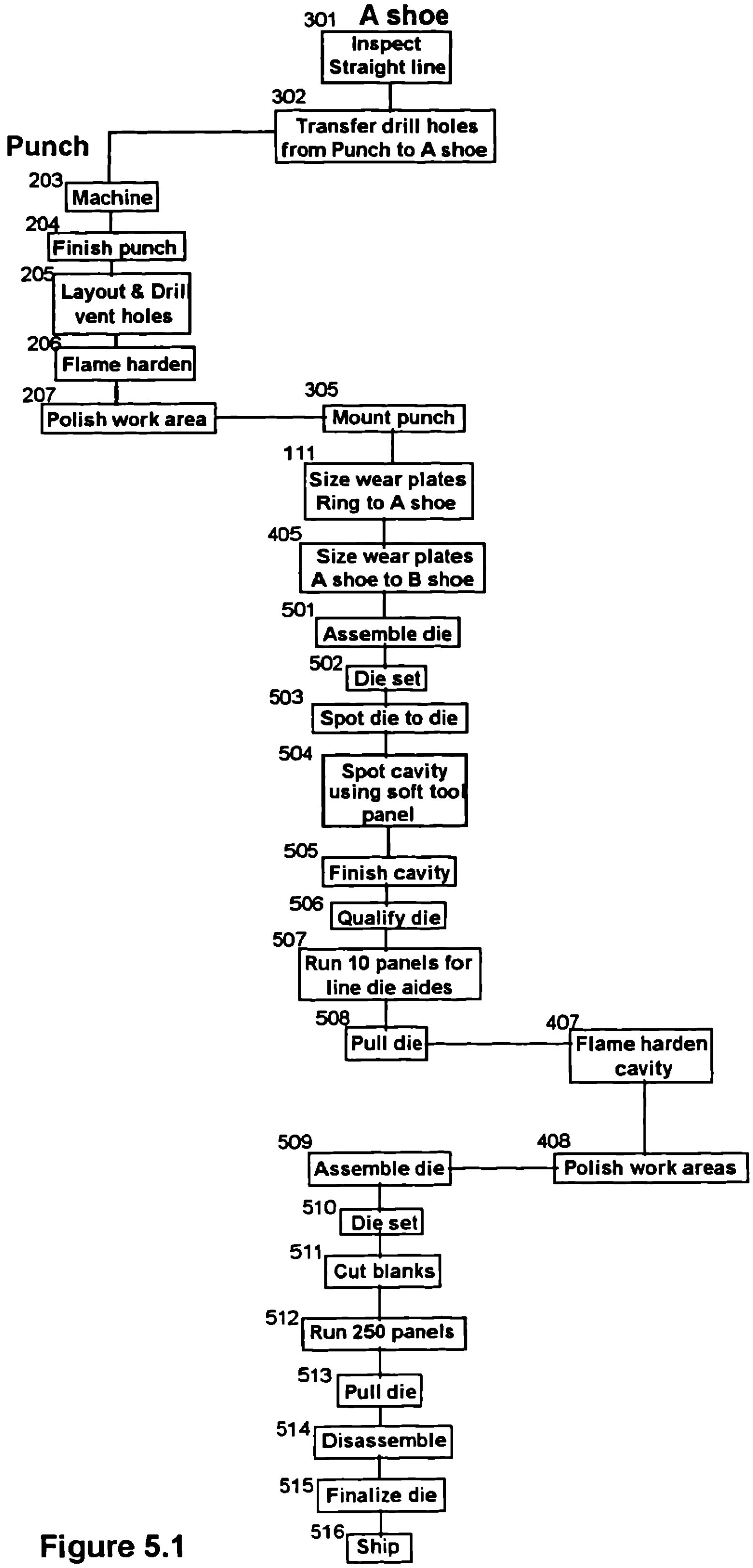


Figure 5.1

Using Figure 5.1, it can be seen that the critical timing path begins with the A shoe. Then when the holes from the Punch are drilled to the A shoe, the Punch becomes part of the critical path. Even after the Punch is separated from the A shoe and is machined, the punch is still part of the critical path. As the Punch is assembled with the Ring, A and B shoe, the next sequence of operations is on the critical path until the die is pulled from the press. This occurs when the B shoe is flame hardened and the ring has holes drilled. The remaining operations in the process are on the critical timing path.

5.4 Bottleneck of the process

As mentioned in Chapter 3, by defining the critical timing path, the bottleneck of the process can then be identified. It is the operation on the critical path with the highest cycle time. The bottleneck of the draw die construction process is the operation where 250 panels are run for prototype and test vehicles. This operation consumes the most amount of time and most constrains the throughput and lead time of the process.

There are 3 other operations that also have a significant impact on the process. They are listed in order with the highest cycle times first. They are as follows:

- Punch finishing
- Cut blanks
- Machining

All initial improvements to the process should be made by first examining the above operations, and then, examining the other operations in the process.

Increasing the capacity of those operations with the highest cycle times, is the fastest method of improving the lead time and throughput (Goldratt, 1986).

5.5 Describing capacity constraints and alternatives

Because capacity constraints have a large impact on the lead time, a closer examination of the operations is necessary. Provided below is a detailed description of the most constraining operations. Additionally, in attempts to reduce the cycle time of the operations mentioned previously, the author, in conjunction with die makers in the industry, developed a set of alternatives that address the issue of high cycle times. All of the alternatives are not feasible given manufacturing and cost constraints. However, the purpose of the simulation is to filter out these alternatives based on manufacturing viability.

Operation: Run 250 panels

This operation requires the die makers to assemble the die in the press. Then, they proceed to stamp 250 panels. These panels are used to assist the stamping plant in monitoring the quality of panels and dies over a large sample. They are also used to assist the assembly plant in preparing for full scale ramp up by allowing the assembly plant to practice assembly operations.

While stamping 250 panels is necessary for both the stamping and assembly plant, it does not have to be performed in the die facility. Instead, it can be performed in the stamping plant. Moreover, because the stamping plant is in charge of the high volume production of stampings, this operation should be performed by that plant. Stamping 250 parts can then serve as a training exercise to help the stamping plant ramp-up to full production of stampings for this die.

After speaking with several representatives from two American automotive companies, they all agree that the stamping plant is more capable of running 250 panels than the die shop. One representative stated that one of their die shop's objectives is to work closely with the stamping plant so that these operations can be transferred to the stamping plant as soon as it is possible. However, all of the representatives agree that some small number of stampings should be produced to measure the quality of the die before it goes to the stamping plant. One representative stated that producing a limited number of stampings will allow the die shop to correct problem areas on the die. He continued by stating that the die shop did not want to send poor quality dies to the stamping plant.

Operation: Punch finishing

The punch finishing operation is the long and tedious process of removing the machine marks from the surface of the casting. This operation is necessary to produce a stamping of high quality.

There are several alternatives that can be examined to improve the cycle time of the operation and subsequently the lead time of the process. First, the plant can add an additional shift to increase overall operational capacity. As mentioned previously, the plant only runs 2 shifts. So, an additional shift will increase capacity.

Second, the plant should investigate the viability of purchasing a polishing machine. Many die facilities have noted that these machines have improved capacity of this operation by 50%. This technology will be discussed in greater detail in Chapter 8.

The third alternative is to perform more machining so that the casting requires less finishing. This implies obtaining a closer cut to the surface. The closer the casting is to the desired shape and surface quality, the less finishing is required. In order to decrease the cycle time of the punch finishing operation, an increase in machine cycle time is necessary. However, because the machining operation is not the most constraining, an increase in its cycle time will not affect the throughput rate. So, its cycle time can be increased.

In comparing the finishing operation in an American facility to that of a Japanese facility, it can be seen that the American die facility typically has excess stock on the castings after machining. As seen in Figure 5.2, the Japanese facility has an advantage in the finishing operation because they are able to machine more of the excess material. After machining, they have only .0004" of excess material remaining on the casting (Drees, 1991). This is in contrast to the American facility where .004" of material remains on the castings after machining (Drees, 1991). Consequently, this requires the American facility to perform more finishing than its Japanese counterparts (Drees, 1991).

Amount of Excess Material Remaining on Castings After Machining

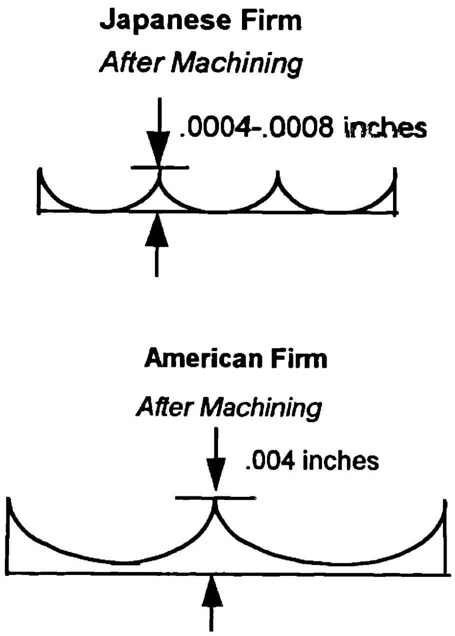


Figure 5.2

The last alternative is to increase the number of die finishers performing the operation. Because the size of the die limits the number of die finishers that can work on one part, additional die finishers can only assist in finishing dies that are in work-in-process. Although the finishing operation's capacity is partially dictated by the number of die finishers, the problem of space restricts the substantial increase in the operation's cycle time. The maximum number of finishers working on one die is 2. Die space restricts any additional die finishers from working in the same space. So, any increase in die finishers would have little effect on the operations cycle time but a greater effect on the operations capacity. As dies accumulate in the queue, additional die makers can finish those dies in the queue. This reduces inventory and wait time.

Operation: Cutting Blanks

To reduce the cycle time for cutting blanks, two alternatives can be examined. First, dedicated workers can perform the operation in parallel with the main die construction process. This requires the operation to start further up stream. As a result of moving the operation, lead time is reduced by 300 hours or 12.5 days. Figure 5.3 describes the possible location of the blank cutting operation.

Location of Blank Cutting Operation in Parallel with Process

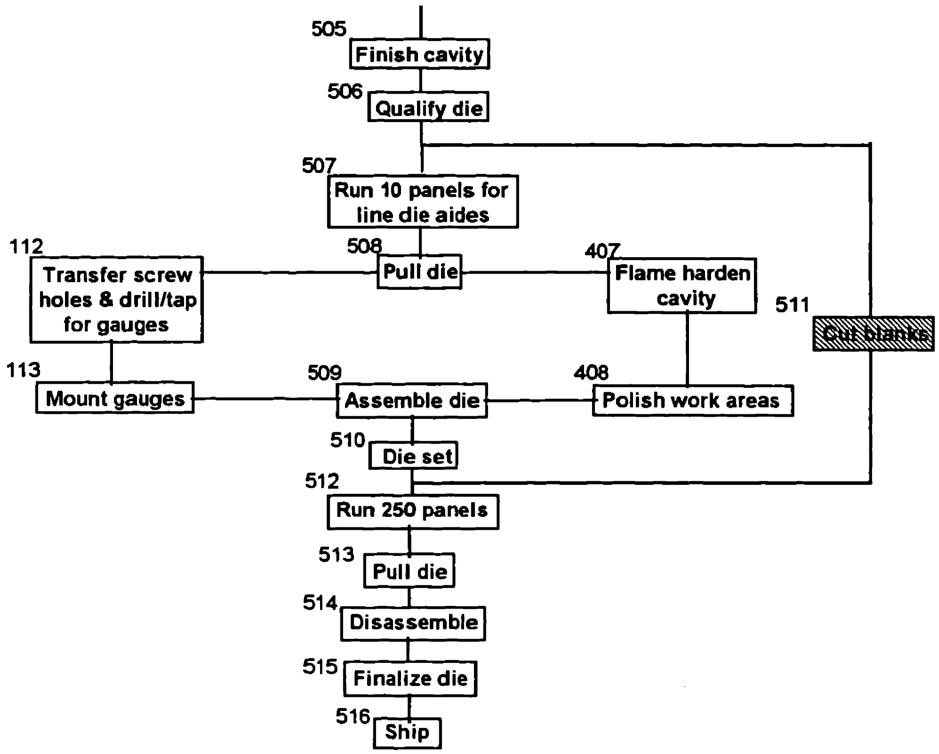


Figure 5.3

A second alternative is to utilize the laser cutter to cut the blanks. This machine is currently used to cut blanks with complex shapes. It is not used extensively for simple shapes due to the large amount of programming required. However, if the programming is expedited and simplified, the laser can also be used to cut simple shapes quickly. Thus, this is a valid alternative deserving further consideration.

Operation: Machining for punch

Adding additional machines increases the capacity of the machining operation. However, this is often a very expensive solution to the capacity problem. Therefore, before examining the purchase of additional machines, the analyst must examine the current state and use of machines. This includes analyzing the reliability and maintainability of the machines. Chapter 4 provided an in-depth analysis of the downtime. It verifies that downtime is a factor worth considering for decreasing lead time.

The analyst must also examine the machine utilization policies. Currently, castings are machined based on machine availability. If a machine is available, the policy is to machine a casting regardless of whether it needs machining then. In other words, machines cut castings on an "as soon as possible" basis. This increases the utilization of the machine unnecessarily, and causes the resource to be used inefficiently. For example, instead of die makers working on dies downstream, they instead work on the castings entered prematurely. Consequently, castings wait in inventory further downstream.

5.6 Filtering the alternatives

The next step of the methodology, the simulation, filters the alternatives elaborated previously. While the critical timing path is useful in determining the operations that most impact the overall lead time, it does not consider the other factors prevalent on the plant floor. Examples of these factors are resource constraints, inventory fluctuations, or cycle time variations. Because the simulation can account for many of the these factors, it is an important tool for analyzing the process.

Chapter 6

Simulating the Die Construction Process

This chapter is devoted to describing the simulation model developed to examine the process of die construction. This chapter will discuss the various assumptions made to create a model that is accurate but not too complex. Unlike the critical path method, the simulation handles uncertainty. This includes randomness in cycle times, machine downtimes and uptimes, move times, and machine availability due to external loads in the process. Because the simulation handles uncertainty, it accounts for more factors that impact the real process than does any other tool used thus far. It considers the effect of machine constraints, labor constraints, and work-in process on the lead time. Overall, it provides the user with a quasi-realistic depiction of the true work environment using real work flow schedules.

6.1 Description of software used

The software used for designing the simulation was entitled Automod. It is a menu-driven system that includes programming options. These options give the user greater flexibility in modeling the system. Although the programming language is unique to the software package, it is similar to FORTRAN.

6.2 Operations

6.2.1 Description of the operations included

The operations used in the simulation were the same as those used in the process flow diagram in Figure 4.1. The precedence relationships between operations are the same as in the process flow diagram. Additionally, there are several move operations included to depict some of the time used to move castings from one part of the plant to another.

Operations were added to the model to control the flow of materials from one station to another. These operations tell the computer where to send a load next, or how long to hold the current load. As a result of these additional operations, the distribution of operations is as follows: 50 die construction operations, and 22 move operations.

6.2.2 Cycle times for the operations

The cycle times for each of the operations are the same as those presented in Table 4.2. Each operation is programmed to choose a cycle time that is appropriate to the size casting entering the operation. An example of the selection process programmed into the computer can be seen in Figure 6.1. Punch_large, Punch_med, and Punch_small refer to the size of the punch casting. As seen in the figure, there are different cycle times associated with each of the different sizes. "IF" logic is used to decide the appropriate cycle time for each of the different sizes. This type of logic is used in most of the operations when deciding the appropriate cycle time.

Programming Code for Castings with Different Cycle Times

```
begin
if load type = Punch_large
  use 1 of rdiemakers for uniform(3.6, 4.4) hr
else if load type = Punch_med
  use 1 of rdiemaker for uniform (2.34, 2.86)  hr
else if load type = Punch_small
  use 1 of rdiemaker for uniform (1, 1.32) hr
end
```

Figure 6.1

As seen in Figure 6.1, once the size of the die is selected, the computer uses a uniform distribution to calculate the time a die maker uses a resource. For the simulated model created, the uniform distribution gives an equal probability of a cycle time lasting plus or minus 10% of the most likely cycle time. The 10% variation is due in part to the statistical fluctuations that occur in the manufacturing process (Goldratt, 1986). This figure was determined on the basis of interviews with plant personnel. However, both the cycle time and variance can be determined by measuring the actual cycle times.

Based on observation, the cycle times never exceeded the lower and upper ranges of the uniformed distribution. The uniform distribution was selected because the probability distribution is defined on a finite interval (Nahmias, 1989). In the simulation, the interval was plus or minus 10% of the estimated cycle time. Because the cycle time has an upper and lower bound, a uniform distribution is used to describe the distribution of individual cycle times (Nahmias, 1989). The normal distribution was not selected because the cycle times were bounded. In addition, worker's believed that most values were equally likely.

In addition to the previously mentioned operations, there are also move operation incorporated in the process. These operations represent the movement of castings from one location in the plant to another. Each move operation requires at least 2 die makers, and takes about 2 hours to perform. However, depending on the availability of the crane, the move time can vary from 15 min. to 3-1/2 hours. This is modeled in the simulation as a uniform distribution with the average time being 2 hours, and the maximum and minimum being 3-1/2 and 15 min. respectively. These times are based on interviews conducted with die makers.

6.2.3 Capacity of an operation

Because most operations in the die construction process have their capacity determined by the number of workers available, its capacity can fluctuate according to the number of workers. However, for the machining operations, its capacity is determined by the ability of the machine to produce parts at a certain rate in a certain time period.

The current model assumes that all of the machines used in the machining operation are available for different types of dies. These dies could be blank, pierce, or form dies. The other dies will consume some of the capacity of the machines. This reduction in capacity is modeled in the simulation by introducing dummy loads into the machining operation. This is shown in Figure

6.2. These loads are representative of outside loads demanding a portion of a machine's capacity. While the average utilization of outside loads are based on actual data, the specific timing of these loads are artificially created. They are based on the historical percentage that the non-draw dies will require the machine 82% of the time. These percentages and average machine times were found by examining data on the typical amount of time a non-draw die required machining as compared to a draw die. Table 6.1. presents the distribution of machining time for all machines.

Insertion of Dummy Loads into the Machining Operation

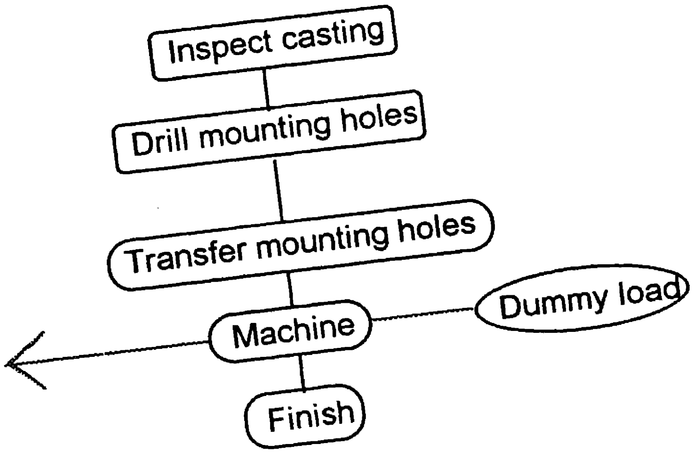


Figure 6.2

Percent of Required Machine Time for Each Die Type

Draw type	% of Machining Times
Draw	18%
Trim	22%
Form	23%
Pierce	27%
Other	10%

Table 6.1

As previously mentioned, the draw die loads share the machining resources with other types of dies such as blank, pierce, and form. At time equal to zero, the simulation creates both draw die loads and non-draw die loads. The draw die loads proceed through the operations in the process starting at the beginning. While the draw die is moving through the process, the dummy load is executing its program as seen in Figure 6.3. According to the program, the non-draw die loads first wait an average of 48.8 hrs with a minimum wait of 0 hrs and a maximum wait of 97.6. The 48.8 hours was calculated based on the average amount of time a draw die used a machine. Because the cycle time was based on a uniform distribution, there is an equal probability that the non-draw die will wait from time 0 to time 97.6. After the wait time is complete, the non-draw die will attempt to use Machine #1. If during this time period the machine is being used by a draw die, the non-draw die will wait until the machine is available. Then, it will use that resource for a uniformed (42, 302.3) hours. After using the resource, Machine #1, the resource is then released, and is freed to machine any load. Note that 48.8 is 18% of the sum of 222.3 and 48.8. Hence, the timing simulates two processes that are competing for the same resource.

Programming Code for Dummy Load

```
 begin
wait for a uniform (0, 97.6) hr
get rmachine1
wait for a uniform (142, 302.3) hr
free rmachine1
return to beginning
end
```

Figure 6.3

6.3 Resources

6.3.1 Types of resources modeled

The simulation has 4 resources modeled. They are as follows:

- 9 CNC Machines
- 18 Draw die makers
- 2 Die setters
- 2 Die finishers

There are 9 CNC machines modeled. These are the same machines that were described in Chapter 4. According to worker schedules, there are roughly 18 draw die makers. They are workers whose specialty and experience is concentrated in draw die construction. Moreover, there are 2 die setters whose task is to assemble and disassemble dies in run position. This is a different classification from that of a die maker because it requires a different set of skills.

The last resource listed is that of the die finisher. This resource was not used extensively in the model. Its purpose was to test alternatives such as the effect of having dedicated die finishers perform finishing operations on a casting. It was not used in the main model because the job description of the die maker includes finishing. So, according to this description, all die makers should be able to finish as well as perform other operations. Although the die maker's job description is broad, specific skills, expertise, and interest dictate which operations die makers work best. So, the idea that die makers move wherever they are needed is not practical. For this reason, the die finisher resource is separate from the die maker resource. Consequently, a distinct group of resources should be modeled to represent those workers whose skills and interests are in die finishing. This is the intent of the die finisher resource.

6.3.2 Capacity of resources

The capacity for the machine resources is dictated by the number of parts that can be worked on at a particular time. For example, the load capacity of each CNC is one. All of the machines are capable of working on only one die at a time. Moreover, the capacity of the die maker resource is simply the number of die makers in the resource pool. This pool consists of 18 die makers. Moreover, the capacity of the die setters and die finishers are 2.

6.3.3 Downtime of resources

The downtime of the machining resources was discussed in Chapter 4. In this chapter, the mean time between failures and the mean time to repair were specified as an exponential distribution for each of the 9 machines. This distribution is modeled into the simulation to give it a more realistic depiction of the occurrences in the plant.

6.3.4 Description of shifts and worker schedules

The labor resources in the plant such as die makers, finishers, and setters are also modeled into the simulation. The resources are modeled based on actual labor hours. The plant runs two 8 hour shifts, 7 days a week. They also run a third shift where machining is performed and castings are moved. Machining is performed on the third shift in attempts to increase some of the capacity of the machining operation.

6.4 Loads

6.4.1 Schedule

The loads were modeled in the simulation based on the master program schedule. This schedule indicates what parts should be started at a given time period. This enables the user to model the loads in the simulation exactly as they are supposed to enter the plant. Thus, it offers another level of reality to the model. The number of dies or loads in the program schedule is 84. The loads, as seen in Table 6.2, are based on the start times of actual loads in the plant.

List of Dies Entering the Simulation

Part name	Start date
Ext side frnt fender to h/l	12/11/91
Ext side frnt fender to h/l	12/11/91
Ext side frnt fender to h/l	12/11/91
Panel door outer	12/20/91
Panel door outer	12/20/91
Panel door outer	12/20/91
Pnl qtr innr upr	12/20/91
Pnl qtr innr upr	12/20/91
Pnl qtr innr upr	12/20/91
Side front fender rh	2/3/92
Side front fender rh	2/3/92
Side front fender rh	2/3/92
Support cowl side inner to floor	3/4/92
Hood inner pnl	3/16/92
Hood inner pnl	3/16/92
Hood inner pnl	3/16/92
Beam frt fndr shld upr load path	3/30/92
beam frt fndr shld upr load path	3/30/92
Hood outer pnl	4/3/92
Hood outer pnl	4/3/92
Hood outer pnl	4/3/92
Pnl lower deck opening outer	6/5/92
Pnl lower deck opening outer	6/5/92
Dash pnl upper	6/8/92
Dash pnl upper	6/8/92
Reinf-frt s/rail eng mt rt	7/3/92
Reinf-frt s/rail eng mt rt	7/3/92
Pnl qtr inr lwr	7/10/92
Pnl qtr inr lwr	7/10/92
Reinf-w/h inr shk abs mtg	7/10/92
Reinf-w/h inr shk abs mtg	7/10/92
Roof outer*	7/10/92
Roof outer*	7/10/92
Supt-rad clsr toupr c/mbr	7/20/92
Reinf frt s/rail eng mt rt	7/21/92
Reinf frt s/rail eng mt rt	7/21/92
Panel-rr w/house inner	7/24/92
Panel-rr w/house inner	7/24/92
REinf-deck opng lwr otr pnl	7/24/92
REinf-deck opng lwr otr pnl	7/24/92
Brace Frt S/rail to sill inr	7/31/92
Brace Frt S/rail to sill inr	7/31/92
Cowl side ch18	7/31/92
Cowl side ch18	7/31/92
reinf-shelf panel rr center	7/31/92
Reinf door frame frt	8/12/92
Reinf door frame frt	8/12/92
Reinf door frame frt	8/12/92
Rail frt side rear	8/17/92
Rail frt side rear	8/17/92
Rail frt side rear	8/17/92
Rail frt s/frt	8/21/92
Rail frt s/frt	8/21/92
Dash panel upper	8/24/92
Dash panel upper	8/24/92
Pnl rr w.house outer	8/24/92
Pnl rr w.house outer	8/24/92
RR w/hse inr rr	8/25/92
RR w/hse inr rr	8/25/92
RR w/hse inr rr	8/25/92
Ext frt side rail	9/18/92
Frt fender side shield	9/18/92
Frt fender side shield	9/18/92
Gusset floor pan to sill	9/21/92
Gusset floor pan to sill	9/21/92
Roof outer(only the p1 date avail)	9/28/92
Roof outer(only the p1 date avail)	9/28/92
Twr-frt susp iso strut rt	10/2/92
Twr-frt susp iso strut rt	10/2/92
Twr-frt susp iso strut rt	10/2/92
Reinf frt seat c/mbr rr	10/19/92
Support l/door latch reinf	11/2/92
Panel hood inner	11/20/92
Panel hood inner	11/20/92
Panel hood inner	11/20/92
Panel hood outer	11/27/92
Panel hood outer	11/27/92
Pan front floor	12/4/92
Panel roof outer	1/1/93
Panel roof outer	1/1/93
reinf hood slaminr pnl slam	1/11/93
reinf hood slaminr pnl slam	1/11/93
Reinf tunnel fr/st c/mbr rr m30	1/15/93
Reinf tunnel fr/st c/mbr rr m30	1/15/93

Table 6.2

6.4.2 Overlapping loads to achieve steady state

Initially, the simulation began with zero loads in the plant. This can be seen in Figure 6.4. The number of loads before December of 1991 is zero. The simulation only accounts for loads in the system at the previously mentioned times. This is unrealistic because it does not represent the true loads in the plant during that time period. Moreover, in the plant, there are always some number of loads in the process. While over time the number of loads may vary to represent the cyclical nature of the business, it still has loads residing in the process during start-up of a new product line.

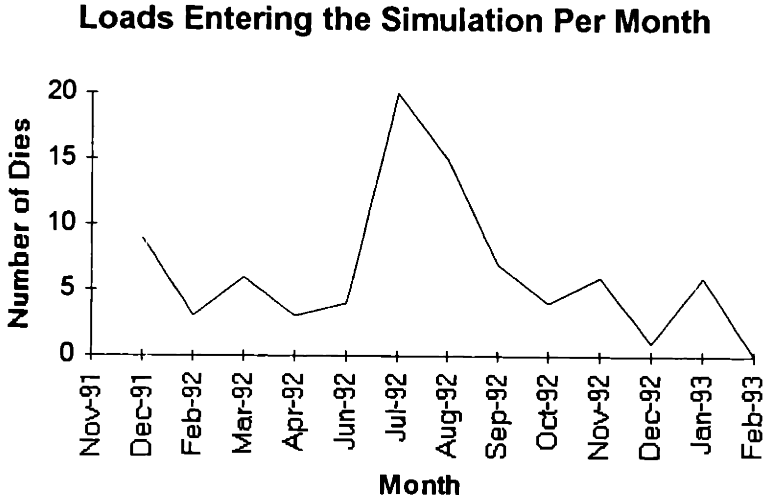

Loads Entering the Simulation Per Month

Figure 6.4

To best mimic the real process, the simulated loads presented in Figure 6.4 were duplicated and then shifted backwards by 4 months. Additionally, to compensate for unusually low demand in November of 1992 through February of 1993, the loads presented in Figure 6.4 were duplicated and shifted forwards by 4 months. These shifts are represented in Figure 6.5. It can now be seen that loads are in the system at the start of the program schedule in November of 1991, and loads in the system at the completion of the program schedule in February of 1993.

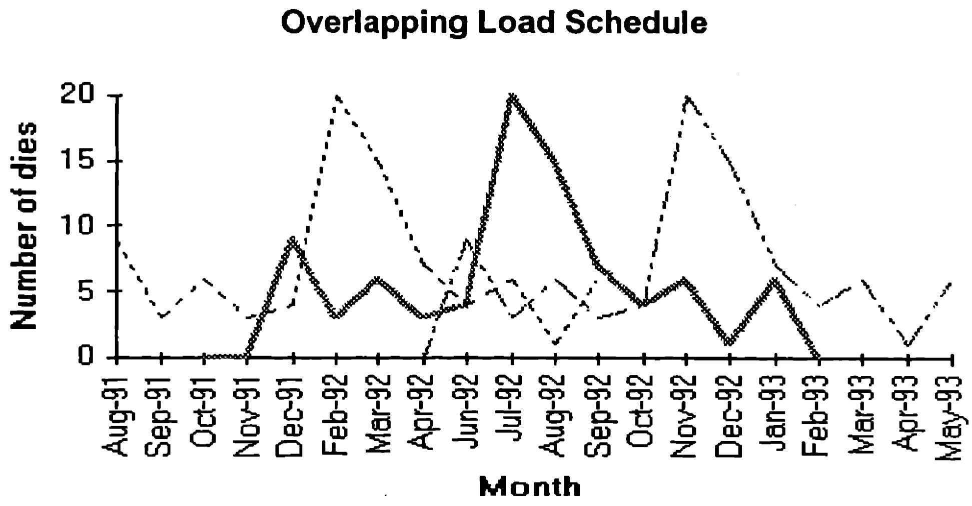


Figure 6.5

6.4.3 Description of the type of loads

As mentioned previously, there are 84 dies that enter and leave the simulation. However, because a die consists of four different castings, the actual number of loads entering the simulation is 336. They enter as ring, punch, B shoe, and A shoe castings. These castings leave the simulation as one complete die. A detailed description of the die is enclosed in Appendix A.

6.5 Queues

Queues are used in the simulation to model areas in the process where inventory builds. They are placed between every operation in the process. This will ensure that inventory levels can be monitored throughout the simulation. Queues facilitate the identification of areas where inventory is rampant. They are also used in the simulation to monitor the amount of time a part waits in work-in-process. Both the reduction of wait times and inventories are essential to improving the lead time and cost of the overall process.

6.6 Decision rules

6.6.1 Deciding priority system

The priority system for dies moving through the plant is based on a first-in first out or FIFO basis. This priority system allows the user to identify the lead time of each of the loads in the system. Because the dies that entered the process first have to also leave first, the lead time between beginning and completion of construction can be calculated. Moreover, if more than one die is in a queue, the die that entered the queue first will be the one to leave first.

6.6.2 Resource allocation decisions

Decision rules are also used to decide which resources should be allocated to certain loads. The simulation uses "IF" logic to assign machining resources to meet the needs of various sized castings. An example of this logic can be seen in Figure 6.6

Resource Allocation Decision Flow Chart

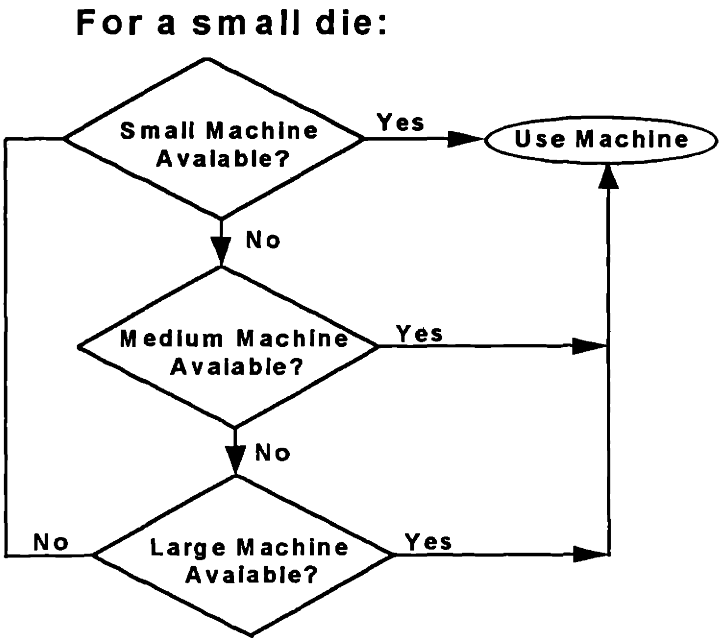


Figure 6.6

As seen in the above figure, if a small casting is to be machined, the simulation searches for a small machine available to perform the operation. However, if there are no small machines available, the simulation searches for a medium sized machine that can machine the small part. Once again, if a medium sized machine is not available, then the simulation searches for a larger machine available to perform the operation. Finally, if there is still no machines available, the part moves into a queue, and the simulation starts the selection process from the beginning. This type of decision making is prevalent in all of the machining operations in the process. It is based on the decision making policies used in the plant.

6.7 Random number generators

In an attempt to better predict the behavior of a process, the random number generator is used to depict possible outcomes based on a system's constraints and initial conditions. Random numbers are used to introduce the element of uncertainty into the model, and make the model stochastic (Automod, 1991).

As the random numbers change, the results often change because the initial conditions are altered. So, to ensure robustness of the model, the simulation should be run under different initial conditions. Random number generators allow the analyst to examine the systems using different initial conditions. The generator used for this simulation is described below.

For the simulation, a linear congruential generator was used (LCG). The LCG is a commonly used generator. It allows the user to skip a specified number of samples within any stream before beginning to use the numbers generated (Automod, 1991). This ensures that different streams do not overlap before the random stream repeats itself .

Simulated production runs were performed with 4 different random number streams. The first was run by using the first numbers in the random number stream. The second run was performed using the numbers after the first 30,000 random numbers were skipped. The next two runs were performed without the first 60,000 and then 90,000 random numbers.

6.8 Results from the simulation

After building the model, the simulation was then run to identify areas for possible improvement. Based on the results from the simulation, the analyst identified several potential problems. The first problem was the accumulation of inventory. Table 6.3 shows the highest levels of inventory during simulated production, and the average wait times of that inventory.

Figure 6.7 highlights the area in the process where the inventory builds. The operation where 250 stampings are made is labeled Inv 1. At peak production, inventories in this area escalate to a maximum of 26 dies. Because dies have to wait in queues before being run, their wait times are also high.

Additionally, the machining operation consistently creates large inventories. It can be seen from Table 6.3 that machining operations have relatively high levels of inventories forming in front of the operation. This suggests that the machining operations as a whole are a serious constraint in the system. The machining operations are labeled Inv 4,6,7 and 8 in Figure 6.7.

Inventory and Wait Times for the Most Constraining Operations

Operation	Highest Inv. level	Wait Times
1. Run 513	26	594
2. Blank cutting 511	15	292
3. Mount Stop Blck 304	14	768
4. Machine 203	13	208
5. Grind 404	11	516
6. Machine 402	11	348
7. Machine 103	10	167
8. Machine 105	10	207

Table 6.3

Another area where improvement can be made is in the scheduling of dies in the simulation. Because all of the castings entered the process at the same time, some castings have to wait to be assembled. This is due to the difference in cycle times of the operations on each path. As mentioned earlier, the path that the punch follows is on the critical path. This implies that the these operations take longer to complete as compared to the other paths. Subsequently, the other castings that mate with the punch have to wait until the punch has finished its sequence of operations. Moreover, the B shoe, A shoe, and ring castings have to wait for the punch before they are all assembled. Once again, Figure 6.7 locates these areas on the process chart where inventories are high. These areas are labeled Inv. 3 and Inv 5.

Inv 3 corresponds to the area in the process where the A shoe is waiting to mate with the punch. Because the cycle time of the operations on the A shoe path are much less than the cycle times on the punch's path, the A shoe waits. Also, since both dies are started at the same time, the A shoe is completed first, and then has to wait to be mated with the punch. This is the reason behind the high inventories, and the high wait times evident in this area.

Inv 5 corresponds to the area where the B shoe waits to be mated with the partially assembled die. This die consists of the punch, A shoe ,and ring. Because the cycle times of the operations on the B shoe path are less than those cycle times on the punch path, the B shoe has to wait to be mated with the partially assembled die. Once again, this causes an increase in inventory and wait times.

Process Flow Chart with Inventory Areas Identified

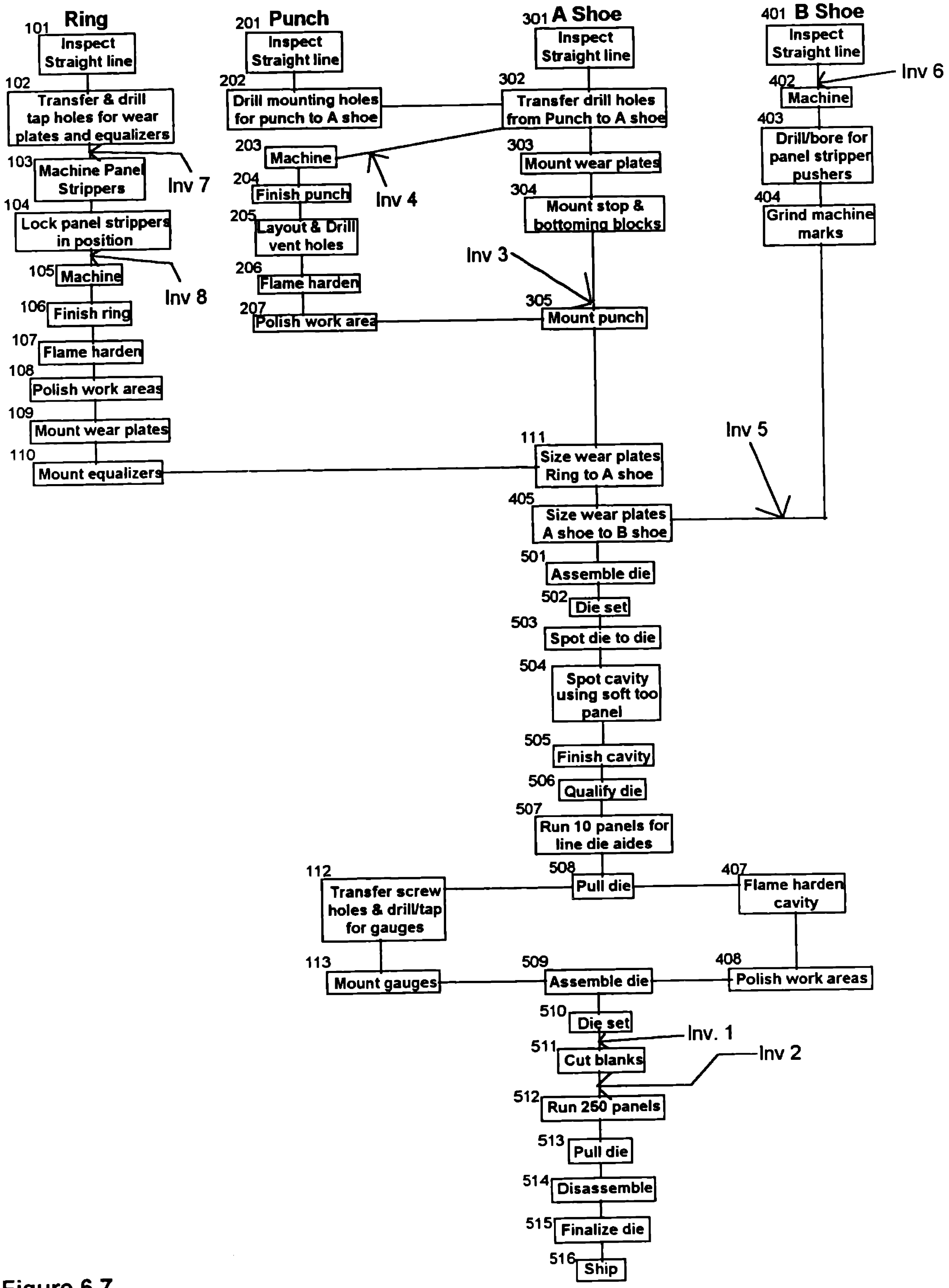


Figure 6.7

6.9 Verifying the results

The next step in the process improvement methodology is to compare the results from the simulation with results from the actual process. This is done to verify that the simulation is accurately depicting the events on the plant floor. As seen in Table 6.4, the actual lead time of the die construction process was compared to the simulated lead time. Note that the values in Table 6.4 are disguised for proprietary reasons. The true lead times are smaller in accordance with the linear equation presented in Chapter 4. Therefore, the difference between the actual and simulated lead time is also smaller. As seen in the table, positive values for the difference in lead times indicates that the simulation underestimated the true lead time. Moreover, a negative for the difference in lead times indicates that the simulation overestimated the true lead time.

Given the information on lead time, it can be seen that the simulation can predict the overall lead time of a part with some margin of error. This error can be attributed to several factors. The most prevalent factor is engineering changes. These changes are not modeled in the simulation. However, during the construction of a die, many changes are made that often consume a significant portion of the die construction time.

Another reason for some of the discrepancy is the simplified assumptions made. Among the assumptions are the predictable arrival times of dummy loads, constant work force, and first-in first-out priority system. If any of these or any other assumptions change in the plant, deviations will occur between the actual process and the simulated process. If deviations are large enough, changes should be made in the simulation to compensate for the deviations. We judged the deviations between the actual process and the simulated process to be reasonable.

Table comparing actual lead times to simulated lead times

Part name	Start date	End date	Actual Lead time (days)	Simulation Lead time (days)	Actual-Simulated (days)
Ext side frnt fender	12/11/91	4/7/92	118.7	91	28
Ext side frnt fender	12/11/91	4/9/92	120.8	97	24
Ext side frnt fender	12/11/91	4/11/92	122.1	106	17
Panel door outer	12/20/91	4/11/92	113.9	85	29
Panel door outer	12/20/91	4/8/92	110.6	101	10
Panel door outer	12/20/91	4/9/92	111.4	109	3
Pnl qtr innr upr ch195	12/20/91	8/8/92	232.7	211	22
Pnl qtr innr upr ch195	12/20/91	8/9/92	233.2	226	8
Pnl qtr innr upr ch195	12/20/91	8/6/92	230.7	235	-4
Side front fender rh	2/3/92	7/7/92	155	139	17
Side front fender rh	2/3/92	7/4/92	152.4	142	11
Side front fender rh	2/3/92	7/10/92	158.1	145	14
Support cowl side innr	3/4/92	8/30/92	179.9	157	23
Hood inner pnl	3/16/92	9/23/92	191.6	145	47
Hood inner pnl	3/16/92	9/20/92	188	157	32

Table 6.4

6.10 Alternatives to improve the simulated model

Based on the problems with the simulated model identified above, we formulated a series of alternatives to address these problems. Provided below are detailed explanations of the alternatives to problems identified by the simulation.

Increase the capacity of the machining operation

The capacity of the machining operation must be increased in attempts to reduce the inventory and wait times in front of these operations. This can be accomplished in one of the following ways:

- Purchase another CNC machine
- Minimize machine downtime
- Examine scheduling policies

Examine the scheduling of dies

One of the biggest problems with the current system is that all of the castings enter the process at the same time. This causes the resources to be used unnecessarily because they could be allocated to jobs that had higher priority. Furthermore, the dies such as the ring and the B shoe wait for an extended time period to mate with the punch and the partially assembled die. An alternative to improve the process is to delay the start of each casting by its slack time as defined on the critical timing path. For example, because the A shoe initially has no slack times, then it should enter the process immediately. However, for the B shoe, it should be delayed by approximately 28 days. This time was taken from the slack time presented in Table 5.1. This time is optimistic because it does not take into consideration possible variations such as statistical variations. However, it is a starting point. For this reason, 28 days should be used initially.

Delaying the start of certain castings conserves and better utilizes resources. Because die construction is so labor intensive, it is important that resources be used as efficiently as possible. Constructing a die that is not needed in the foreseeable future, wastes the plant's human resources. These die makers should be working on dies that have an earlier finish dates. Focusing efforts initially on those dies due earliest allows die makers to perform more immediate operations or tasks necessary to ensure timely delivery.

Additionally, starting castings early consumes valuable machining resources unnecessarily. When all of the castings are released into the die shop at the same time, each casting seeks a machine at some point in time. These castings place additional loads on the machines. Moreover, later in the process, these castings wait to mate with the punch. As a result of the unnecessary load placed on the machining resources, the punch often waits to use a machine. Because the punch is on the critical path, any wait time that it experiences will impact the overall lead time. So, loading the plant with all four castings at the same time, places unnecessary loads on the machines. Castings such as the punch have to wait. Consequently, lead times are increased.

As seen in Figure 5.1, the A shoe is initially on the critical path. For this reason, the A shoe must start first. However, after the mounting holes are transferred to the A shoe, the punch's path then becomes the critical path. This causes a problem because after the transfer of holes is complete, the A shoe must then wait for the punch to complete its series of operations before mating can occur. This causes high wait times for A shoe castings and inventory build-up. To eliminate this problem, the transfer operation, operation 302, should be performed after the punch finishing operation, operation 204. This will take the A shoe completely off the critical path. The Punch will then be the only casting on the critical path until after the assembly operation, operation 501. By moving the transfer operation, the start time of the A shoe can now be delayed.

Eliminate the blank cutting and stamping 250 panels

The die facility cannot perform the job of cutting blanks and then stamping 250 parts. This is evident by the high inventory and associated wait times as exhibited in Table 6.1. As mentioned in Chapter 5, there are several alternatives to minimize the high cycle times of these processes. They are as follows:

To reduce the cycle time of blank cutting operation:
- Utilize a laser cutter for blank cutting
- Place the blank cutting operation in parallel with the process
- Place the operation in the stamping facility

To reduce the cycle time of the running 250 panels
- Place the operation in parallel with the process
- Place the operation in the stamping facility

Given an overview of the simulated model and preliminary results, the next chapter will discuss the observations made by examining the process over an extended period of time. It will also describe the application of the alternatives developed in Chapter 5, and will present the effect of the alternatives on the simulated process. This is the first step in deciding whether an alternative will be viable in the plant.

6.11 Varying the number stream

To test the robustness of the process, the simulation ran using 4 different random number streams. The first stream used the first number produced by the number generator. The other streams used numbers after skipping the first 30,000, 60,000, and 90,000 numbers created by the generator.

After running the simulation using the above streams, the results did not show any significant difference. As seen in Table 6.5, the different number streams had only a minute effect on the overall lead time of the die. This suggests that changes in the initial conditions had little effect on the process.

Different number streams had little effect on lead time

No. Stream	**0**	**30,000**	**60,000**	**90,000**
Avg. Lead Time(days)	115.2	112.8	112.2	115.8

Table 6.5

Another issue addressed was inventory build-up and its associated wait times. To better understand the effect of different streams on other aspects of the process, the simulation was examined using the same four random number streams. The results are presented in Tables 6.6 and 6.7. Once again, the different random number streams have little effect on the overall inventory levels and wait times. While there is discrepancy between inventories for cutting blanks and running 250 panels, the difference is small.

Because the lead time, inventory, and cycle times did not differ substantially when the number streams were changed, the results from the first number stream were arbitrarily selected as the nominal results. All of the alternatives will be compared to the nominal results.

Inventory levels for operations using different number streams

Operation	Number Streams 0	30,000	60,000	90,000
Run 513	26	21	25	26
Blank Cutting 511	15	9	11	15
Mounting Stop Blck 304	16	14	15	14
Machine 203	11	12	10	13
Grind 404	12	14	10	11
Machine 402	10	10	11	11
Machine 103	10	9	7	10
Machine 105	9	10	7	10
Finishing 204	7	7	6	5

Table 6.6

Cycle times (hrs) for operations given different random numbers

Operation	Number Streams 0	30,000	60,000	90,000
Run 513	577.3	462.3	619.5	595.8
Blank Cutting 511	306.3	242.04	234.3	291
Mounting Stop Blck 304	759	780.96	742.8	768
Machine 203	274.5	285	266.7	280.5
Grind 404	506.1	554.4	488.4	518.4
Machine 402	335.7	333.96	339	350.4
Machine 103	160.2	158.4	157.2	167.4
Machine 105	183.3	199.5	171.8	208.5
Finishing 204	261	259.8	258	261.3

Table 6.7

Chapter 7

Examining Alternatives Using the Simulation

This chapter examines the alternatives discussed in Chapters 4, 5 and 6. It describes the use of the simulation as a tool to understand the potential effects of these alternatives on the real environment. The use of the simulation allows the user to test a multitude of alternatives without impacting the actual manufacturing process. It allows the user to perform "what-if" analyses, and to eliminate alternatives that might have an adverse effect on the process. Thus, the remaining alternatives would be the most viable in the simulated process and subsequently the actual process.

This chapter revisits several of the alternatives in the process. Provided below is a listing of the these alternatives. Additionally, this chapter describes many of the underlying assumptions, subsequent results, and recommendations.

7.1 Increasing the capacity of machines

7.1.1 Additional machines to increase capacity

Listed below are several alternatives to increase the capacity of the machining operations. The first alternative is to purchase an additional machine. We modeled this alternative by adding another CNC to the pool of available machines. This CNC machine could surface large, medium, or small castings. Its mean time to failure and a mean time to repair was identical to Machine #6 machine. Because Machine #6 was new, we assumed that the additional machine would have similar reliability characteristics.

The simulation was then run to study the effects of the additional machine. The results from the simulation show only a moderate improvement in lead time and inventories. As seen in Figure 7.1, the improvement in lead time is a modest 6 days.

Effect of additional machine on lead time

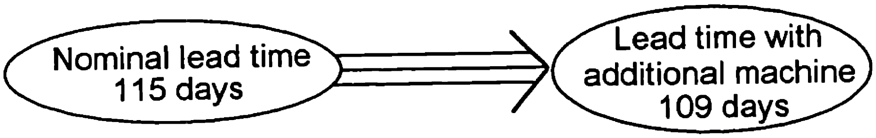


Figure 7.1

Although the additional machine has had some positive effects on the cycle time of operations listed in Table 7.1, cycle time reductions of operations on the critical path are the only ones that directly reduce the lead time of the parts moving through the process. Machining 203, finishing 204, blank cutting 511, and run 513, are all on the critical path. Summing the differences in cycle times in Table 7.1 for only those operations on the critical timing path, the total cycle time reduction is 134.4 hours or 6 days. This is equal to the reduction of the overall lead time of 6 days. Hence, the simulation is consistent with the critical path analysis.

Additionally, by reducing the cycle time of operations on the critical path, it can be seen that the lead time of the process is directly affected. A greater impact on lead time is made if those operations with the highest cycle times are reduced first. After these cycle times have been reduced, the other operations on the critical path with smaller cycle times can be examined.

Cycle times (hrs) for operations

Operation	Nominal Values	Add CNC Machine	Difference
Run 513	577.3	546.9	30.4
Blank Cutting 511	306.3	275.1	31.2
Mounting Stop Blck 304	759	693.6	65.4
Machine 203	274.5	200.1	74.4
Grind 404	506.1	472.8	33.2
Machine 402	335.7	287.7	48
Machine 103	160.2	102.6	57.6
Machine 105	183.3	146.1	37.2
Finishing 204	261	261.6	-.6

Table 7.1

The 6 day reduction of lead time as a result of the additional machine has had little effect on inventory levels in the process. As seen in Table 7.2, machine 103 is the only operation where inventory is substantially reduced. This can be attributed to the reduction of the operation's cycle time. Table 7.1 shows that the additional machine had a significant impact on the operation machine 103. Consequently, this reduction in cycle time allowed more parts to be machined in the same time period. This led to a reduction in inventory for that operation.

Inventory level for operations with the highest cycle time

	Nominal Value	Add CNC Machine
Run 513	26	25
Blank Cutting 511	15	14
Mounting Stop Blck 304	16	15
Machine 203	11	11
Grind 404	12	12
Machine 402	10	10
Machine 103	10	7
Machine 105	9	9
Finishing 204	7	6

Table 7.2

7.1.2 Decreasing the amount of machine downtime in machining

Another method of increasing the capacity of machines is to minimize the amount of machine downtime. This requires close examination of downtime data. Chapter 4 listed the machines used in the simulation and described their maintainability characteristics such as mean time to repair and mean time between failure.

Currently, maintenance is performed on an "as needed basis." Normally, a machine is maintained only when it breaks down. Moreover, the plant does not follow a preventative maintenance program. This was modeled into the simulation accordingly.

To examine the effects of changing the reliability characteristics, the mean time between failure and the mean time to repair were varied in the simulation. First, the mean time between failure for all of the machines was varied from .25x to 1.75x the nominal amount using intervals .25. Currently, the machines in the plant operate with the mean time between failures at 1x. The 1x indicates a mean time between failure at 1 times the nominal amount. While the mean time between failure was varied, the mean time to repair was held constant. Next, the mean time to repair was then varied using the same interval, and the mean time between failure was held constant.

Figure 7.2 shows the effect of varying the mean time between failure. This figure shows that as the mean time between failure decreases the overall lead time increases. Moreover, as the amount of time between failures decreases, the amount of time required to machine parts increases. Consequently, the lead time increases.

Lead time using different mean time between failure values

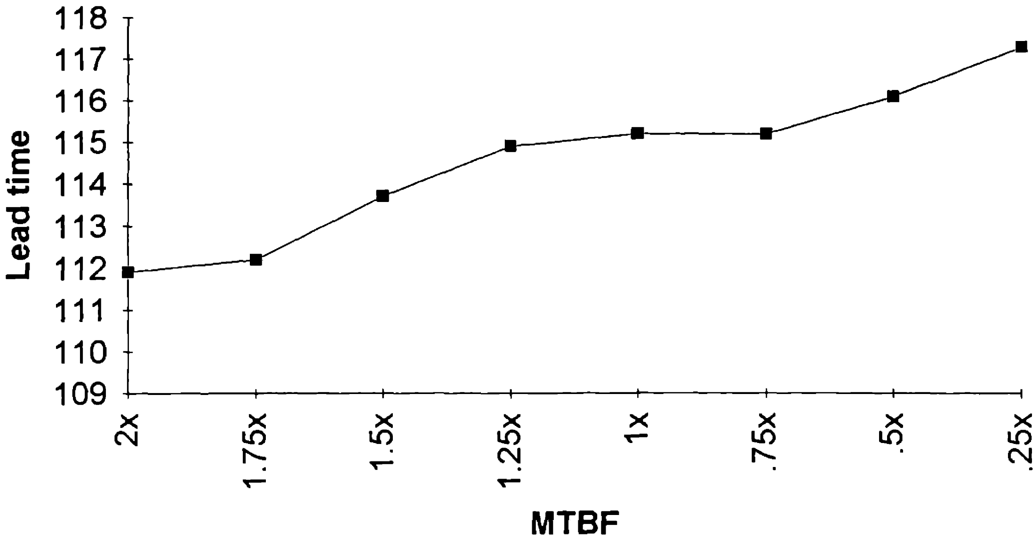


Figure 7.2

With the current mean time to failure at 1x, the average lead time of a part is 115.2 days. By increasing the mean time between failure by 50%, the lead time will then be 113.7 days. So, the total reduction in lead time by increasing the mean time between failures is 1.5 days. However, by increasing the mean time between failure by 100% , the lead time will be 111.9 days. This is a reduction of lead time by 3.3 days.

A decrease in lead time of 3.3 days is enough to suggest that improving the mean time between failure might be a viable alternative for implementation in the plant. However, the cost of improving the mean time between failure must be weighed into the decision. Therefore, a trade-off must be made between the benefit of reduced lead time and the cost of improvement.

The mean time to repair was examined next. As seen in Figure 7.3, the standard values for mean time to repair give a lead time of 115.2 days. Improving the mean time to repair by 50% will produce a lead time of 111 days. This is a difference from the nominal of 4.2 days.

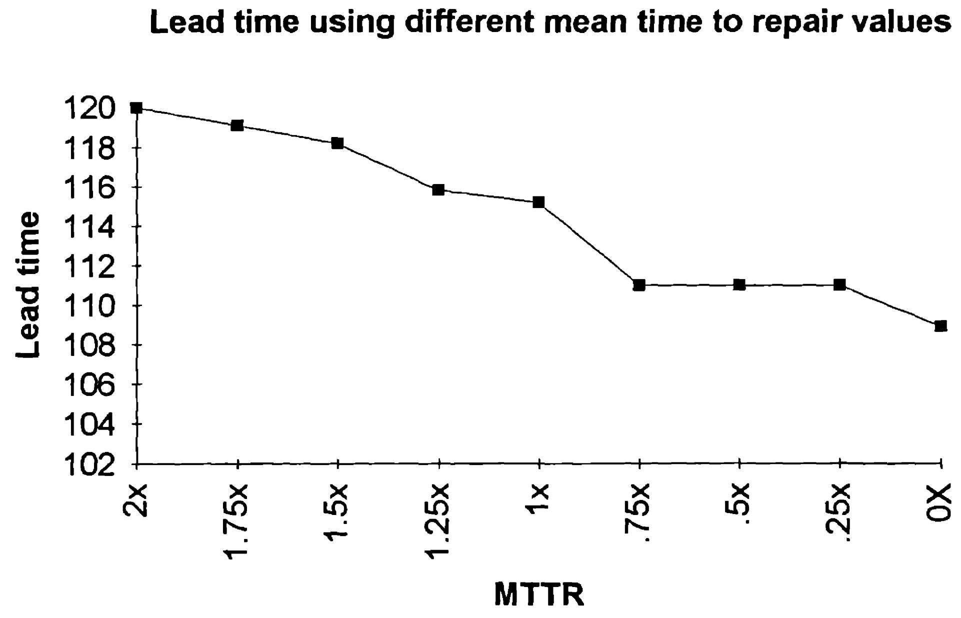


Figure 7.3

By decreasing the mean time to repair by 100%, a lead time of 108.9 days can be achieved. This is a difference of 6.3 days This is a substantial reduction in lead time. Therefore, it is worthy of consideration for implementation in the plant when only manufacturing viability is considered. However, before implementation the alternative must be analyzed using cost-benefit analysis. Once again, a trade-off must be made concerning the cost of improvement and the benefit of reduced lead time.

In Figure 7.3, for the mean time to repair equal to zero, the lead time is 108.9 days. This means that when a machine fails, on average, it is repaired with no loss of time. Given no downtime, the machine is now capable of running continuously. Therefore, the minimum lead time that can be achieved through any downtime improvement effort is 108.9 days. This is a reduction of 6.3 days.

The lead time for increasing mean time between failure by 100% and decreasing the mean time to repair by 100% is the same. Therefore, to achieve the greatest reduction in lead time two alternatives are available. They are as follows:

- Continuously improve the mean time to repair so that machines do not fail.
- Continuously improve the mean time between failures so that the machines fail less frequently.

Either alternative will yield the same benefit in lead time reduction. Moreover, they are both feasible in the manufacturing plant, and are suggested alternatives to reducing the lead time of dies. However, the issue of cost must be addressed before implementing these alternatives. Because many of the machines are archaic, improving their reliability characteristics is not an easy task. The cost of improving these characteristics might be great enough to purchase a another machine. For this reason, plant personnel have to know the capabilities of the machine and the cost of improving their capabilities.

To better understand the effect of varying the mean time to repair (MTTR) as well as the mean time between failure (MTBF), the simulation was run for different values of MTBF and MTTR. The values varied and resulting lead times can be seen in Table 7.3.

The effect of variations in MTTR & MTBF on lead time

MTBF	MTTR	Lead time
0.25	1.75	159
0.5	1.5	125.1
0.75	1.25	115.5
1	1	114
1.25	0.75	114
1.5	0.5	113.1
1.75	0.25	109.2

Table 7.3

As the mean time between failure increases the lead time decreases. Moreover, as the mean time to repair increases the lead time increases. This trend is similar to those presented earlier in this chapter.

As seen in Figure 7.4, when the mean time to repair approaches zero, the line on the graph appears to flatten. This would indicate that as the mean time to repair gets smaller, the lead time tends to converge toward the minimum lead time value of 108.9 days.

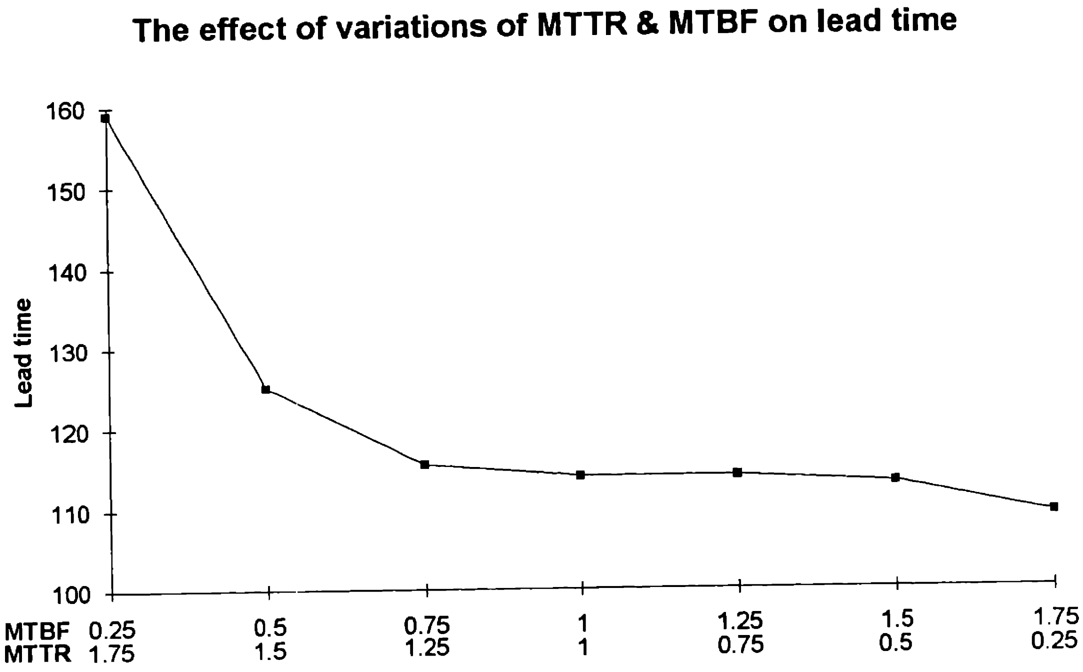


Figure 7.4

To understand the effect of the variations on the machine cycle time and inventory, the mean time to repair and the mean time between failure were varied according to Table 7.3. Additionally, Table 7.4 and Table 7.5 compare the inventory levels and cycle times for the different machining operations. As expected, the longer the machines are operational, the less inventory builds. In Table 7.5, it can be seen that because the mean time between failures is high, the cycle time of the machining operation is lower. Both of these observations are consistent with the information presented earlier in this chapter.

Effect of variation in MTTR & MTBF on machine inventory

	MTBF 1.75 & MTTR .25	MTBF .5 & MTTR 1.5
Machine 402	10	14
Machine 203	10	14
Machine 103	7	13
Machine 105	8	11

Table 7.4

The effect of variations in MTTR & MTBF on machine cycle times

	MTBF 1.75 & MTTR .25	MTBF .5 & MTTR 1.5
Machine 402	293.7	429.9
Machine 203	219.9	391.5
Machine 103	114.9	265.8
Machine 105	162	246

Table 7.5

7.2 Increasing the number of die makers

Increasing the number of die makers has several potential benefits. Since most operations have their capacity determined by the number of die makers, an increase in the number of die makers would increase the capacity of most operations. The operations where capacity needs to be improved are those operations on the critical path with the highest cycle time. Specifically, the operations of concern are the finishing 204, blanking 511, and run 513. Other reasons for examining the number of die makers needed is to understand the effect that the number of die makers has on the lead time, inventory, and operational cycle times.

The simulation was run varying the number of die makers. For the simulated runs, the number of die makers was set at 10, 11,12,13,15,18,27,and infinity. Figure 7.5 shows the effect of an increased in the number of die makers on the lead time. As seen in this figure, the number of die makers has a significant impact on the overall lead time. Ten die makers is the minimum number required to construct a die. Fewer die makers would mean that many of the dies would not be completed in a timely fashion. As the number of die makers increases, the lead time is initially reduced dramatically, but begins to level out as the number of die makers approaches 30.

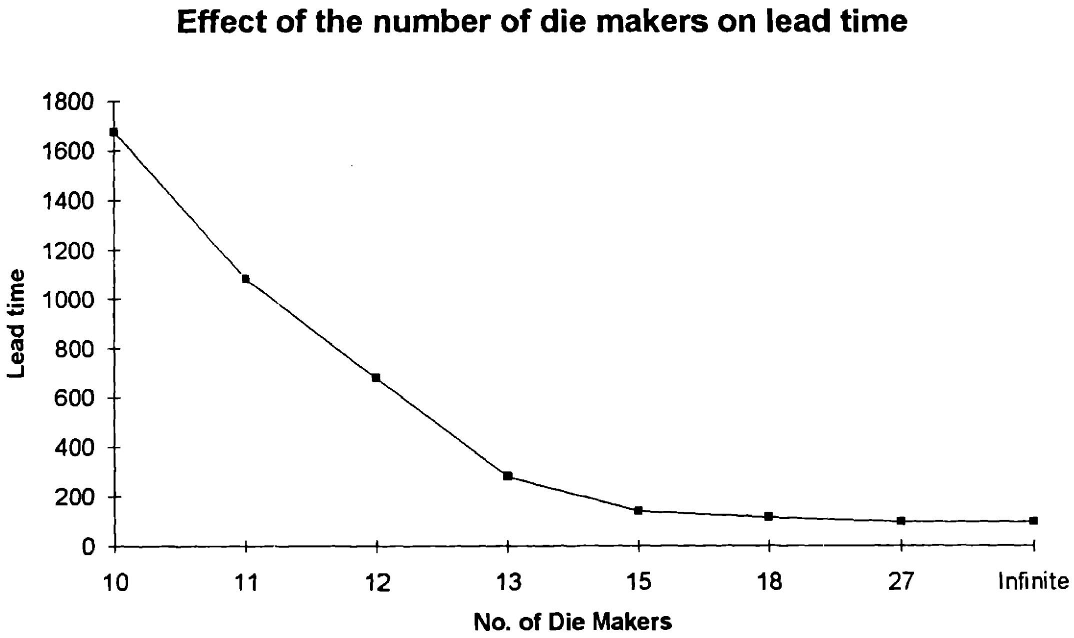


Figure 7.5

No.of die makers	10	11	12	13	15	18	27	Infinite
Lead time(days)	1675.8	1082.1	676.5	279.6	140.7	115.2	97.2	96.9

Table 7.6

In the plant, the number of die makers is 18. As in the figure above, 18 die makers does not seem to be enough to reap the full benefit of lead time reduction. As seen in Table 7.6, additional die makers would have a significant effect on the lead time. However, if there were fewer die makers the lead time would increase substantially.

The next step is to analyze the impact of the number of die makers in the workforce on inventory. Using the same methodology presented earlier, the analyst varied the number of die makers in the simulation. Based on the output from the simulation, the effect of the size of the workforce on inventory and operational cycle time can now be examined.

According to Table 7.7 inventory for the blank 511 and run 513 operations are reduced immensely. From this table, it can be seen that the increased number of die makers has a beneficial effect on these inventories. This reduction in inventory can be attributed to a significant reduction in cycle times for the operations as seen in Table 7.8. As the cycle times decrease, more castings can be processed in the same time period. As a result, inventory is reduced.

Inventory levels of operations as the number of die makers increases

	# of die makers		
Operations	**13**	**18**	**45**
Finish 204	6	7	7
Blank 511	105	15	8
Run 513	138	26	7
Machine 402	11	10	11
Machine 103	7	10	10
Machine 105	7	9	9
Machine 203	8	11	12

Table 7.7

The cycle time of the finishing operation is not impacted by an increase in the number of die makers. Currently, the finishing operation only requires 2 die makers. A workforce of 13, 18 or 45 is sufficient to perform any finishing operation in a timely fashion. However, because the run 513 operation requires 6 people and the blank 511 operation requires 4 people, these two operations place a greater constraint on the system. So, any increase in the number of die makers would improve these operation's cycle times.

Cycle time(hrs) of operations as the number of die makers increases

	# of die makers		
Operations	**13**	**18**	**45**
Finish 204	262.5	261.6	259.8
Blank 511	10434	306.3	169.2
Run 513	17703	577.5	215.7

Table 7.8

Machining operations were listed in Table 7.7 to show that an increase in the number of die makers has an impact on the inventory in front of the machining operations. Because the machining operations are constrained by the machine and not the operator, an increase in the number of die makers has no effect on machining cycle times. However, for those operations upstream that are more labor intensive, an increase in the number of die makers reduces their cycle times. Consequently, those operations feed the machining operations more parts at a faster rate. The machining operations cannot adjust to the increase in loads entering the operation. As a result, inventory builds.

An increase in the number of die makers offers benefits to the plant. First, increasing the number of die makers to 27 can decrease the lead time by 20 days. Second, an increase in the number of die makers decreases the amount of inventory. These two benefits give merit to the consideration of increasing the number of die makers in the plant. Hiring more workers does significantly increase cost, but in most American automotive die shops, labor is in abundance. Due to the slow economy in 1991 through 1992, many die shops laid-off workers. However, because of union contracts these workers are still employed by the company. In this case, increasing the number of die makers only requires calling die makers back to work. The cost of calling workers back is less significant than hiring new workers. So, for those companies who have die makers laid-off, the option of increasing the work force through call backs is an acceptable way to reduce lead time, and inventory while keeping cost down. However, for those shops who do not have an excess of die makers, careful consideration must be given to the cost involved in hiring new die makers.

7.3 Increasing the capacity of the polishing operations

The polishing operation is a long and tedious process that consumes a significant portion of the lead time. There are three different alternatives that can be used to improve the cycle time of the operation and subsequently the overall lead time of the process. These alternatives are as follows:

- Finish on the third shift
- Purchase polishing machine
- More detailing and less finishing
- Increase the number of die finishers

7.3.1 Finish on the third shift

Currently, the punch finishing operation only runs two shifts. So, finishing the punch using three shifts adds capacity to the operation. To examine the effect of additional punch finishing capacity on lead time and inventory, the simulation was run using three shifts for punch finishing.

As seen in Table 7.9, the additional shift did not have a profound impact on the cycle time of the operation nor on the lead time of parts. However, a decrease in inventory is evident. An analysis must be performed to determine the cost of keeping the inventory level at 7 as compared to the cost of having workers dedicated to punch finishing on the third shift. The outcome from this analysis will decide whether to add the additional shift or not.

Punch Finishing by Shifts

	2 shifts	3 shifts
Finishing operation	261.6 hrs	252 hrs
Overall lead time	115.2 days	114.8 days
Inventory	7	2

Table 7.9

7.3.2 Purchase a polishing machine

Although polishing machines are a relatively new technology, many people in the die industry are proclaiming great benefits from its use. Based on several interviews conducted with managers at plants who use die polishing machines, managers stated that 50% reductions in finishing times were obtained by using this machine. To model the use of this machine in the simulation, the cycle time of the punch finishing operation was cut by 50%. Additionally, the machine was modeled so that it was only able to polish one die at a time.

Because the plant runs two shifts for polishing, the polishing machine was modeled so that it initially only ran two shifts.

Using the polishing machine on two shifts, substantial reductions in lead time were obtained in the simulation. As seen in Table 7.10, a 12.3 day reduction in lead time was obtained. Inventory slightly increased. This is attributed to the load capacity of the machine. The polishing machine can only polish one die at a time. Consequently, inventory builds in front of the operation. When die polishing was manual, several dies could be polished at one time. This kept inventory low.

Polishing Machine Used on Punch for 2 Shifts

	Manual	Polishing Mach.
Finishing operation	261.6 hrs	130.8 hrs
Overall lead time	115.2 days	102.9 days
Inventory	7	8

Table 7.10

Polishing Machine Used on Punch for 3 Shifts

	Manual	Polishing Mach.
Finishing operation	261.6 hrs	130.8 hrs
Overall lead time	115.2 days	102 days
Inventory	7	6

Table 7.11

If the polishing machine's capacity is increased by using it on three shifts, the lead time is not affected, but inventory is reduced. This can be seen in Table

7.11. Because the cycle time of the finishing operation is increased, the operation is able to feed subsequent operations more parts at a faster rate. The subsequent operations cannot keep pace with the finishing operation. Consequently, castings wait in work-in-process downstream. This is seen in Table 7.12. The operations that follow the finishing operation have a slight increase in inventory.

Inventory levels of operations following the punch finishing operation

Operations	Manual	Polishing Mach.
Finishing 204	7	6
Lay out holes 205	3	5
Flame harden 206	4	3
Polish 207	4	5

Table 7.12

Although the finishing operation now has additional capacity, it is not needed on the third shift, and is often idle during this time period. The polishing machine is capable of finishing most castings on the first two shifts. Moreover, the benefits in reduced lead time are received on the first and second shift.

7.3.3 More detailing and less finishing

Another alternative to reduce the cycle time of the punch finishing operation is to increase the amount of machining performed on the punch. As the die is cut closer to the desired surface, less finishing will be required. To examine the effects of increased machining to obtain less finishing, it was assumed that 8 additional hours of machining were needed to reduce the amount of finishing by 16 hours for large dies. This was determined on the basis of interviews with die makers. Additionally, the increase in machine time and decrease in finish time are proportional to the size of the casting machined.

After running the simulation, the lead time for this alternative was found to be 109.8 days. This is an improvement over the nominal 115.2 days. Because only the machining operation was increased, additional inventory was not evident in front of the machining operation. Moreover, the slight decrease in finishing time did not reduce inventory at that operation. The only benefit of increasing the amount of machining is the reduction in overall lead time of 5.4 days.

7.3.4 Increase the number of die finishers

As seen in Section 7.2, the addition of die makers does not significantly impact the finishing operation. When the number of die makers is unlimited, the finishing operation still takes a certain time period regardless of the number of die makers. It is a task that is semi-dependent on the number of die makers. However, due to the amount of space on a die, only 2 die makers can work on one die. An increase in the number of die makers would not decrease the amount of time required to finish a part. This is seen in Table 7.8. For this reason, an increase in the number of die makers is not recommended if it is done only to decrease the cycle time and inventory of the finishing operation.

Given the four alternatives, purchasing a polishing machine yields the greatest benefits. However, the average cost of a polishing machine is approximately $600,000. So, a cost analysis must be performed to determine if the cost of purchasing the machine produces benefits of equal value. If a polishing machine is not financially feasible, the next alternative is to increase the amount of detailing on the machines to reduce the amount of finishing. This will yield benefits of 5.4 days.

7.4 Move transfer operations until after the punch finishing

The next alternative to be evaluated requires shifting operations. Currently, the critical path begins with the A shoe. After holes are transferred from the punch to the A shoe, the punch is then on the critical path. Because the A shoe is initially on the critical path, construction of the A shoe must start immediately. However, after the holes are transferred, the A shoe must wait for the punch at operation 305 before mating can occur. While the A shoe waits, inventory builds and wait times escalate.

To reduce the wait time experienced by the A shoe, it must be moved until after the punch finishing operation. This will take the A shoe off the critical path. Instead, the critical path will start with the punch. Thus, its start time can be delayed so that the A shoe is released with just enough to complete the needed operations and then mate with the A shoe. This can be seen in Figure 7.6. As the punch finishing operation is completing, the A shoe is being inspected and straight lined. Once the punch has completed the finishing operation, the A shoe is ready to be mated with the punch, and holes transferred.

Location of the transfer operation

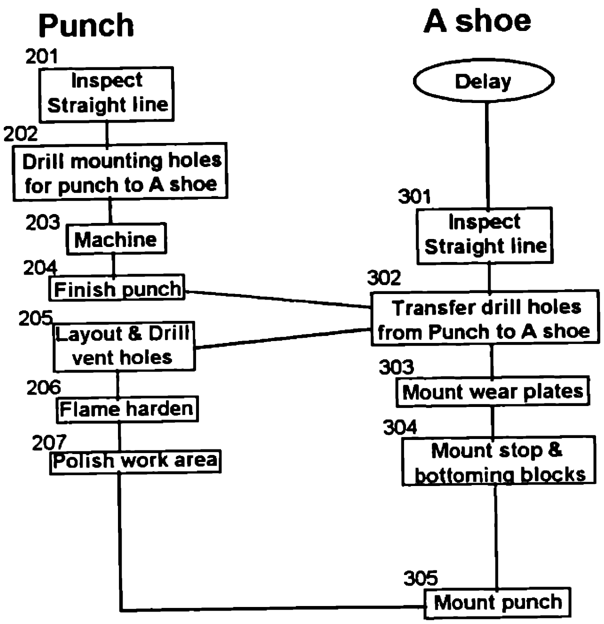


Figure 7.6

As a result of moving the transfer holes' operation, the wait time is reduced by 544.9 hrs, and inventories are reduced by 10 dies. Additionally, the cycle time of the overall process is reduced to 105.9 days. This can be seen in Table 7.13.

The effect of moving the transfer operation

	Nominal	After transfer operation
Inventory	16	6
Wait time	756.6 hrs	211.7 hrs
Overall lead time	115.2 days	105.9 days

Table 7.13

By moving one operation, the lead time of the process can be reduced. This is possible because starting the A shoe later frees needed human resources. These resources then move to operations where they are needed. Based on reduced inventory, lead time, and inventory wait time, this is an alternative that should be considered for implementation in the plant.

7.5 Eliminate unnecessary operations

7.5.1 Move operations to the stamping plant

The operations of cutting blanks and stamping 250 panels are not essential operations needed to be performed in the die facility. Instead, these operations should be performed at the stamping plant. This will enable the plant to gain familiarity with the die before normal full-scale production begins.

The simulation was run with the blank 511 and run 513 operations eliminated. The results of the simulation show that the lead time can be reduced to about 70.5 days by eliminating the operations. The elimination of these operations will decrease the lead time of the die construction process. However, these operations will still impact the overall lead time of new car development. By moving the most time consuming operations to other facilities, the burden has been shifted to the other facilities. Given the stamping plant's expertise, it is believed that the stamping plant is more capable of performing the blank cutting and stamping operations. Therefore, these operations should be their responsibility.

7.5.2 Improving operations within the plant

If the blank cutting and stamping operations cannot be moved to the stamping plant, one alternative is to place the blank cutting operation in parallel with the other operations in the process. This will enable the blanks to be cut without an added serial step in the process. By placing the operation in parallel, the lead time can be reduced to 106.5 days.

The laser cutting machine is an alternative to manually cutting the blanks. Based on several interviews, die makers conclude that the use of the laser can reduce the cycle time of blanking operation by 60%. These die makers assumed that programming time was negligible. With the blank cutting operation placed in series with the other operations, the analyst ran the simulation. The results showed that the lead time can be reduced to 104.7 days.

If the blank cutting and stamping operations remain in the die facility, the best alternative is to place the blank cutting operation in parallel with the other operations in the process. Because the laser cutter scenario assumed that program time was negligible, a significant portion of its cycle time was omitted. In the plant, programming time consumes a substantial portion of the overall cycle time. For this reason, the lead time is much higher than 104.7 days. This leaves the first alternative of placing operations in parallel as the best option to reduce the lead time.

7.7 Examine Schedule Policies

The current scheduling policy is to start all castings at the same time. As a result, castings wait to be mated with other castings. During these waits, inventory accumulates. All of these times can be reduced completely. A better policy is to have the castings not on the critical path delayed by their slack time amount. This was modeled in the simulation.

Comparing the results in Table 7.15 to those of the nominal values in Table 7.14, it can be seen that delaying the start of the ring, B shoe, and A shoe have a tremendous impact on inventory accumulation at the mating locations. The policy is now to send castings through the system "as needed" as opposed to the current policy of "as soon as possible." By changing the scheduling policy, reductions in inventory and wait times can be obtained. Additionally, reductions in lead time can also be experienced. The lead time due to the change in policy is 105 days.

The lead time is reduced due to the delayed release of castings in the process. As mentioned in the last chapter, delaying the release of dies allows resources to work on castings that are due early. It allows the die makers to work only on those dies that have early due dates. Delaying the release of certain castings also reduces the number of loads demanding the resources. Moreover, reducing the demand on machines allows castings to be machined with less competition from other loads. As a result these castings wait less to use a machine. This reduced wait time translates in to reduced lead times.

Nominal values for operations where mating of castings is performed

Operations	**Inventory**	**Wait times**
Mount equal 110	5	164.2 hrs
Mount stop blcks 304	16	759.6
Grind 404	12	506.1

Overall lead time = 115.2

Table 7.14

Results from the simulation when beginning operations are delayed

Operations	Inventory	Wait times
Mount equal 110	0	0
Mount stop blcks 304	6	211.7 hrs
Grind 404	0	0

Overall lead time = 105 days

Table 7.15

An important part in changing the scheduling policy is communication. The die makers constructing the punch need to communicate with the other die makers so they know when to begin construction of their castings. For example, on the A shoe, the die makers constructing the punch need to tell the die makers working on the A shoe to begin construction of the A shoe when the punch finishing operation is 8 hours from completion. This will give the die makers on the A shoe just enough time to inspect the casting and perform straight line operations. Without communication, the process of coordinating the start times is difficult. To reap the benefits of reduced inventories, wait times, and lead time, communication is essential.

7.8 Conclusions from the simulation

This chapter listed several alternatives to improve the process of die construction. Examining alternatives in the simulation allows the analyst to test alternatives in an environment that is similar to the plant. Furthermore, the process of testing alternatives in the simulation allows the stronger alternatives to emerge.

To recapitulate, the stronger alternatives that are worthy of consideration are as follows:

- Increase the number of die makers
- Purchase polishing machines
- Move blank 511 and run 513 operations to stamping plant
- Change scheduling policy to send castings though the process "as needed"
- Move transfer operation until after punch finishing operation
- Improve preventative maintenance program to obtain 100% reduction in mean time to repair

Although there were other viable alternatives, the ones listed above will yield the greatest benefits in the plant. The next step is to perform a cost analysis on these alternatives to find the most cost effective and beneficial way to improve the process.

Chapter 8

Benchmarking the die construction process

This chapter will compare the process used at the American die facility where research was conducted to other facilities across the world. Specifically, the processes at an independent American die shop, a Japanese automotive die facility, and an independent Japanese die shop will all be discussed. The author obtained information on these plants through plant trips, interviews, and literature searches. Additionally, this chapter will discuss the technology used by die shops in the industry. Examples of this technology are die polishing machines and totally automated die construction process.

8.1 The die construction process at an independent American die shop

The first die shop analyzed was an American facility located in the Midwest. The die construction process at this facility does not differ from the process at the facility where research was conducted. Based on visual observation, the steps in the process were almost identical. There were two main observations made. First, the amount of downtime in this facility was very low. The plant used a preventative maintenance program that kept machine uptime above 90%, The other observation that was made concerned the use of relatively new technology. The plant used die polishing machines to finish their dies. This technological observation will be discussed later in this chapter.

8.1.1 Workforce

The work force in this plant is non-unionized. Moreover, it consists of 8 build crews of 10 men each capable of constructing various types of line dies. The machine crew consists of 5 machinists per shift. Their sole function is to operate the machines, check for quality, and assist in maintenance. Each of these teams has a crew leader. His responsibility is to develop micro-production plans.

The team approach to die building is somewhat different and warrants further discussion. Each of the teams is responsible for a die, the moment a die enters the plant. The crew leader delegates the construction responsibilities to the various team members , and construction begins. This group consists of workers with different experiences and expertise all of which is vital to the construction process. Work is allocated to team members based on the skills of each member. Also, the first and second shifts work together to complete the same dies. Where one shift stops, the other shift would resume. This type of team work is encouraged, and workers are rewarded accordingly.

8.1.2 Control of the process

As is typical any many job shops, process flows charts and operation sheets are not used at this facility. However, cycle times are now being tracked. These times are grouped into sections in the construction process. Aggregated cycle times are kept for 8 different categories. They are as follows:

- Assembly
- Press spotting
- Minor machining
- CAD/CAM
- Bench Spotting
- Major machining
- Contour milling
- Tryout

The cycle times of these aggregated categories are collected from the die makers at the end of each day. Each employee submits the amount of time spent on an assignment to the time clerk. The time clerk's responsibility is to collect the cycle times and then enter them into the computer. The times are then verified by the shift supervisor. The intent of this system is to keep a data base of past work. Using this database, they hope to enhance their tracking and scheduling of dies in the plant.

8.1.3 Technology

The plant uses die polishing technology that is relatively new to the industry. These machines polish the plant's major outer body panels. Managers at this facility claim that these machines reduce cycle times for the finishing operation by 50%. In the past, it took on average two to three weeks to hand finish large body dies. With the use of the die polishing machine, this time in now approximately to four days.

Another piece of technology that the plant is using is 5 axis machining. Managers at the this plant state that the use of these machines significantly reduces the amount of machining required. It also reduces the number of setups and tool changes needed. It is the ability of the tool to move and adjust to the changes in the contour of the work surface that makes this technology unique. Moreover, software is now available to assist plants in predicting the tool path for 5 axis machines.

8.1.4 Analysis

One flaw in the process of tracking parts is the inability to define the specific individual tasks that make up the process. Improvements to the process cannot be made when only the aggregate processes are examined. Moreover, without identifying and then examining every operation, the hidden costs and cycle times will never be uncovered. Consequently, substantial improvements will be difficult to obtain.

One positive aspect was the team based approach. It seemed to work well in this facility. It allowed workers to communicate across shifts, and localized responsibility for the construction of a specific die. This responsibility improved accountability.

8.2 Die construction within Toyota

Toyota has taken a new approach to die construction. They have totally automated their operation from machining to tryout. This system is capable of running 24 hours a day, 7 a days week. It can run continuously unmanned for as many as 10 days. Moreover, it is utilized at about 85% with no breaks throughout the year. It operates 7450 hours out of the year's 8760 available hours (Yamaguchi, 1991).

As mentioned in a Business Japan article, Toyota estimates that their fully automated die construction process reduces the time required to manufacture stamping dies for inner panels by 60%. Additionally, the article states that manual finishing time is reduced by 50% using the automated die polishing machines. The overall result is improved body quality and decreased lead time.

8.2.1 Reasons to automate

Toyota's development objectives were as follows:

- Improve productivity
- Shorten production preparation and production lead time
- Raise machining accuracy for inner panel dies

Toyota has met these objectives. Yamaguchi states that this new system's productivity is twice that of the conventional die making process. Moreover, Toyota has reduced lead time by 50%, and has improved machining accuracy to plus/minus 20μm.

As stated by a manager at an independently-owned American die facility, the only reason that the Japanese are able to automate their processes is because they have a steady flow of work. It is the fluctuation and uncertainty of the work flows that makes automation unrealistic in most die shops. This manager makes an interesting point. Because Toyota's die shop has a long-term relationship with its parent company, its work flows are more predictable, and the investment will be amortized over a long period. In contrast, an independently owned die facility has less certainty in demand. As a result, any substantial increases in automation could lead to an independent die maker's demise if demand decreases.

8.2.2 Die construction process

Figure 8.1 shows Toyota's plant layout. The major areas in the plant are as follows:

- NC machines
- Rack-type warehouse
- Pallets
- Automatically guided vehicles
- Workpiece setup areas

Toyota's Plant Layout

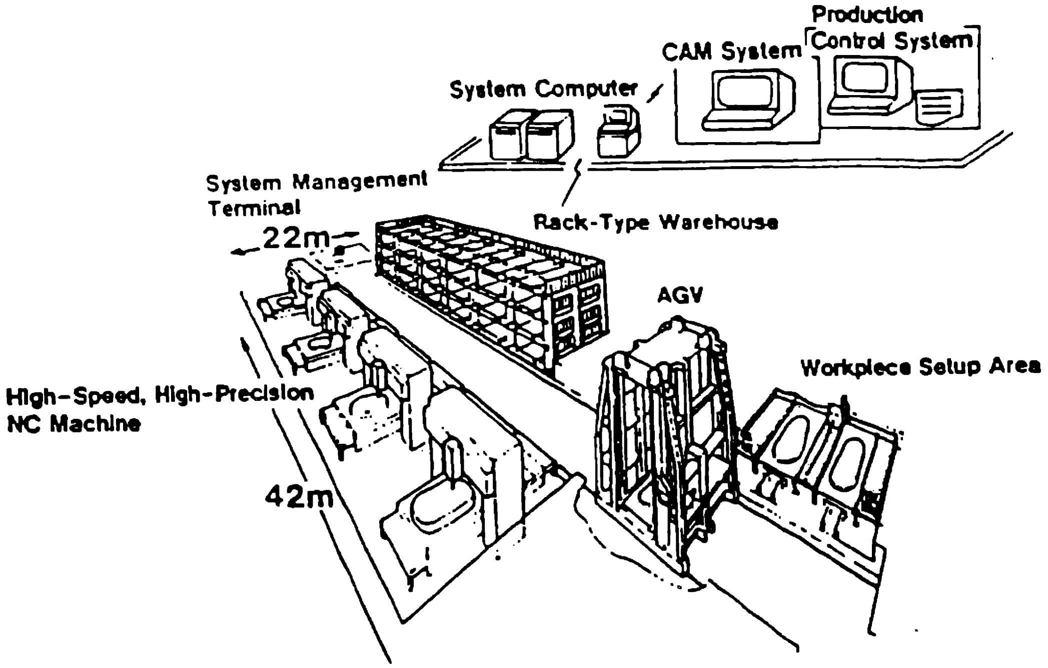


Figure 8.1

High speed, precision NC machines are used extensively. Some of the attributes of these machines are the automatic tool changer, automatic attachment changer, and automatic pallet changer. These attributes allow the casting to be loaded, machined, and then unloaded automatically.

Another major piece of equipment is the AGV that moves the castings from the workpiece setup area to the NC machines and then to the warehouse. The rack type warehouse is capable of storing up to 24 work pieces, and the workpiece setup area is capable of setting or removing up to 2 workpieces.

8.2.3 Analysis

Toyota's approach to die construction is indeed innovative. They have developed this system with one sole goal in mind, and that is to decrease the lead time of the die construction process. Toyota feels that this is a source of a competitive advantage. While the benefits from increased productivity and quality, and decreased lead time are all outstanding feats, the question of cost arises. Although cost information is not available for Toyota's automated die facility, it is an important issue when purchasing automation. Moreover, before making any decisions on automation a careful analysis must be performed.

While Toyota's die construction process is formidable, this author believes that other die makers can significantly reduce the lead time and improve productivity given a better understanding of the process. Toyota understood the die making process well enough to automate it. If they did not have a sound grasp on the fundamentals of the die construction process, automating the process would have led to failure. So, before automating a process, it is suggested that the process be thoroughly understood.

8.3 Die construction at an independent Japanese die maker

The next die facility examined was that of an independent Japanese die maker. Independent implies that it is not a subsidiary of an automotive company.

Sales of this subsidiary were $159,000,000, and the company employs 700 workers. Its major customers are General Motors, Ford, Chrysler, Volkswagen, Toyota, and Mazda.

This die facility uses modern production methods to construct dies despite the low volumes and high product mix. The workers in this facility realize that the industry is changing rapidly. Cost and accuracy are essentials for carving a competitive position in the market. To improve their competitiveness, the plant began to systemize the process of die construction.

8.3.1 Systematic approach to die construction

Systemization was implemented in four stages. First, data was collected concerning the current process. This data was passed on to production-related departments and the suppliers. Then, managers at the plant standardized work procedures in an attempt to eliminate the difference between individual skill, to increase quality, and to increase efficiency. This was accomplished through job training. The third phase in the implementation plan was to create production schedules that were flexible. Flexibility was important because it would ensure that engineering changes and other unforeseen problems could be accommodated. Fourth, waste and variability were eliminated from the process.

The plant used several tools to achieve systemization. Operation sheets were first used to eliminate the differences in individual skill, to focus workers on a task, and to reduce cycle times. The next tool used was the critical path. It was used to find the sequence of operations that most impacted the overall lead time. The plant also used it to schedule loads moving through the process. Lastly, visual production control charts were used. Examples of these charts as well as work orders and progress reports can be seen in Appendix C. The managers in the plant state that by using visual charts greater understanding of the process is achieved.

As a result of using this systematic approach, the plant can forecast more accurately, improve work efficiency, reduce cost, and ensure timely delivery.

8.3.2 Process of die construction

Figure 8.2 shows the process of die construction for this die shop. Additionally, Table 8.1 indicates the operations, highlights the critical timing path. Those operations with zero total slack times are the operations on the critical path. Figure 8.3 shows the process flow chart for only those operations on the critical path.

8.3.3 Analysis

This Japanese die facility seems to be moving the in right direction as far as improvements to the current process. Using the systematic approach to die construction has allowed them to better understand the process, eliminate waste and variation, and reduce cost. This approach should be undergone before any automation is installed. The improvements that can be gained from the systematic approach are far reaching. Thus, this is a valid approach for analyzing the process of die construction.

Flow Chart for Independent Japanese Die Maker

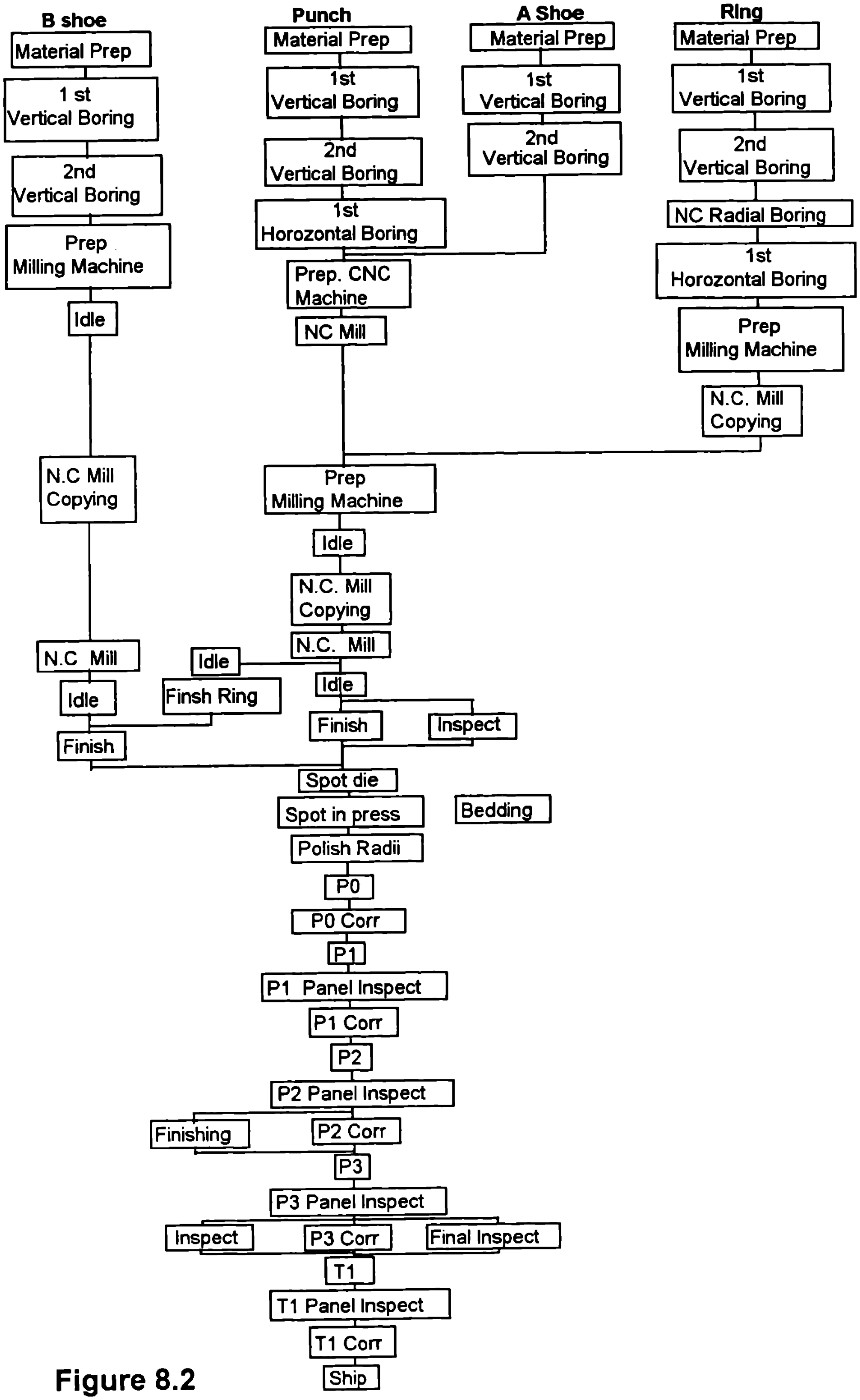


Figure 8.2

8.4 Differences in the approach to die construction

Examining the differences between the previously mentioned die construction facilities and the one where research was conducted, provided insight into the competitive trends in the industry. First, the independent Japanese die maker used a systematic approach to improve the process. This approach was also used by Toyota, and the approach enabled Toyota to gain a greater understanding of the process of die construction. In fact, this understanding was so comprehensive that it allowed the company to automate its die construction facilities. This thorough and in-depth understanding of the process is essential to improving the overall competitiveness of a die making facility.

The second major difference is the productionizing the process. This implies that the process is treated not as a job shop but more as a batch or automated facility. Examining the system as production process, allows for the use of modern production tools such as the critical timing path, process flow charts, and operation sheets. Also, examining the system in this manner, allows for the plant to exploit the commonalties of the die construction process. Additionally, this approach allows the plant to better examine the process and identify the bottleneck of the process. Moreover, the approach facilitates the formulation of alternatives aimed at increasing the capacity of the bottleneck. The previously mentioned benefits are just a few of the countless benefits that productionization allows. For this reason, productionizing the process was used by both Toyota and the independent Japanese die maker.

The third difference is in the use of technology in the plant. Specifically, the use of polishing machines has been noted to decrease the cycle time of finishing operations by more than 50%. Because many of the finishing operations in the process are on the critical path, decreasing the time required to finish parts directly impacts the overall lead time of the part.

Examining the critical timing path developed for the independent Japanese die maker (Figure 8.3), it can be seen that the critical path begins with the ring and then progresses to the punch. This is in contrast to the critical path developed for facility where research was performed. This path began with the A shoe, then progressed to the punch. The difference is small, but worthy of mention because it effects the start of construction on the castings. In the Japanese facility, the ring has to began as soon as possible. However, in the American facility, the A shoe must start as soon as possible while all other castings should have their start times be delayed. This difference only effects resource allocation decisions, and does not provide either company with an advantage in lead time, cost, or quality.

8.5 Similarities between the die construction process

Comparing the die construction process flow chart of the independent Japanese die maker and the American facility where research was conducted, strong similarities are noted. Specifically, both processes start with four different castings, and the sequence of operations are the practically the same. Moreover, the mating operations occur in similar locations. Comparing the two process shows that the there is no significant differences. Additionally, as mentioned previously, the process at the independent die construction facility in the Midwest did not seem to be significantly different either.

8.6 Summary of bench marking analysis

Every company listed in this chapter has approached the challenge of meeting customer demand, reducing lead time, and increasing productivity in a different way. Moreover, there is no one right answer. This chapter was geared towards showing the reader different ways of approaching the same goal. Choosing the right path depends on where the company starts and how much the company is willing to change.

Table 8.1

Critical Timing Path Schedule

B Shoe	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Mtrl Prep	1/4/93 12:00am	1/4/93 12:00am	1/9/93 9:42am	1/9/93 9:42am	0d	10d
1st Vertical B	1/4/93 6:30am	1/4/93 3:49pm	1/9/93 9:42am	1/9/93 7:01pm	0d	10d
2nd Vertical B	1/4/93 3:49pm	1/5/93 9:18am	1/9/93 7:01pm	1/10/93 12:30pm	0d	10d
1st Horizontal B.	1/5/93 9:18am	1/5/93 11:30am	1/10/93 12:30pm	1/10/93 2:43pm	0d	10d
Prep C mill	1/5/93 11:30am	1/5/93 1:06pm	1/10/93 2:43pm	1/10/93 4:19pm	0d	10d
Idle	1/5/93 1:06pm	1/5/93 1:06pm	1/10/93 4:19pm	1/10/93 4:19pm	0d	10d
Copying	1/5/93 1:06pm	1/7/93 7:12am	1/10/93 4:19pm	1/12/93 10:24am	0d	10d
2nd N.C milling	1/7/93 7:12am	1/7/93 8:24am	1/12/93 10:24am	1/12/93 11:36am	0d	10d
Idle	1/7/93 8:24am	1/7/93 8:24am	1/12/93 11:36am	1/12/93 11:36am	10d	10d
Finishing M/Half	1/12/93 11:36am	1/14/93 4:31pm	1/12/93 11:36am	1/14/93 4:31pm	0d	0d

Table 8.1 cont.

Punch

	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Matl Purchase	1/4/93 12:00am	1/4/93 12:00am	1/4/93 9:48am	1/4/93 9:48am	0d	1d
!st Veritcal B	1/4/93 6:30am	1/4/93 10:12am	1/4/93 9:48am	1/4/93 1:30pm	0d	1d
2nd Vertical B	1/4/93 10:12am	1/4/93 6:31pm	1/4/93 1:30pm	1/4/93 9:49pm	0d	1d
1st Horizontal B.	1/4/93 6:31pm	1/5/93 8:42am	1/4/93 9:49pm	1/5/93 12:00pm	0d	1d
Prep for C mill	1/5/93 8:42am	1/5/93 4:31pm	1/5/93 12:00pm	1/5/93 7:49pm	0d	1d
1st N.C. mach.	1/5/93 4:31pm	1/6/93 9:24am	1/5/93 7:49pm	1/6/93 12:42pm	1d	1d
Prep for C mill	1/6/93 12:42pm	1/7/93 8:36am	1/6/93 12:42pm	1/7/93 8:36am	0d	0d
Idle	1/7/93 8:36am	1/7/93 8:36am	1/7/93 8:36am	1/7/93 8:36am	0d	0d
Copying	1/7/93 8:36am	1/9/93 9:30am	1/7/93 8:36am	1/9/93 9:30am	0d	0d
2nd N.C. mach.	1/9/93 9:30am	1/9/93 10:42am	1/9/93 9:30am	1/9/93 10:42am	0d	0d
idle	1/9/93 10:42am	1/9/93 10:42am	1/10/93 9:54am	1/10/93 9:54am	0d	2d
Finishing M/Hal	1/9/93 10:42am	1/13/93 5:19pm	1/10/93 9:54am	1/14/93 4:31pm	2d	2d
Insp. M/H IN	1/9/93 10:42am	1/9/93 6:43pm	1/14/93 8:30am	1/14/93 4:31pm	10d	10d

Ring

Material Prep	1/4/93 12:00am	1/4/93 12:00am	1/4/93 6:30am	1/4/93 6:30am	0d	0d
Radial Boring -1	1/4/93 6:30am	1/4/93 3:49pm	1/4/93 6:30am	1/4/93 3:49pm	0d	0d
Radial Boring -2	1/4/93 3:49pm	1/5/93 7:36am	1/4/93 3:49pm	1/5/93 7:36am	0d	0d
N.C. Vertical B.	1/5/93 7:36am	1/5/93 11:42am	1/5/93 7:36am	1/5/93 11:42am	0d	0d
Horizontal B.	1/5/93 11:42am	1/5/93 3:01pm	1/5/93 11:42am	1/5/93 3:01pm	0d	0d
Prep C mill	1/5/93 3:01pm	1/5/93 7:49pm	1/5/93 3:01pm	1/5/93 7:49pm	0d	0d
N.C. --1 mill	1/5/93 7:49pm	1/6/93 12:42pm	1/5/93 7:49pm	1/6/93 12:42pm	0d	0d
idle	1/9/93 10:42am	1/9/93 4:43pm	1/9/93 10:42am	1/9/93 4:43pm	0d	0d
Finishing M/Half	1/9/93 4:43pm	1/12/93 11:36am	1/9/93 4:43pm	1/12/93 11:36am	0d	0d

A shoe

Material Prep	1/4/93 12:00am	1/4/93 12:00am	1/4/93 8:37pm	1/4/93 8:37pm	0d	2d
Radial Boring --1	1/4/93 6:30am	1/4/93 11:18am	1/4/93 8:37pm	1/5/93 9:24am	0d	2d
Radial Boring --2	1/4/93 11:18am	1/4/93 1:54pm	1/5/93 9:24am	1/5/93 12:00pm	2d	2d

Table 8.1 cont.

Assembled die

	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Free Slack	Total Slack
Die spot	1/14/93 4:31pm	1/18/93 8:00am	1/14/93 4:31pm	1/18/93 8:00am	0d	0d
Spot in press	1/18/93 8:00am	1/20/93 10:48am	1/18/93 8:00am	1/20/93 10:48am	0d	0d
Bedding	1/20/93 10:48am	1/22/93 1:30pm	1/20/93 10:48am	1/22/93 1:30pm	0d	0d
3rd finishing	1/22/93 1:30pm	1/26/93 6:55pm	1/22/93 1:30pm	1/26/93 6:55pm	0d	0d
P0 bedding	1/26/93 6:55pm	1/27/93 2:37pm	1/26/93 6:55pm	1/27/93 2:37pm	0d	0d
Finishing P0	1/27/93 2:37pm	1/30/93 6:43pm	1/27/93 2:37pm	1/30/93 6:43pm	0d	0d
P1	1/30/93 6:43pm	1/31/93 9:24am	1/30/93 6:43pm	1/31/93 9:24am	0d	0d
P1 Panel insp	1/31/93 9:24am	2/1/93 9:54am	1/31/93 9:24am	2/1/93 9:54am	0d	0d
Finishing P1	2/1/93 9:54am	2/3/93 8:54am	2/1/93 9:54am	2/3/93 8:54am	0d	0d
P2	2/3/93 8:54am	2/3/93 1:24pm	2/3/93 8:54am	2/3/93 1:24pm	0d	0d
P2 inspection	2/3/93 1:24pm	2/4/93 6:54am	2/3/93 1:24pm	2/4/93 6:54am	0d	0d
Inspect D/O CH	2/4/93 6:54am	2/4/93 11:24am	2/4/93 5:55pm	2/4/93 10:25pm	1d	1d
Finishing P2	2/4/93 6:54am	2/4/93 10:25pm	2/4/93 6:54am	2/4/93 10:25pm	0d	0d
P3	2/4/93 10:25pm	2/5/93 10:48am	2/4/93 10:25pm	2/5/93 10:48am	0d	0d
P3 inspection	2/5/93 10:48am	2/5/93 7:19pm	2/5/93 10:48am	2/5/93 7:19pm	0d	0d
Inspect D/O CH	2/5/93 7:19pm	2/5/93 10:25pm	2/6/93 3:43pm	2/6/93 6:49pm	2d	2d
Finishing P3	2/5/93 7:19pm	2/6/93 6:49pm	2/5/93 7:19pm	2/6/93 6:49pm	0d	0d
Final Inspection	2/5/93 7:19pm	2/6/93 11:18am	2/6/93 10:48am	2/6/93 6:49pm	1d	1d
T1	2/6/93 6:49pm	2/7/93 7:12am	2/6/93 6:49pm	2/7/93 7:12am	0d	0d
Inspect T1	2/7/93 7:12am	2/7/93 4:43pm	2/7/93 7:12am	2/7/93 4:43pm	0d	0d
Finishing T1	2/7/93 4:43pm	2/8/93 4:13pm	2/7/93 4:43pm	2/8/93 4:13pm	0d	0d
Ship	2/8/93 4:13pm	2/9/93 4:13pm	2/8/93 4:13pm	2/9/93 4:13pm	0d	0d

Critical Path for Independent Japanese Die Maker

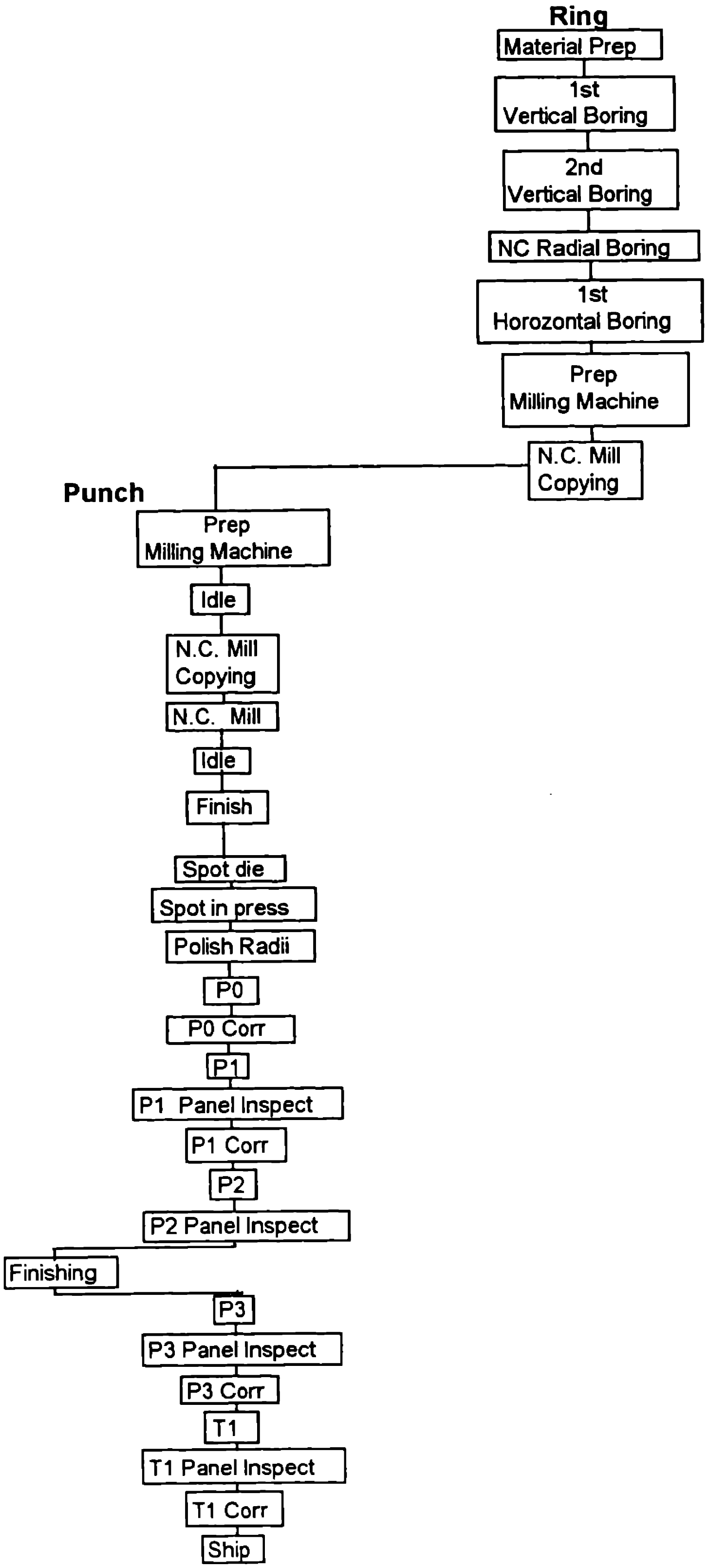


Figure 8.3

8.7 Die polishing technology

Die polishing machines are among the newest technologies in the die construction industry. Their purpose is to eliminate the tedious and menial task of manual finishing. These machines will replace human labor. These machines have been known to decrease the cycle time of machining operations by approximately 50%. Because surface finishing accounts for more than 40% of the total time required to complete a die, the polishing machines can play a vital role in lead time reduction (Balser,1991). As seen in the simulation in Chapter 8, the effect of the polishing machine was great in reducing the overall lead time. Because of the potential benefits that can be seen from using the system, a detailed description of the machine has been included in this section.

For many years the process of die construction has been manual. This is due to the complexity of the tool motions required, the variety of tools needed, and the need for feedback of details relating to the surface finish (Balser,1991). However, with the use of numerically controlled machines appropriate motion can be simulated to yield acceptable results. The numerically controlled machines have a polishing tool attached, and move according to a specified program. These machines generally have force control on them. The purpose of force control is to maintain the appropriate force on the surface of the die over a range. The closed loop feedback system will account for noise caused by changes in the die's surface. These mechanisms can be pneumatic, or mechanical such as springs and sponges (Derby, 1988). The advantage of using springs and sponges is that they can be used for both force control and compliance.

One convenience of using a numerically controlled machine for die polishing is the availability of NC cutter path data (Balser, 1991). This data tells the finishing machine the path that the surfacing machine followed. Using this data, programming the machine to follow a given path has been facilitated. However, because the machine has certain constraints such as 3 axis capability, the maneuverability of the machine and the tool is limited. This is a constraint that must be considered when purchasing a polishing machine. Another type of polishing machine available uses a robot arm to hold the polishing tool. Using the robot arm, the degrees of freedom are increased subsequently the maneuverability is also increased.

The next essential element in the polishing operation is the appropriate selection of a tool. There are three components to a stoning end-effector: the abrasive, compliance mechanism, and force control mechanism.

The use of compliant tools is a necessity in the polishing machines. The compliance mechanism is used to prevent jamming the stone against the surface, and to ensure proper contact against the surface (Derby, 1988). Additionally, compliance compensates for tool positioning errors. (Balser, 1991) It also compensates for wear and workpiece location error. Compliance is achieved through applying a force on the die via a pneumatic, hydraulic, or magnetic device (Lilly, 1988). A benefit in using compliant tools is that they do not alter the geometry of the die. Another benefit is that it is less susceptible to dynamic instability.

8.8 5-Axis technology

5-axis technology has been available for over a decade. However during that time period software that would predict the machines cutter paths were not sufficient for most companies. The significance of predicting these paths is that potential collisions between the tool and part can be avoided. Collision predicting software allows the programmer to view exactly what would happen when the tool was cutting the metal.

One of the benefits of using a 5-axis machine is improved surface finish. This is ensured by the nutating spindle head. This allows the spindle centerline and drive shaft to maintain constant relationship with one another (Capes, 1990). As a result, the spindle head nutates to achieve angular position. This achieves a stiffer relationship between the cutter and workpiece and improves the finish.

Another benefit of the machine is the increase in productivity. 5-axis machining enables complex feature lines and forms to be produced in a minimal number of passes. Using conventional 3 axis machines, several setups were required to position a part in an appropriate configuration for machining. This was done because the machine was unable to machine many surfaces. This limitation is overcome by the 5 axis machine because it has greater degrees of freedom. Because the number of passes and the number of setups are minimized, the use of 5-axis machines can increase productivity.

8.9 Summary of die polishing technology

5-axis and polishing machine technology are relatively new but preliminary results show that they can make a profound impact on the cycle time of their respective operations, and can subsequently reduce the lead time of overall die construction process. Careful consideration should be given to these technologies in the future as improvements and enhancements are made.

Chapter 9

Conclusion

Based on the results obtained through testing alternatives in the simulation, the author concludes that process analysis is indeed a viable methodology for improving the process of die construction. Process analysis allows companies to develop a deeper, more penetrating understanding of the process. With this understanding and the proper application of tools such as the process flow charts, operation sheets, critical path methods, and the simulation, alternatives can be formulated to address the issues concerning the plant. Process analysis enables the user to systematically examine a process, gather pertinent information, formulate alternatives, and test alternatives in a simulated environment. By implementing process analysis, the process is standardized, value added operations identified, and essential operations defined. All of which give the user a better understanding of the process. Consequently, companies can improve their competitive positions.

Bibliography

Amber, Elizabeth, "Tooled Up", *Grand Rapids Business Journal*, Gemini Publications, August 1992. Vol 10, No. 32, Sec 2, Pg B-1.

Amstadter, Bertam, L. Reliability Mathematics, Fundamentals, Practices, Procedures, McGraw-Hill Book Company, 1971.

Automod Simulations, User's Manual, 1991

Balcer, Daniel, "Automated Die and Mold Polishing Research", Graduate Thesis, The Ohio State University, Columbus, Ohio, 1991.

Blanchard, Benjamin, S. E. Edward Lowery, Maintainability Principles and Practices, McGraw-Hill Book Company, 1969.

Business Japan," Toyota Motor: Stamping Die Facility Wins Praise for Toyota", *Business Japan,* March 1990, Vol 3, Pg 15-16.

Capes, Phillip. "Quality First in Rover's Toolroom" *American Machinist*. Vol 134, Pg 55-7, April 1990.

Clark, Kim B., Takahiro Fujimoto . Product Development Performance: Strategy, Organization, and Management in the World Auto Industry. Harvard University Press: Cambridge, MA, 1991.

Clark, Kim, B., Takahiro Fujimoto, "Overlapping Problem Solving in Product Development", *Managing International Manufacturing*, Elsevier Science Publishers, 1989.

Derby, S. B. Rasmussen. "Design and Evaluation of Robotic End Effectors for an Automated Die Finishing System", *Computer-Aided Design and Manufacture of Dies and Molds*. PED-Vol. 32, 1988.

Drees, Franz R. A. (1991) "Comparative Analysis of Best Practice in the Manufacture of Hard Dies for Automotive Stamping Operations", MIT, Master's Thesis, Cambridge, MA.

Goldratt, M. Eliyahu, Jeff Cox, The Goal: A Process of Ongoing Improvement, North River Press, Inc., NY., 1986.

Knight, W.A. "Group Technology in Forging and Stamping", *Metallurgia and Metal Forming*, September, 1971.

Law, Averill, M., W. David Kelton, *Simulation Modeling and Analysis*, McGraw-Hill Book Company, NY, 1982.

Lilly, B.W. "Automated Finishing of Dies and Molds: A State of the Art Review", *Design and Manufacture of Dies and Molds*, PED. Vol 32, 1988.

Nahmias, Steven, Production and Operations Analysis, Irwin, 1989.

Robson, D. George, CPI: Simplifying Work Flow Systems, The Free Press: New York, 1991.

Roodvoets, Scott, (1991) "An Evaluation of the Influence of Platform team Organization on Product Development Performance", MIT, Master's Thesis, Cambridge, MA.

Sharf, Stephan, Ward's Auto World, June, 1992, Vol. 28, No. 6, Pg. 17.

Vonderembse, Mark. A. Gregory P. White, Operations Management: Concepts, Methods, and Strategies, West Publishing Company, St. Paul, MN. 1991.

Winter, Drew, Ward's Auto World, July, 1992 Vol. 28, No. 7, Pg 65.

Yamaguchi, Jack "Toyota's 'Year Round' Press Die-making System", *Automotive Engineering*, Vol. 112, Pg. 112-113, 1991.

Zuboff, Shoshana, "Automate/Informate: TheTwo Faces of Intelligent Technology", Massachusetts Institute of Technology, Sloan School of Management, Class Notes, 1993.

Appendix A

Description of the Die Construction Process

The intent of this appendix is to describe the components that make up a die, and to outline the steps in the die construction process. The description of the process is intended to introduce the reader to some of the intricacies of the process, but more importantly, to provide a basis of understanding. This should enable the reader to better understand the process improvement methodology as it is applied to the die construction process.

A.1 Description of an Air Draw Die

Drawing is the process by which a punch causes flat metal to flow into a die cavity to assume a given shape. A blank is placed in a press, a binder or ring holds the metal in place. The force from the punch causes the metal to flow plastically as it is pushed into the cavity. The subsequent use of draw dies can increase metal properties such as stiffness and strength due to the process of work hardening.

Drawing is an important aspect in the manufacture of automotive parts. Draw dies are most commonly used to produce the following exterior panels:

- Hoods
- Fenders
- Roof tops
- Quarter panels
- Doors
- Deck lids

The process of drawing is also used to form interior panels such as instrument panels and window moldings (Internal Document).

A.2 Components of the Draw Die

The draw die consists of four basic components. The first component is the punch. This is used to force the metal to flow into the cavity. It is one of two independently moving parts. The press acts as a ram to force the punch to descend. This allows the punch to apply a force on the metal. The force supplied by the punch is sufficient to alter the material state. In fact, it makes the metal flow plastically. Drawing causes deformation of metal to occur over a major portion of the part's surface.

The second main component is the ring. It is the second moving part of the die, and holds the sheet metal in place while the punch deforms pushes the metal into the cavity. The ring has beads on its surface. These are used to restrict metal flow to secure the desired shape. It helps to control the amount of material released into the cavity. If too little material is released, the sheet metal will split. However, if too much material is released, the metal might wrinkle or the sheet metal may overlap.

The third part is the cavity which is also called the B shoe. This component is used to confine the flow of material to a defined area. The B shoe has beads that match those on the ring. The purpose of the beads is identical to those on the ring. The forth and last component is the A shoe. The punch is attached to this shoe, and it enables the punch to fit into the press.

A1.3 The planning, design, and manufacture of a draw die

Pre-draw die committee

The first step in the die construction process is the planning process. This process is conducted through weekly meetings with a cross-functional team. This team consists of members from the following areas: quality control, assembly, wiring, trim, structure, metal lab, draw development engineering, manufacturing, and product design. At these meetings, team members discuss product feasibility and product manufacturing concessions.

Draw die committee

Once again a cross functional team is represented. This team consists of members from the following areas: manufacturing engineering mangers from the stamping plants, die process and die design, draw development engineering, product engineering, quality control, and advanced manufacturing members. At these meetings, there is discussion concerning draw die designs and ring lay-ups. Punch openings and contact points are also studied. On the recommendation of the committee alterations will be made. When consensus is reached based on the design, the prints are released to the pattern shop.

Pattern Shop

When the design department releases its prints, the pattern shop will start making Styrofoam patterns for all castings. Due to the simplicity of most of the shapes, these patterns are created by hand. Also, patterns that have deep cavities are built by hand. However, for complex shapes, the pattern is cut using numerically controlled machines. Moreover, it is common for the pattern shop to construct patterns for a line of dies at one time.

Foundry

The Styrofoam castings created in the pattern shop are now sent to the die caster. The patterns are then sand casted to form the metal dies. The line of dies is then sent back to the die shop.

Die construction process

After the patterns are casted, they are sent back to the plant. The first step in the die construction process is to inspect the ring, punch, A shoe, and B shoe castings for conformance to die prints. The operations for all of the castings begin at the same time. They progress in parallel with each other. The following will detail the steps in each process.

Construction of the Ring

After the ring has been inspected, holes for the wear plates and equalizers are then made. Then, the panel strippers are cut using the CNC machines. These strippers are use to remove the metal from the ring after the metal has been formed. Once the panel strippers are cut, the strippers are locked in position on the ring.

The surface of the ring is machined using numerical control. Upon completion of machining, the ring is finished using a hand grinder and an assortment of polishing stones. The purpose of this operations is to alleviate the machine marks.

Next, the casting is outsourced for the flame hardening operation. Flame hardening increases the strength and hardness of the die. Because the flame hardening operation leaves a dark residue on the die, it must be polished upon arrival in the plant.

The wear plates are added to the ring. These plates serve as a friction reduction devices, and ensure a close fit between interconnecting dies. They are also used to absorb side thrusts when unbalanced forces are present. After this operation the equalizers are mounted. The role of the equalizers is to ensure that the pressure on the metal sheet is distributed equally over the punch and subsequently the metal. The ring is then mated to the A shoe and the punch.

Construction of the punch

After the punch is inspected, the parts are moved to a radial drill press. Here, mounting holes for the punch are drilled. These holes will enable the punch to be mounted to the A shoe at a later time. To ensure that the holes on the A shoe are in their proper location, the punch is mated with the A shoe. Then , the holes from the punch are transferred to the A shoe.

Upon completion of the hole transfer, the punch is then machined to achieve a closer tolerance to the desired shape. The punch is then moved to the finishing area, where it is finished to achieve a quality surface. Because of the complexity of the surface and importance of the punch in material flow, finishing is a very difficult and time consuming operation.

Next, the punch has vent holes drilled. This enables air to escape. This ensures better quality stampings because no air bubbles will blemish the surface of the metal. Once the vent holes are drilled, the casting is outsourced to be flame hardened. Upon its return to the plant, it is polished to remove flame harden residue. It is then mated with the A shoe.

Construction of A shoe

After the inspection of the A shoe casting, it is then mated with the punch. This will allow the mounting holes from the punch to be transferred to the A shoe. At this time, the wear plates, stop and bottoming blocks are mounted. The A shoe casting is then mounted with the punch. Upon mating the punch a A shoe, the two castings are then mated with the ring.

Construction of B shoe

The B shoe or cavity is inspected then machined using numerical control to achieve a closer tolerance to the desired shape of the material. The surface of the cavity has to match identically with that of the punch.

After completing the machining operation, the casting is then drilled for panel strippers pushers. Once again, these are used to remove the metal from the die after the deformation. the casting is then finished to achieve a superior surface quality. Next, the B shoe is mated with the A shoe, ring, and punch in an assembly operation.

Construction of the assembled die

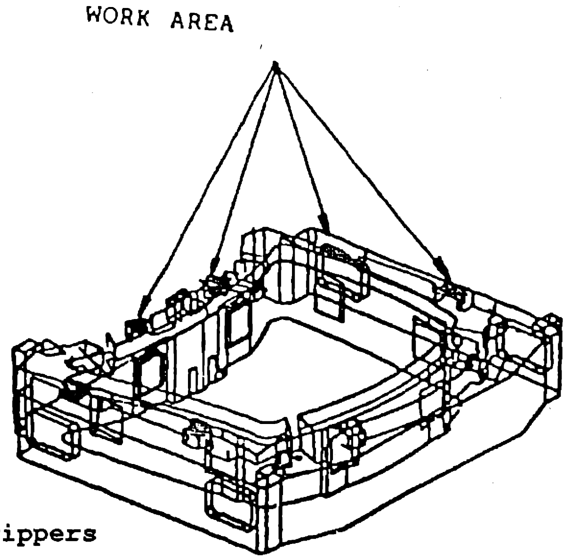
The completion of the B shoe allows for the assembly of all of the castings. The assembly of the castings form a complete die. This die is now placed into a press, and is spotted die to die. This allows the die maker to verify that the shape cavity identically matches the shape of the punch. It also allows the die maker to ensure that the castings do not collide or rub against each other.

Next, the a semi formed panel is placed in the die. The die is then closed, and then reopened. The panel is removed and examined for hard spots. These are areas where pressure from the punch and cavity is uneven. This means that there is more contact from the punch than from the cavity or vice versa. At this time, the cavity and punch are polished to alleviate the hard spots. The die is run in the press then polished and ground until the panels being stamped have an acceptable appearance. Once this occurs, the die makers run 250 panels for prototype vehicles.

The die is then disassembled. The B shoe is outsourced for flame hardening, and is polished upon its return to the plant. During this time, the ring has screw holes drilled for gauges, and gauges are mounted. Upon completion of these operations, the die is re-assembled. It is placed back into the press and more panels are run. The die is then disassembled, painted, and shipped.

Appendix B

Operation Sheets



OPERATION NO: 0103

DESCRIPTION: Machine Panel Strippers

MACHINE: Large Mill

TOOLS:
NC Tapes

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Run NC tapes to cut profile for strippers.	

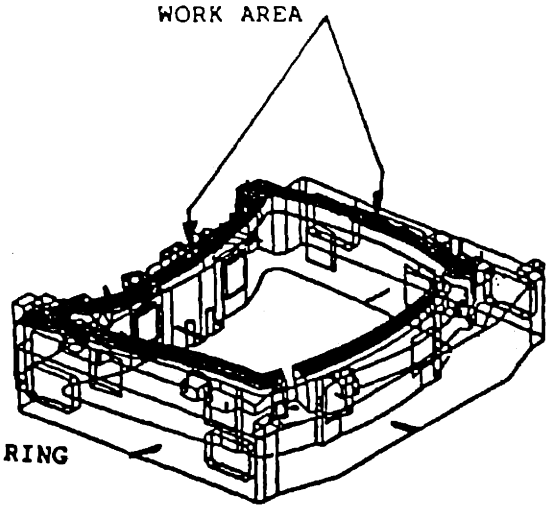
OPERATION NO: 0104

DESCRIPTION: Install Panel Strippers

MACHINE: None

TOOLS:
Allen Wrenches
Socket Head Cap Screws

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Install strippers in ring.	
2.	Fit stripper blocks to ring.	
3.	Lock srippers in home position.	



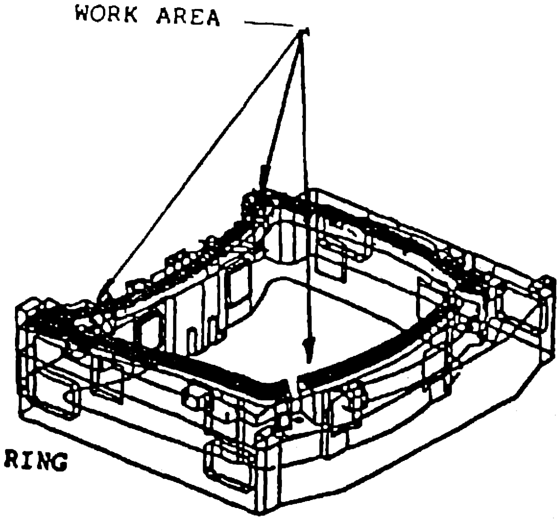
OPERATION NO: 0105

DESCRIPTION: Mill Ring Surface

MACHINE: 3 Axis Mill

TOOLS:
Crane
NC Tapes
NC Set Up Directions
NC List Of Tapes

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load casting onto machine.	
2.	Set up to center line keys.	
3.	Set machine offsets to NC set up directions.	
4.	Load tapes into machine controller.	
5.	When machining is completed, clean chips from detail and return detail to die construction area.	



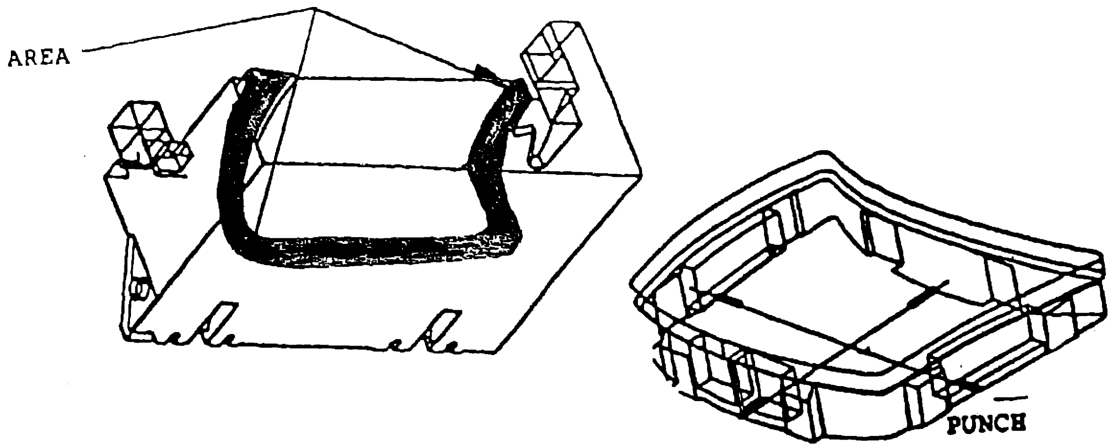
OPERATION NO: 0106

DESCRIPTION: Finish Ring Surface

MACHINE: None

TOOLS:
Hand Grinder
Layout Dye
Assorted Grinding Wheels
Rubbing Stones
Emery Cloth
Files

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Cover ring with layout dye.	
2.	Hand grind parallel to machine cusps lines.	
3.	Leave witness marks on surface.	
4.	Cross stone surface face to remove grind marks.	
5.	Polish radii with emery cloth in areas of flow.	
6.	File feature areas where needed.	



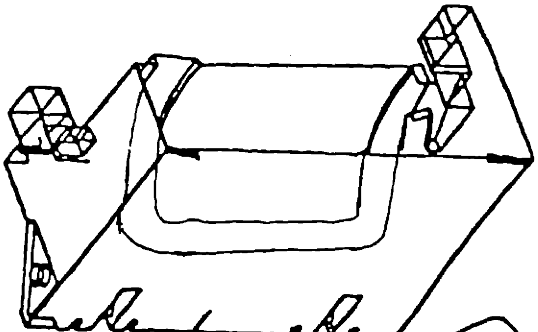
OPERATION NO: 0107-0206-0407

DESCRIPTION: Flame Harden Work Areas

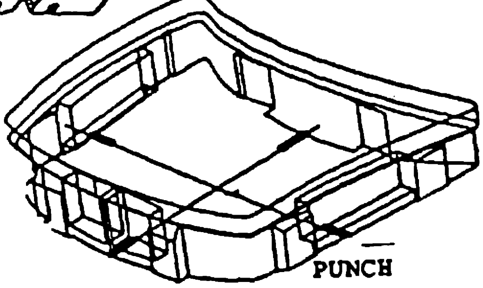
MACHINE: Outside Vendor (Heat Treating)

TOOLS:
Crane
Marking Pen

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Mark Areas to be harden with marking pin.	
2.	Send to vendor for flame hardening.	



B SHOE



PUNCH

OPERATION NO: 0108-0207-0408

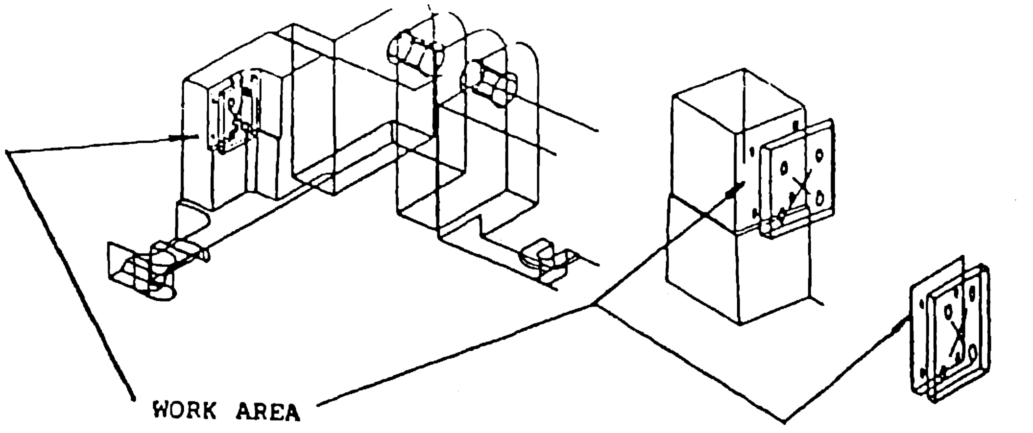
DESCRIPTION: Polish Flame Harden Areas

MACHINE: None

TOOLS:

Crane
Emery Cloth
Rubbing Stones

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	After details return from heat treat, harden areas need to be polished with emery.	



PAD - RING

OPERATION NO: 0109-0303-00304

DESCRIPTION: Mount Wear Plates, Stop and Bottoming Blocks

MACHINE: None

TOOLS:
Allen Wrench
Cap Screws

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Locate details to areas as marked.	
2.	Attach details with proper size screws.	
3.	Tighten screws with Allen Wrench until they are seated and snug.	

OPERATION NO: 0110

DESCRIPTION: Mount Equalizers

MACHINE: None

TOOLS:
Allen Wrench
Cap Screws

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Locate details to areas as marked.	
2.	Attach details with proper size screws.	
3.	Tighten screws with Allen Wrench until they are seated and snug.	

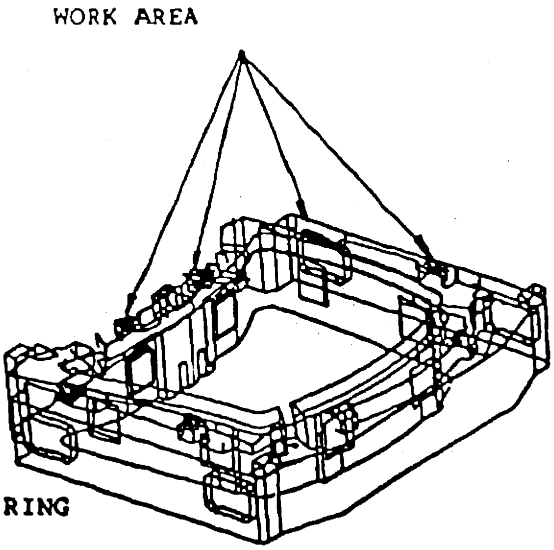
OPERATION NO: 0111-0406

DESCRIPTION: Size Wear Plates

MACHINE: None

TOOLS:
- Crane
- Feeler Stock
- Sliding Parallels
- Micrometer

ITEM	OPERATION ROUTINE
1.	Using crane attempt to put A and B shoe together.
2.	When die shoes are together check clearance of wear plate to mating face. Gap should be .005" between plate and work face.
3.	Should die shoes not fit together remove opposite side wear plates and assemble die set.
4.	Using sliding parallels size thickness of plates.



OPERATION NO: 0112

DESCRIPTION: Drill and Tap Holes For Gauges

MACHINE: RADIAL DRILL

TOOLS:
Drills
Taps
Hammer
Transfer Punches

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Transfer screw holes for gauges.	
2.	Drill and tap screw holes for gauges.	
3.	Mount gauges.	

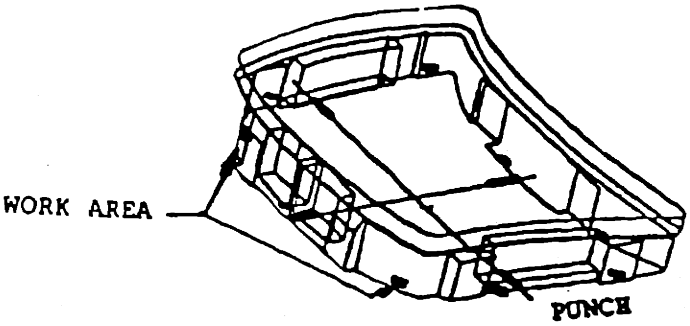
OPERATION NO: 0113

DESCRIPTION: Mount Gauges

MACHINE: None

TOOLS:
Socket Head Cap Screw
Allen Wrench

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Place gauges in proper area.	
2.	Insert screws and tighten with Allen Wrench.	



OPERATION NO. 0202

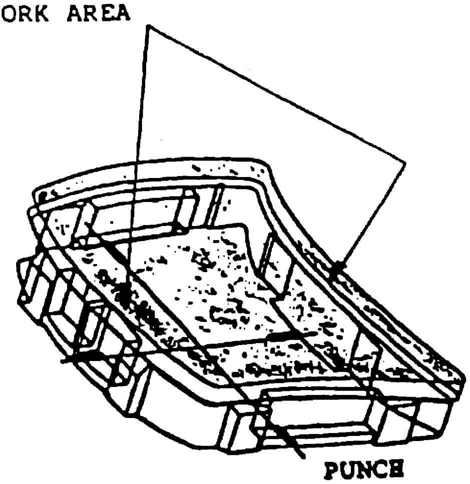
DESCRIPTION: Drill Mounting Holes

MACHINE: Radial Drill Press

TOOLS:

Crane
1 1/16 Tappered Shank Drill
Spot Face Tool
C clamps

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load punch onto radial drill press.	
2.	Clamp punch to parallels of drill press.	
3.	Insert drill into drill press spindle.	
4.	Position drill over areas to be drilled and drill.	
5.	After drilling spot face drilled holes.	
6.	Clean chips from punch and unload drill press.	



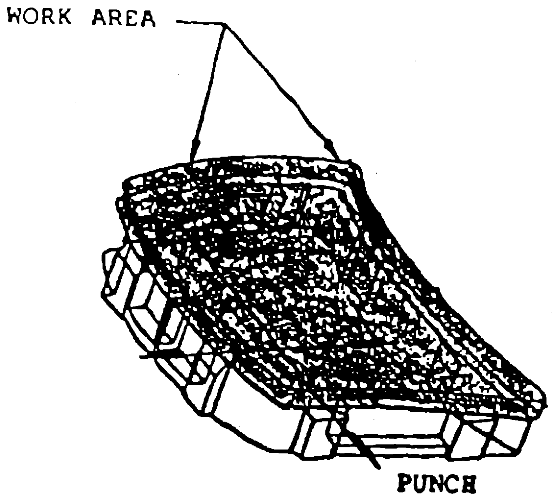
OPERATION NO: 0203

DESCRIPTION: Mill Punch Surface

MACHINE: 3 Axis Mill

TOOLS:
Crane
NC Tapes
NC Set Up Directions
NC List Of Tapes

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load casting onto machine.	
2.	Set up to center line keys.	
3.	Set machine offsets to NC set up directions.	
4.	Load tapes into machine controller.	
5.	When machining is completed, clean chips from detail and return to die construction area.	



OPERATION NO: 0204

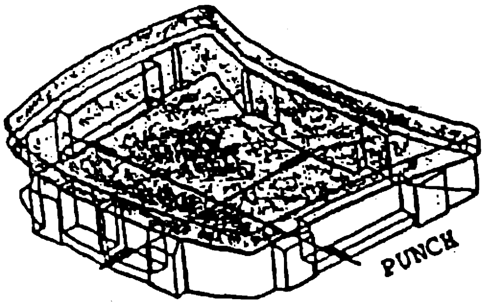
DESCRIPTION: Finish Punch Surface

MACHINE: None

TOOLS:

- Hand Grinder
- Layout Dye
- Assorted Grinding Wheels
- Rubbing Stones
- Emery Cloth
- Files

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Cover punch with layout dye.	
2.	Hand grind parallel to machine cusps lines.	
3.	Leave witness marks on surface.	
4.	Cross stone surface face to remove grind marks.	
5.	Polish radii with emery cloth in areas of flow.	
6.	File feature areas where needed.	
7.	Highlight punch surface.	



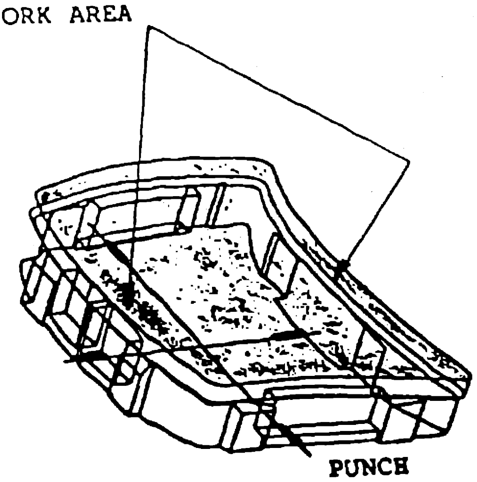
OPERATION NO: 0205

DESCRIPTION: Layout and drill vent holes

MACHINE: Radial Drill Press

TOOLS:
Drills
Drill Chuck
Drill Sleeves
Hammer
Drill Drift

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Layout vent holes in areas where needed.	
2.	Load punch on to Radial Drill press.	
3.	Set up to angles as needed to drill vents into cores.	



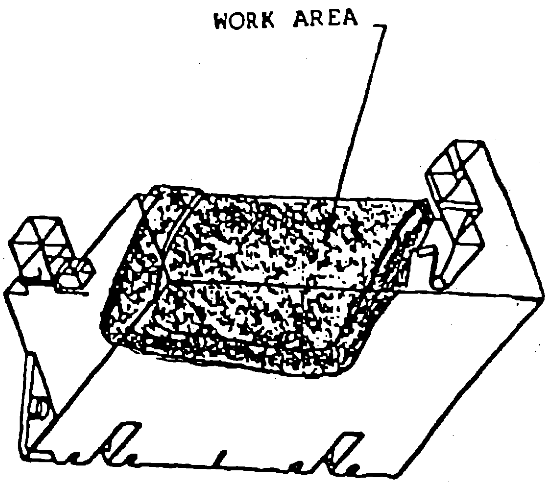
OPERATION NO: 0303

DESCRIPTION: Mill Punch Surface

MACHINE: 3 Axis Mill

TOOLS:
Crane
NC Tapes
NC Set Up Directions
NC List Of Tapes

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load casting onto machine.	
2.	Set up to center line keys.	
3.	Set machine offsets to NC set up directions.	
4.	Load tapes into machine controler.	
5.	When machining is completed, clean chips from detail and return to die construction area.	



B SHOE

OPERATION NO: 04-02

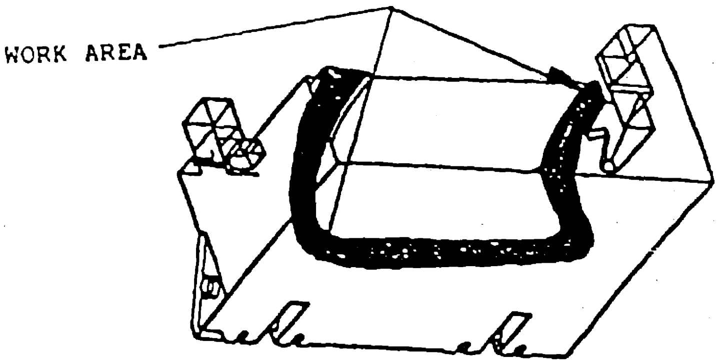
DESCRIPTION: Mill Surface

MACHINE: 3 Axis Mill

TOOLS:

Crane
NC Tapes
NC Set Up Directions
NC List Of Tapes

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load B shoe casting onto machine.	
2.	Set up to center line keys.	
3.	Set machine offsets to NC set up directions.	
4.	Load tapes into machine controler.	
5.	When machining is completed, clean chips from detail and return detail to die construction area.	



OPERATION NO: 0403

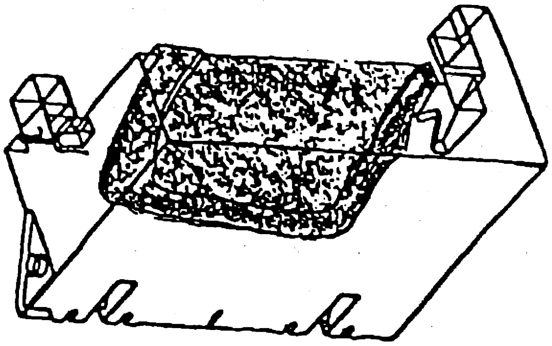
DESCRIPTION: Drill And Bore For Pushers

MACHINE: Milling Machine (Large)

TOOLS:

Crane
Drills
Boring Bar

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Pick up B die shoe with crane.	
2.	Load on to mill.	
3.	Drill casting at areas as marked.	
4.	Bore holes to size as marked.	
5.	Off load casting and send back to die room.	



OPERATION NO: 0404

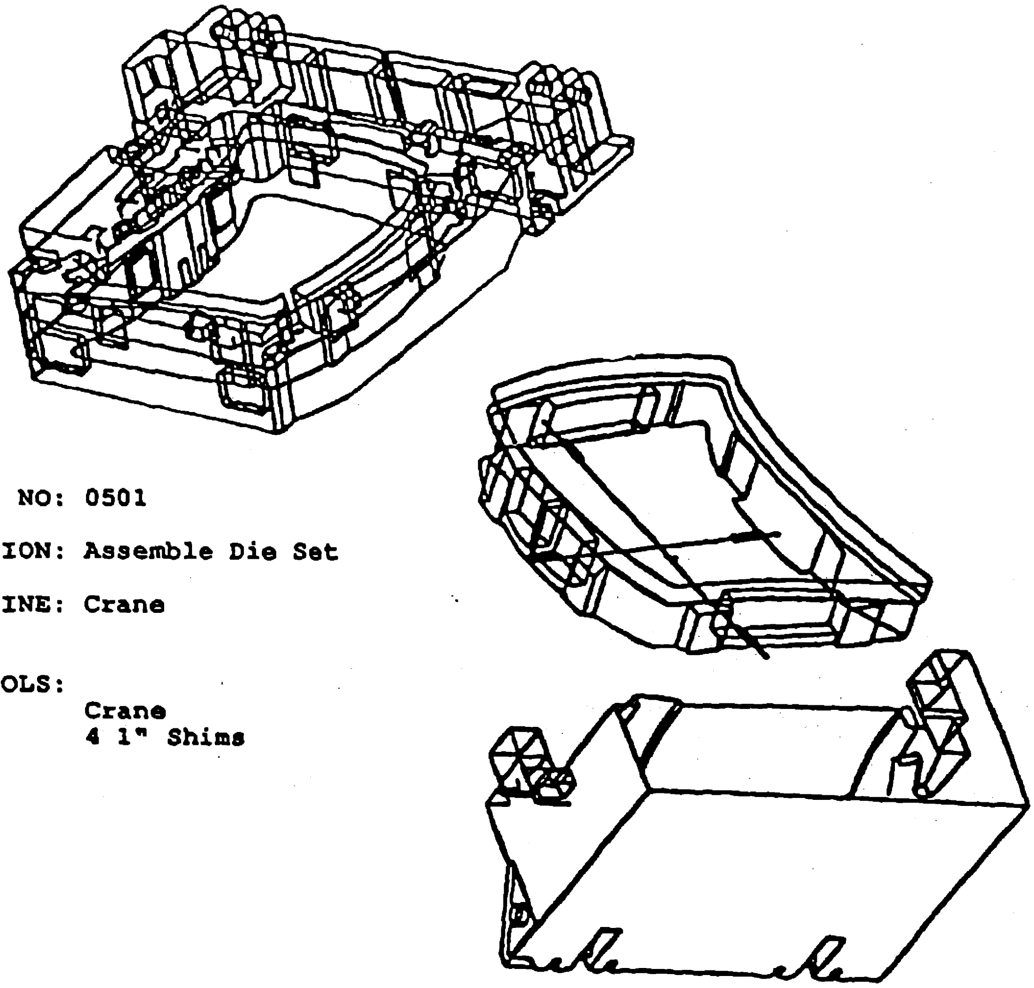
DESCRIPTION: Finish Ring and Cavity Surface

MACHINE: None

TOOLS:

- Hand Grinder
- Assorted Grinding Wheels
- Rubbing Stones
- Emery Cloth
- Files

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Cover cavity and binder with layout dye.	
2.	Hand grind parallel to machine cusps lines.	
3.	Leave witness marks on surface.	



OPERATION NO: 0501

DESCRIPTION: Assemble Die Set

MACHINE: Crane

TOOLS:
Crane
4 1" Shims

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Turn over A shoe with crane.	
2.	Position A shoe over B shoe, place shims on stop blocks.	
3.	Lower A shoe on to B shoe.	
4.	Lower A shoe until it bottoms on 1" shims on stop blocks.	

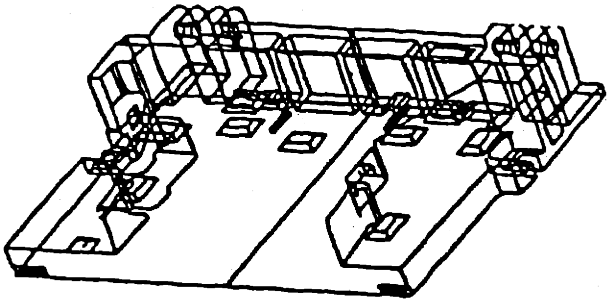
OPERATION NO: 0502

DESCRIPTION: Set Die

MACHINE: Die Setters

TOOLS:
Crane
HighLo

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load die set on HighLo with crane.	
2.	Send to tryout for die setting.	



A SHOE

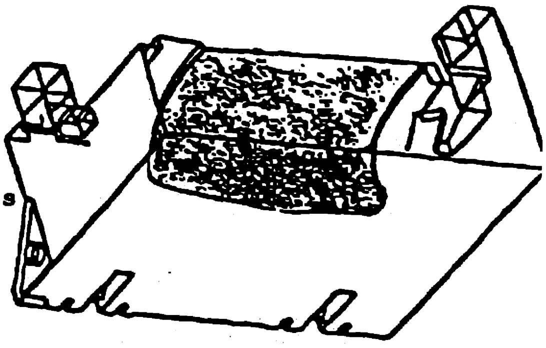
OPERATION NO: 0503

DESCRIPTION: Spot Cavity B Shoe Die To Die

MACHINE: Toggle Press

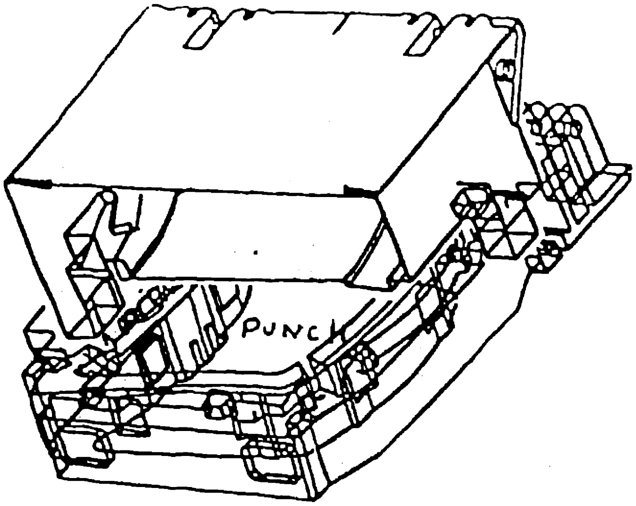
TOOLS:

Toggle Press
Spotting Blue
Hand Grinder
Assortment of Grinding Wheels



B SHOE

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Blue upper half of the die.	
2.	Inch press over and adjust ram until blue marks show on lower die.	
3.	Grind hard spots until permissible bearing is achieved	



OPERATION NO: 0504

DESCRIPTION: Stone Grind Marks

MACHINE: Toggle Press

TOOLS:

Rubbing Stones

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	After spotting die to die stone grind marks.	
2.	Clean die of grit from rubbing stones.	

OPERATION NO: 0505

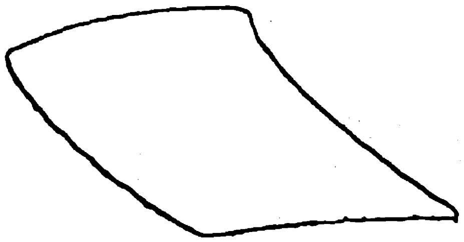
DESCRIPTION: Finish Stone and True Radii

MACHINE: Toggle Press

TOOLS:

Rubbing Stones
Emery Cloth
Files Hand
Radius Gauges

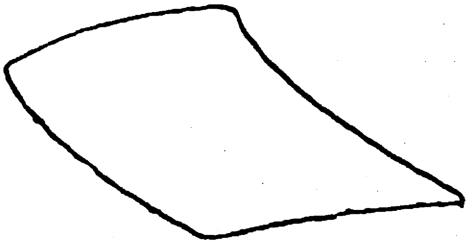
ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Stone out grind marks.	
2.	Check radii for proper size and work if need be.	
3.	Polish cavity and radii.	



OPERATION NO: 0506
DESCRIPTION: Qualify Panel
MACHINE: Toggle Press

TOOLS:
Sheet Metal

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Work die until panel is visually acceptable.	



OPERATION NO: 0507

DESCRIPTION: Line Die Aides

MACHINE: Toggle Press

TOOLS:
Sheel Metal

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Run 10 panels for line dies to be used as aides.	

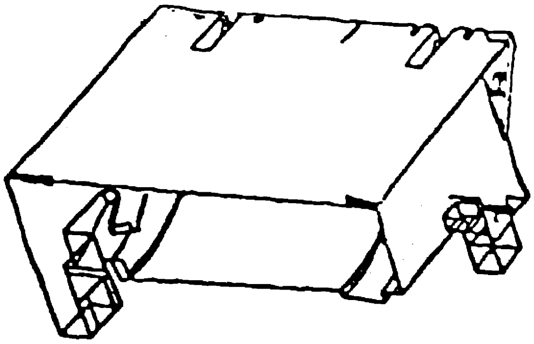
OPERATION NO: 0508

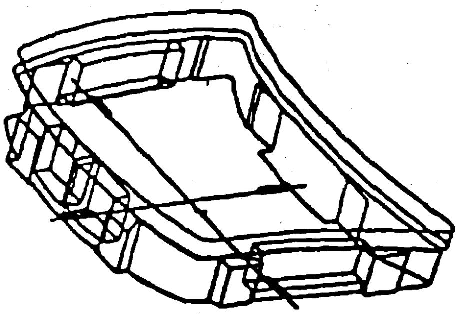
DESCRIPTION: Pull Die Set

MACHINE: Crane

TOOLS:
HighLo
Crane

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Unbolt die set from press bed and ram.	
2.	Pull die from press with HighLo.	
3.	Move die to die construction area.	



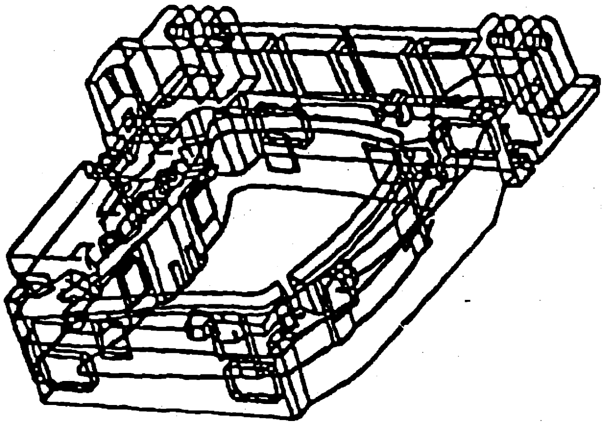


OPERATION NO: 0509

DESCRIPTION: Assemble Die Set

MACHINE: Crane

TOOLS:
Crane



ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Reassemble die set in run position.	

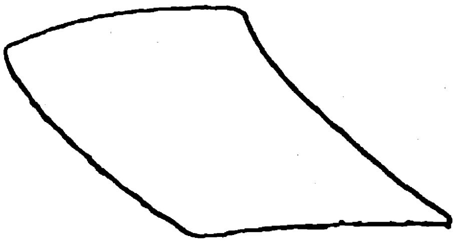
OPERATION NO: 0510

DESCRIPTION: Die Set

MACHINE: Crane

TOOLS:
Crane
HighLo

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load die set on HighLo with crane.	
2.	Send to tryout for die setting.	



OPERATION NO: 0511

DESCRIPTION: Panel Certification

MACHINE: Toggle Press

TOOLS:
Sheet Metal
R1 Fixture

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Run panel through die line.	
2.	Have panel inspected.	
3.	Panel must pass certification.	

OPERATION NO: 0512

DESCRIPTION: Die Viewer Approval

MACHINE: Press Line

TOOLS:
R1 Fixture

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Run panels for die viewer.	
2.	Panel run must be accepted by die viewer.	

OPERATION NO: 0513

DESCRIPTION: P1 and C1 Panels

MACHINE: Press Line

TOOLS:
R1 Fixture
Sheet Metal of Proper Gauge

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Run panels through die line for C1 and P1 panels.	

OPERATION NO: 0514

DESCRIPTION: Pull Die Set

MACHINE: Crane

TOOLS:
HighLo
Crane

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Unbolt die set from press bed and ram.	
2.	Pull die from press with HighLo.	
3.	Move die to die construction area.	

OPERATION NO: 0515

DESCRIPTION: Finalize Die Set

MACHINE: Crane

TOOLS:
Paint
Solvent
Grease

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Disassemble die set with crane.	
2.	Clean die set details.	
3.	Grease die set were needed.	
4.	Repaint areas as needed.	
5.	Reassemble die set.	

OPERATION NO: 0516

DESCRIPTION: Shipping

MACHINE: Semi-Truck

TOOLS:
Crane

ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Load die set on truck and ship to unit plant.	

Appendix C

Process Chart From an Independent Japanese Die Shop

WORK ORDER

ISSUE DATE 19-MAR-88	NEW/REISS	ORDER NO 119378	PAGE 1

FNO 9995	UNO	USER NAME	PART NAME PANEL HOOD OUTER

TOOL NAME DRAW (D/A)	OP/NO 1/4	PIECE UPR PUNCH	WORK BLOCK RB(<2000)

SHOP SCHEDULE BUCKETS 30/ 6 START 2/ 7 FIN (1)	LIST NO #04

ACTIVITY CODE & NAME 402 2ND RADIAL BORING

NO	WORK ELEMENT	STD H	TAR H	BAL H	ACTU
1	MILL KEY SLOT	1.2			
2	MILL DATUM FACE *	.4			
3	MIL SLID SUR PARTLY*	1.1			
4	MILL INSERT SET AREA	.4			
5	MIL SL AREA U&L SHOE	3.3			
6	BORE CENTERING HOLE	.3			
7	SET TOOL F MACHINING	1.6			
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
	(TOTAL)	8.3			

NOTE ACTUAL HR

/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H

PERSON CODE ☐☐☐☐☐ NAME ______ HR ①

PERSON CODE ☐☐☐☐☐ NAME ______ HR ②

ASSISTANCE ③

M/C HRS

M/C CODE ☐☐☐ NAME ______ ④

UNO U - ☐☐

DESIGN CHG HR ☐

REASON FOR DELAY ☐☐☐

ABNORMAL HR ☐

※HRS ① TO ④ CONTAIN DESIGN CHG HRS & ABNORMAL HRS.

FIN DATE ___/___

RESPONSIBLE ______

WORK ORDER

ISSUE DATE 19-MAR-88	NEW/REIS	ORDER NO 119378	PAGE 1

FNO 9995	UNO	USER NAME	PART NAME PANEL HOOD OUTER

TOOL NAME DRAW (D/A)	OP/NO 1/4	PIECE UPR PUNCH	WORK BLOCK RB(<2000)

SHOP SCHEDULE 30/ 6 START 2/ 7 FIN	BUCKETS (1)	LIST NO #04

ACTIVITY CODE & NAME 402 2ND RADIAL BORING

NO	WORK ELEMENT	STD H	TAR H	BAL H	ACTU
1	MILL KEY SLOT	1.2			
2	MILL DATUM FACE *	.4			
3	MIL SLID SUR PARTLY*	1.1			
4	MILL INSERT SET AREA	.4			
5	MIL SL AREA U&L SHOE	3.3			
6	BORE CENTERING HOLE	.3			
7	SET TOOL F MACHINING	1.6			
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
	(T O T A L)	8.3			

NOTE ACTUAL HR

/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H
/ H H	/ H H

PERSON CODE ☐☐☐☐☐ NAME ______ HR ①

PERSON CODE ☐☐☐☐☐ NAME ______ HR ②

ASSISTANCE ③

M/C HRS

M/C CODE ☐☐☐ NAME ______ ④

UNO U- ☐☐ DESIGN CHG HR ☐

REASON FOR DELAY ☐☐☐ ABNORMAL HR ☐

*HRS ① TO ④ CONTAIN DESIGN CHG HRS & ABNORMAL HRS.

FIN DATE ___/___

RESPONSIBLE ______

WORK ORDER

ISSUE DATE 19/ 3/88	NEW/REIS	W/ORDER NO 119380

FNO 9995	UNO	USER NAME	PART NAME PANEL HOOD OUTER

TOOL NAME DRAW (D/A)	OP/NO 1/4	WORK BLOCK DESIGN	SECTION
PERSON NO : : : :	NAME	OUTSIDE SOURCE	RESPONSIBLE

STANDARD SCHEDULE

	D/L DRWG	SCH DRWG	A. F. C. 1	FINL DRW	A. F. C. 2	FOML DRW
PLANNED	18/03 31/03	1/04 19/04	20/04 6/05	7/05 17/05	18/05 25/05	26/05 14/06
ACTUAL						

ACTIVITY 102	NAME SCHEME DRAWING	BUCKETS 5

	START DATE	CHECK DATE	PROGRES DATE	FIN DATE	FIN DAT CHG-1	FIN DAT CHG-2	HOUR	
							STD	TARG
PLANNED	1/04			19/04			94	
ACTUAL								

DESIGN CHG NO	TARG HR DES CH	DESIGN CHG NO	TARG HR DES CH
DESIGN CHG NO	TARG HR DES CH	DESIGN CHG NO	TARG HR DES

REASON FOR DELAY (DAYS)

REASON CODE	

REASON	DETAIL	DAYS

REASON FOR DELAY (HOURS)

REASON CODE	

REASON	DETAIL	HOURS

NOTE : WRITE CODE NO FOR MAJOR DELAYED REASON

WORK ORDER

ISSUE DATE 19-MAR-88	NEW/REIS	W/ORDER NO 119379

FNO 9995	UNO	USER NAME	PART NAME PANEL HOOD-OUTER

TOOL NAME DRAW (D/A)	OP/NO 1/4	PIECE COMMON DIE	

WORK BLOCK PURCHASE	PERSON NO	NAME	VENDOR

(PIECE NAME)

STANDARD SCHEDULE

ACTIVITY CODE 201	ACTIVITY NAME FULL MOLD F CAST MFG
BUCKETS 5	

	START DATE	REPORT DATE-1	REPORT DATE-2	REPORT DATE-3	REPORT DATE-4
PLAND	26/05	9/06			
ACTUL					
DELAY					

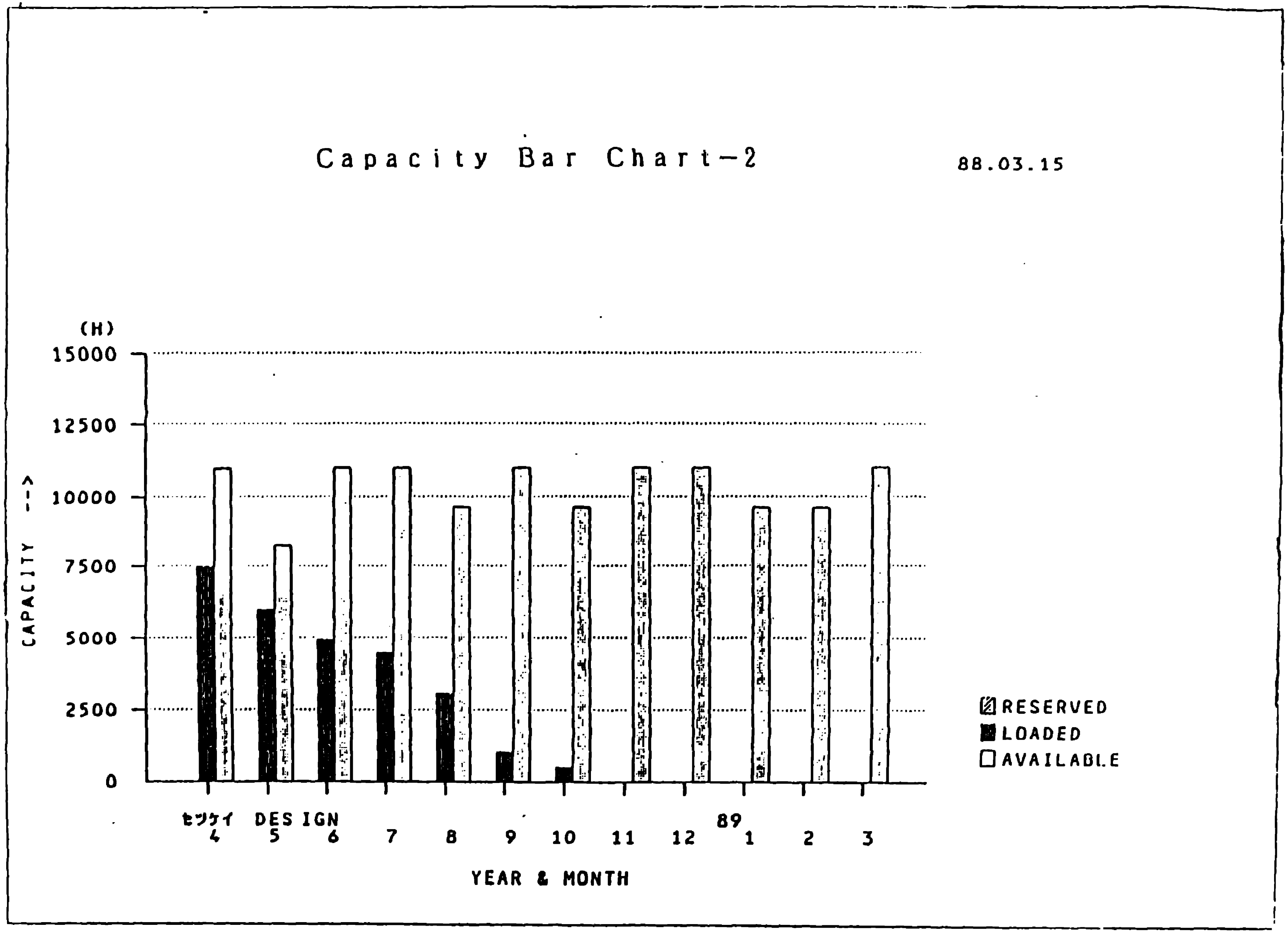
REPORT DATE-5	REPORT DATE-6	REPORT DATE-7

REASON FOR DELAY

REASON CODE	

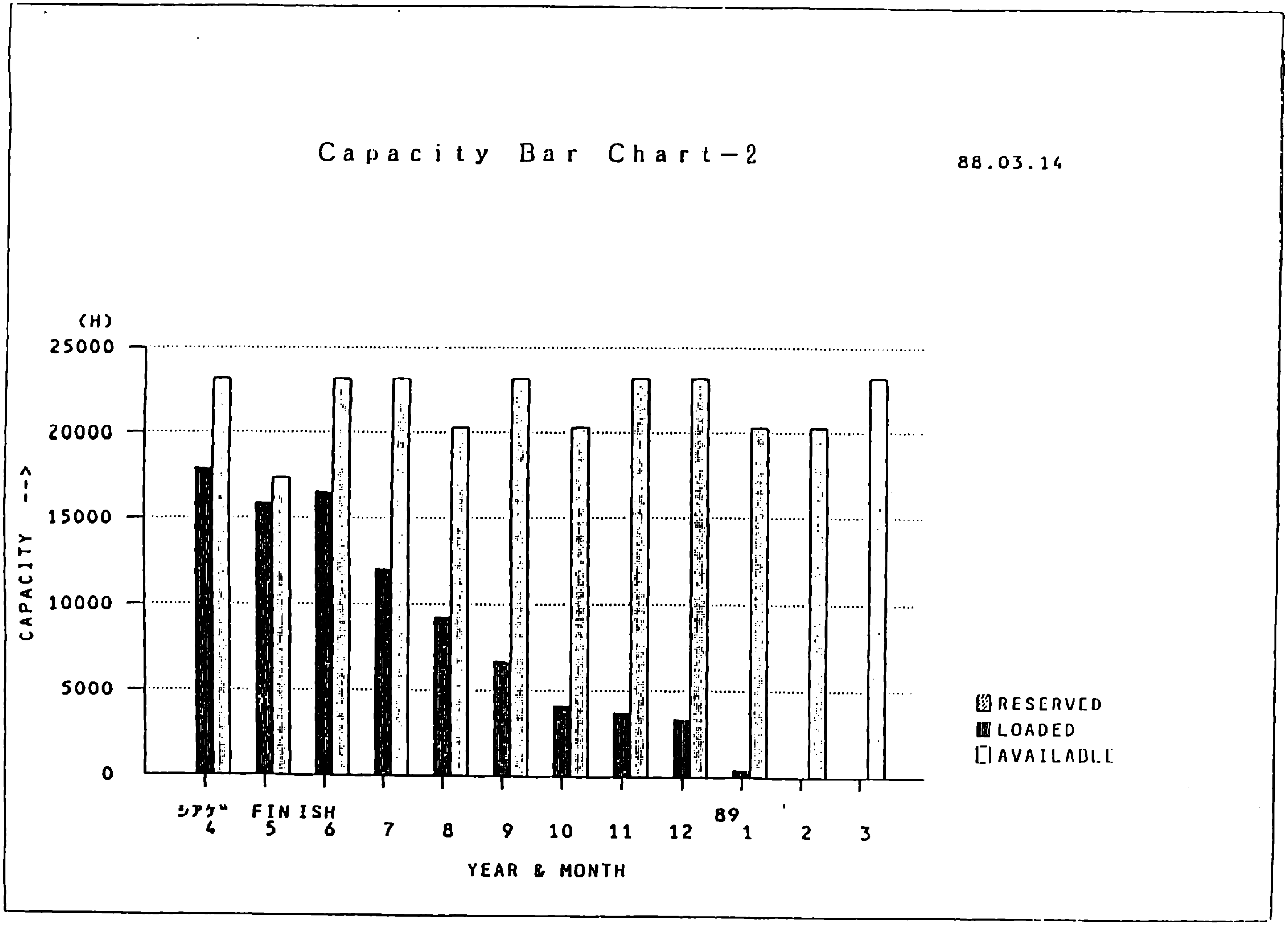
REASON	DETAIL

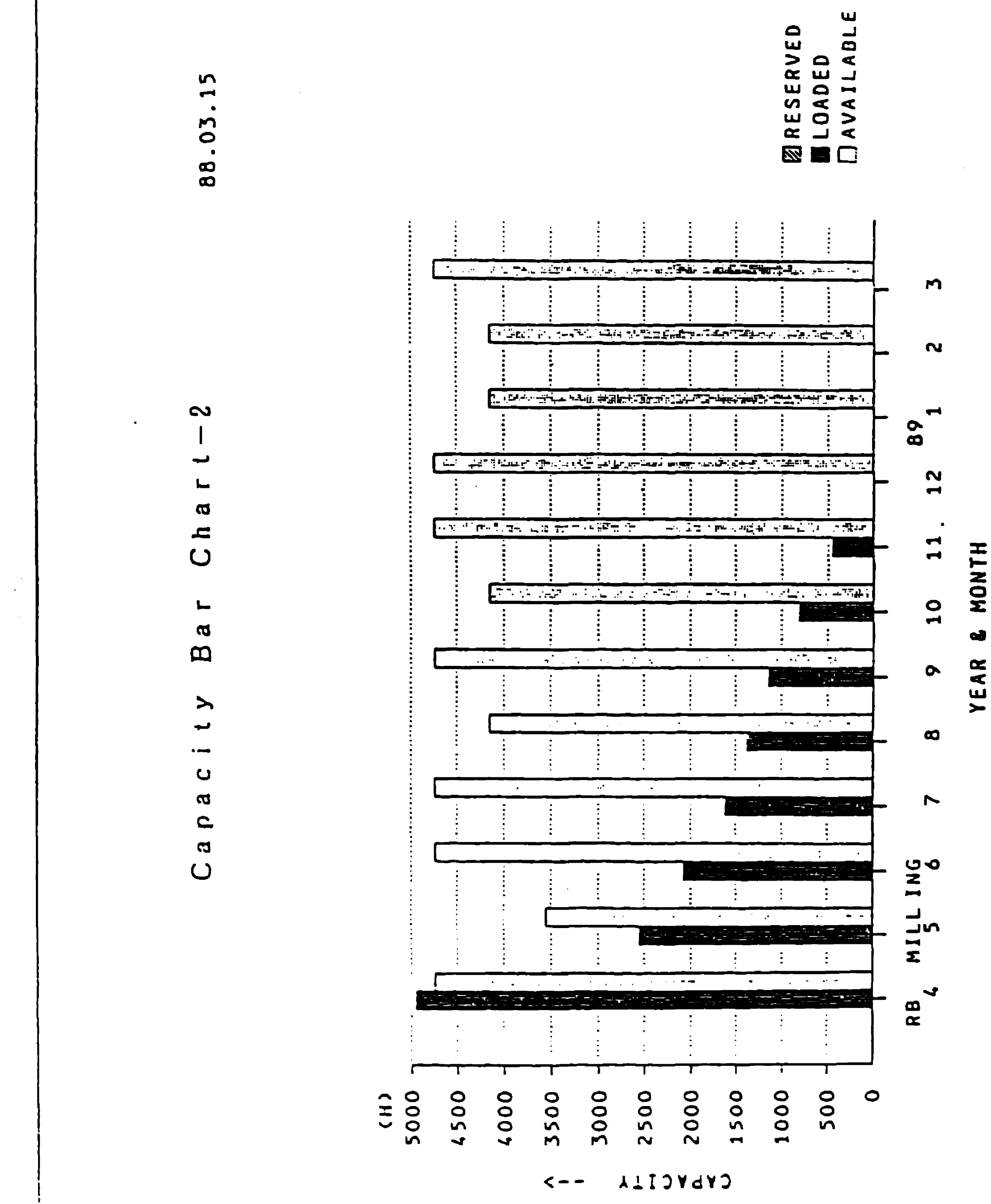
NOTE: WRITE CODE NO FOR MAJOR DELAYED REASON.



Capacity Bar Chart−2

88.03.15


Capacity Bar Chart−2
88.03.14
(H)
25000
20000
15000
10000
5000
0
CAPACITY -->
シアゲ
FINISH
4
5
6
7
8
9
10
11
12
89
1
2
3
YEAR & MONTH
▨ RESERVED
■ LOADED
☐ AVAILABLE



Capacity Bar Chart-2
88.03.15
RESERVED
LOADED
AVAILABLE
CAPACITY -->
(H)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
RB MILLING
4
5
6
7
8
9
10
11
12
89
1
2
3
YEAR & MONTH