Cost and Lead Time Reduction in the Manufacture of Injection Molding Tools

by

Bryan K. Parks

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Signature of Author_______________________________
Department of Mechanical Engineering
Department of Management
May 6, 1994

Certified by_______________________________
Alexander H. Slocum
Associate Professor of Mechanical Engineering

Certified by_______________________________
Stephen C. Graves
Professor of Management Sciences

Accepted by_______________________________
Ain A. Sonin
Chairman, Graduate Committee

Accepted by_______________________________
Jeffrey A. Barks
Associate Dean, Sloan Master's and Bachelor's Programs

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Abstract

New Product Development in many consumer oriented manufacturing companies is increasingly being looked to as a source of competitive advantage. In the current global market place, the ability of an organization to introduce new products at ever faster rates and to do so at a lower cost each time has become important for long term survival. As a result, many companies are focusing attention and resources to examine their traditional approach to product development. In this process each aspect of the product development process is being scrutinized in an effort to eliminate waste of both time and dollars.

For some organizations, one significant component of the new product development process is the acquisition of tooling required to manufacture the individual piece parts of the product. While some industries, such as the auto industry which invests large sums of money into the development and manufacture of progressive dies for automobile panels, have long recognized the costs incurred for tooling, other industries are just beginning to focus attention on this opportunity. For products with a high content of precision injection molded plastic parts, the cost of plastic injection molds can represent a substantial portion of the overall up front development budget. Furthermore, the manufacture and modification of such tools during development often falls on the critical path of the product development process.

The goal of this thesis project was to examine the tooling process of a large corporation engaged in the manufacture of products with a relatively high plastic part count and search for opportunities for the reduction of both cost and time in the manufacture or acquisition of these tools. The corporation studied has the capability to perform complete product design, tooling design, and tooling manufacture. However, these capabilities are not integrated within the organization. A goal of the project was to identify issues that affect either the cost or time required to obtain production ready tooling and focus on a limited set of these issues to determine long term potential benefits.

This thesis examines the tooling process and the relationships between the constituencies involved. It demonstrates two specific opportunities for improvement and illustrates that much of the difficulty in making the improvements come not from the technology issues involved but rather from the need to change organizational mental models and from the need to develop greater partnering efforts between the various parties involved in the product development process.

Thesis Supervisors: Steven C. Graves
Professor of Management Science

Alexander H. Slocum
Associate Professor of Mechanical Engineering

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1 INTRODUCTION

1.1 The Tooling Problem

The fundamental issue that prompted this thesis project was the perception by managers within the Eastman Kodak Equipment Manufacturing Division (KEMD) that their Japanese competitors have an advantage in the introduction of new products. Through benchmarking and contract arrangements, whereby some cameras sold under the Kodak label are made by Far East suppliers, it has become apparent that Kodak's foreign competitors are able to acquire tooling for injection molding at a lower cost and at a faster pace than Kodak can in the United States. This perception, along with the facts that on some past programs tooling for a new product has accounted for upwards of 40% of the up front development cost of the product and the acquisition of such tooling usually falls on the critical path for new product introduction, has prompted KEMD's leadership to take a hard look at the situation. This thesis project focused on precision molded plastic parts for KEMD and is only one small part of a series of actions being taken to explore this issue and root out opportunities to improve performance.

1.2 History of the Problem

The Past Environment

It is useful to briefly touch on Kodak's past history with regard to equipment in an effort to understand how their past successes have led to particular ways of thinking and acting. Over the years, Kodak has grown into a large company with a high degree of vertical integration. The success of the company has been its growth in film sales which have provided the high margins traditionally enjoyed by the company. Equipment to support these activities, while certainly providing an opportunity for additional profit, have not traditionally been looked at as a revenue generating proposition, but rather as a means to stimulate increased film sales which is perceived as the real engine of growth.[1]

Because of its vertical integration, Kodak early on became a supplier of equipment for its consumable products. In its role as an equipment supplier, Kodak has traditionally focused on the mass consumer market to try and make picture taking a part of everyday life. Over the years it has developed new platforms to stimulate demand for its core product (film) such as the 126 cartridge, the 110 cartridge, and disc film. Accompanying each of these new platforms has been a huge equipment program to provide cameras for using the film types. This led to the need for a large manufacturing capability including plastic injection molding and tool building which reached its peak during the early 1980's with the disc program. Remnants of this vast capacity are still evident today at Kodak.

The end of the disc program, coinciding with Kodak's exit from the instant film business after Polaroid's lawsuit, left Kodak with no large camera manufacturing programs, and a huge, costly equipment manufacturing infrastructure. However, the impact of thinking in terms of big programs is still very evident at Kodak and it is common to hear people refer to the "disc days."

The Current Competitive Situation

The mid-1980's brought several changes to the competitive situation in both film and cameras. Competition from overseas film suppliers, notably Fuji, led to new competitive pressures on Kodak's core business and reduced margins. At the same time, 135 film began to grow as the dominate film type and other companies, predominately Japanese, began supplying low cost cameras with an increasing array of features to Kodak's traditional camera market.

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[1] This is much the same as the razor handle- razor blade phenomenon. Blades not handles, provide the long term revenue source.

These changes in the competitive situation forced two major changes on Kodak. First, Kodak's leadership recognized that film and other consumable products could no longer subsidize equipment manufacturing. It simply made no sense when other equipment manufacturer's were willing to supply the market demand for cameras and make a profit doing so. As a result, the company chose a decentralization strategy and created a Line of Business (LOB) structure.[2] In the new scheme, profitability became the LOB's responsibility and non profitable LOB's faced the prospect of extinction. The second change was that Kodak was forced to compete in camera manufacturing with a variety of manufacturers concentrated in the Far East. The second change has been made all the more difficult because of the proliferation of new features offered by other suppliers. As a result the company needs to cater to a variety of markets for which a single camera model with traditionally high volumes will no longer suffice.

Changes and the Roadblock to Success

The changes in the business environment has forced Kodak to reexamine the way it operates relative to equipment manufacturing and it has forced managers to seek different ways of operating. Some of the behavior changes are focused on short term efforts to reduce cost, such as using outside manufacturers to produce many of their cameras and seeking low cost labor areas in which to build others. However, other efforts seem to reflect a commitment to seriously change the existing organization. An example of such a change is the introduction of a structured product development methodology called the Kodak Equipment Commercialization Process (KECP).

With regards to tooling, the changes in the competitive environment are forcing new product development teams and manufacturing engineers to approach the tooling problem differently. Costly and time consuming tooling strategies can no longer be tolerated since they can potentially render a new product unjustifiable on a cost basis. However, to change, some of the obstacles that will have to be addressed are the legacy

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[2] The impact of the LOB structure will be explained in Chapter 2.

of the past, the mental models, and the attitudes that linger and continue to color the way the organization thinks. These issues are potentially more difficult to deal with than problems with a technological root.

1.3 Introduction to Thesis Chapters

This thesis will demonstrate that there are opportunities to improve the tooling process within Eastman Kodak, that many of these opportunities are already recognized, but that the mental models and attitudes within the organization preclude the cooperation required to achieve these benefits. Chapter 1 provides a brief statement of the problem and an understanding of the historical and current competitive forces driving change within KEMD. Chapter 2 introduces the subject of tooling and introduces terminology that will be used in the remainder of the thesis. In addition, this chapter sketches a picture of how the tooling process works in the organization. Chapter 3 focuses on a specific opportunity, family tools, which can be used to reduce tooling cost under certain circumstances. Through a case example, the potential benefits of this technique are illustrated. Chapter 4 examines an organizational process change that uses teams to stimulate the move toward concurrent engineering. The final conclusions are presented in Chapter 5 along with recommendations for pursuing future cost and lead time reductions in the tooling process.

1.4 Methodology of the Project

This thesis is the product of observations made and research done during a six month internship at Eastman Kodak. During this time the author worked closely with the manufacturing engineers in a product development group as well as the tooling personnel in the Precision Plastics Department. The purpose of the project was to explore opportunities for cost and lead time reduction in the acquisition of tools for injection molding. It was made clear to the author from the outset that the organization already recognized that there were a number of small actions that might be taken to help meet their goal. However, they characterized what they were looking for as "outside thinking" in order to try and generate solutions to deal with the labor cost advantage which they felt existed in the Far East.

The approach taken was one of observation, interview, and inquiry. During the first part of the project, the author explored some of the issues affecting how the tooling process is done at Kodak. This was done by reviewing relevant literature; interviewing knowledgeable subjects within the organization in both the design area and in the Precision Plastics Division; and getting involved to observe the issues first hand. The second part of the project involved selecting two opportunities for further examination (family tools and mini-teams) and working with a group of people to understand how these opportunities could be exploited.

2 TOOLING AT EASTMAN KODAK

2.1 Chapter Introduction

The intent of this chapter is to provide the reader with a background on the nomenclature that will be used throughout the remainder of this document. In addition, basic background information is provided regarding the process of making and acquiring tooling within the subject company. The information provided is not intended to be a comprehensive primer on either injection molding or tool manufacturing but rather is intended to provide a sufficient introduction such that the reader who might be unfamiliar with the subject or the organization will be able to follow the flow of information presented in subsequent chapters.

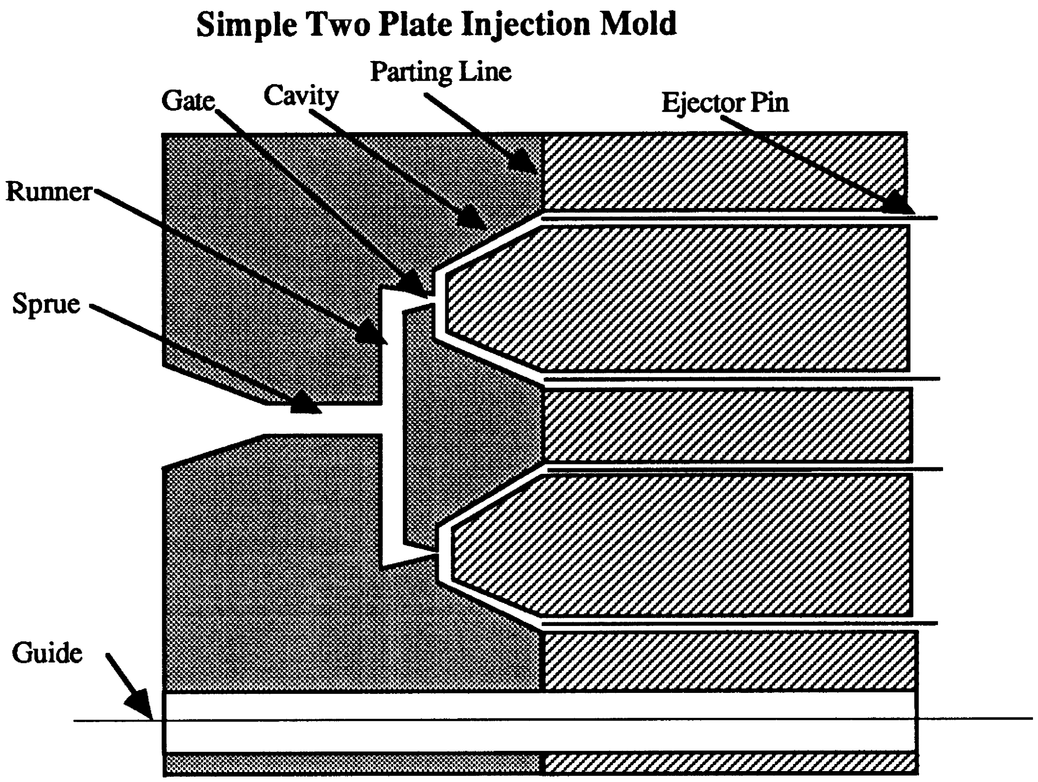
2.2 Description of Injection Molding and the Tools for Injection Molding

Injection molding is a process by which plastic parts are made. It is essentially a four step process encompassing a melting process, an injection process, a cooling process, and an ejection process. In the first step (melting), raw material in the form of small plastic pellets or granules are fed from a hopper into a heated cylinder with a rotating screw. The heat along with the plasticizing action of the screw melts the plastic pellets. In the injection step, the molten plastic is forced under pressure into a mold cavity where it forms the shape of the part being made. During the cooling process, the plastic is held under pressure in the mold and allowed to cool. Heat is transferred from the plastic material through the walls of the mold cavity to cooling water circulating through water lines contained in the mold base. In the final step of the process, once the newly formed part has cooled sufficiently to retain its shape, the mold halves are opened and the part is ejected from the mold.

Modern injection molding machinery is very complex, incorporating microprocessors and computers to control a variety of factors including the temperature in various zones of the machine, injection speed, injection pressure, holding times, and numerous other parameters vital to the creation of a good part. Molding machines are rated on a number of criteria but most commonly by tonnage. The tonnage rating is the force required to keep the two halves of the mold together during the injection process and can range from small bench top machines with a rating of several tons to huge machines rated at several thousand tons for making very large parts. The critical parameter in a mold which drives the clamping tonnage required is the cross-sectional area of the part projected to the plane of the mold parting line.

Injection molds themselves consist of a variety of components as shown in the simple mold depicted in Figure 2.2. At a minimum, a mold will consist of two base halves, two cavity halves, a runner system, a sprue system, and a gate. Most molds will also have cooling channels, ejector pins, and be of a two or three plate design. A two plate design is the simplest. In this type of mold the cooled part with its attached runner system are ejected as a unit. In a three plate design, the runner and part are separated by a mechanical action during ejection. More complex molds may have side draws, kickers, unscrewing mandrels, or other devices to allow for parts with undercuts, internal threads, external threads, and other complex part features.

The number of cavities in a mold determines how many parts will be made during each cycle between successive mold openings. Molds can be built with either one cavity or a multitude of cavities. For very complex or very large parts it is not unusual to have a single cavity mold. However, for simple parts such as a plastic bottle cap, molds with over sixty cavities are not uncommon. Cooling time is one of the primary drivers for determining mold cycle times. Since cooling time is most directly influenced by the maximum thickness of the part produced rather than the number of cavities in the mold, the output of the molding press is typically increased by using molds with a higher number of cavities.



Simple Two Plate Injection Mold

Figure 2.2

The concept of runner systems is also important to this discussion. Molten plastic enters the mold through what is known as the sprue opening. From there it enters a channel or series of channels as it flows towards the cavities. This channel system is called the runner system. In a cold runner system, when parts are ejected the runner is also ejected. There are hot runner systems which keep the plastic in the runner channels molten throughout the molding cycle. In this case the runner is not ejected and the production of scrap is minimized. These systems are more expensive than cold runners however and need to be justified on a case by case basis.

2.3 Tool Manufacturing

The actual molds described in Section 2.2 (or tools as they are frequently called) are manufactured via a multistep process. The major steps, shown in Figure 2.3 in a very simplified form, are: tool design, individual tool part fabrication, tool assembly, tool try out and tune up. The process usually begins with the release of a part drawing to the tool manufacturer. Although historically this has been a paper based drawing, increasing use of computer aided design (CAD) tools has made electronic media transfer the preferred choice amongst the more advanced tooling houses. During the tool design phase, the mold base, cavity layout, and parting line are decided. At this point, the gating system is decided upon, the waterlines are located, and the ejector pin layout are determined. Detailed drawings of the proposed tool are then produced. At the tail end of this process, the layout of electromagnetic discharge machine electrode patterns (for the creation of individual part features within the mold) is accomplished.

Major Steps in the Manufacture of an Injection Mold

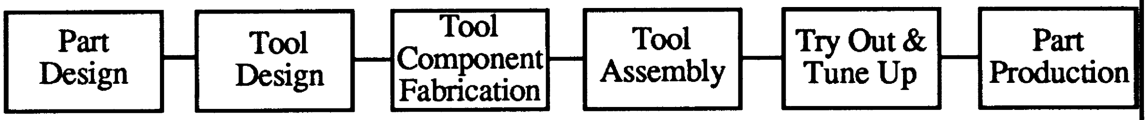


Figure 2.3

In the second step of the process, the individual piece parts of the mold are manufactured. The mold base is often purchased from a specialty supplier. If possible, tool makers prefer to use a standard base as this reduces both the procurement time and cost. However, custom bases can be ordered for more complex parts which cannot be accommodated by a standard base. The remaining parts of the mold, including the cavity and the core, are manufactured using a variety of processes. Because of the nature and size of features required on a particular part, traditional milling is often not suitable for creating these features directly (for instance, the creation of sharp 90 degree inside corners). As a result, three of the most common processes employed are surface grinding, wire electromagnetic discharge machining (EDM), and plunge EDM.[3]

The use of plunge EDM creates additional production steps due the need to fabricate the electrodes consumed in this process. These copper or graphite electrodes are commonly made by milling and grinding to form the appropriate shape. For the creation of a particular part feature, a series of electrodes may be required to accomplish the rough burns as well as the final burn. In addition, the material used for fabrication of the mold can result in additional processing steps. Tools designed for long life can be made of soft steels which are hardened after the majority of the machining is completed. Due to dimensional changes in the cavity material which occur during the hardening process, these parts often have to under go further finishing machining prior to the assembly step.

Once all the parts for the mold have been fabricated, they are built up into the completed mold. Depending upon the quality of the previous work and the tolerances achieved during machining of the individual components, this can be a time consuming step.[4] Parts that are incorrect are identified and are corrected immediately so that the fitting process can continue. This requires dedicated personnel and equipment, thus increasing the cost of the finished mold.

Tune up and tryout is the final step in the production of the mold. At this point, the mold is mounted into a press and cycled manually to ensure proper operation of the mold. Once the mechanical operation of the mold is verified, it is run to produce parts. The initial samples are compared to the desired part specifications via an inspection process to determine what modifications may be required within the mold. In a multi-cavity mold, samples from each cavity will be examined to determine what intercavity variations exist that need to be eliminated. Again, depending on the quality of the work,

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[3] EDM uses electromagnetic discharges, or arcs, between the material being machined and the electrode to remove material. Although the intent is only to remove material from the object being machined, the electrodes are also slowly consumed in this process.

[4] Data collected on the internship would indicate that assembly and fitting can account for 13 to 25% of the total time involved in tool manufacturing.

tolerances held, and the accuracy of the previous work, the tune up phase has the potential to be a time consuming, iterative phase.

The previous discussion is intended to illustrate the complex nature of the tool manufacturing process. The advent of CAD, electronic information exchange, and numerical control for machining equipment has provided opportunities to speed up the process as well as reduce the incidence of careless errors. Furthermore, new materials and manufacturing process continue to offer promising opportunities to improve this process. Nevertheless, tool manufacturing is still a costly, time consuming part of the overall product development process.

2.4 Constituencies Involved at Kodak

Within Kodak, the process of proceeding from the initial part concept, through tooling, to the establishment of a stream of acceptable quality parts involves a variety of people in various parts of the organization. To better understand this process, a brief description of the applicable parts of the organizational structure will be provided in this section. To aid in understanding the roles that the various constituencies involved play during this process, a description of each is also provided.

Within the LOB structure of KEMD, there are various organizations devoted to maintaining particular products. As an example, we will consider Consumer Imaging although we could have easily have chosen another group such as Copy Products. Within Consumer Imaging there are several sub groups tasked with providing support to existing products (continuing engineering teams) and others working on derivative or completely new products (product development teams). The product development teams generate the requirement for new plastic parts. It is also this group that designs the parts and ultimately takes responsibility for developing a reliable stream of parts prior to turning the project over to a continuing engineering team.

While product and part design resides within the product development team, the actual manufacturing capability is in what is informally known within KEMD as the "core." The core was basically all the manufacturing capability that was left over once the LOB concept was implemented. The core is divided up into several areas including Electronic Products, Optical Products, and Mechanical Products. The Precision Plastics Department is a part of Mechanical Products and has the capability to provide full service support for plastic parts production. This includes tool engineering, design, manufacturing, maintenance, and part production.

The relationship between the various product development teams and the Precision Plastics Department is one of customer and supplier. In fact while there is a strong preference from management to keep work in house and "load the factory," core often competes with outside vendors for work that the product development teams need to have done. This has tended to be a historical source of tension within the organization. The product development teams voice complaints that they are pressured into working with the core even if the core is not cost competitive with outside vendors. The core, on the other hand, feels that the product development teams have unrealistic expectations and that they (the product development teams) take advantage of the fact that the core is a captive supplier. At the time of this study, this tension was very evident due to layoff concerns.

Within the product development teams there are three groups of people involved in the development of parts and tools: part engineers,[5] part designers, and manufacturing engineers. The part engineers are usually formally trained engineers responsible for some subsystem of the product under development. They work with the designers in the design and analysis of individual parts. Part designers are, for the most part, technically inclined individuals who have undergone some amount of formal engineering schooling but are

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[5] Part engineers are actually known as design engineers. However, when used, this terminology seems to cause confusion due to the similarity of the title to the part designers. To avoid this, design engineers will be referred to throughout this document as part engineers.

not degreed engineers. They are particularly adept at designing with CAD tools and often do a great deal of the detail design work for individual parts. The manufacturing engineers are ultimately responsible for being able to ensure that the individual parts are manufacturable. These individuals come from a wide variety of backgrounds. Many are formally trained engineers but others gained their experience as skilled tradespeople in other parts of the organization. Their function is to serve as a liaison between the individuals doing the actual design work and the suppliers (often, but certainly not exclusively, other Kodak departments) who will develop tooling or who will produce the parts.

Within Precision Plastics there are four principle groups of people who are involved in the tooling process: tool engineers, tool designers, lead tool makers, and process engineers. These people are supported by other individuals such as the NC programmers, skilled machinists, tool makers, and injection molding operators.

Tool engineers serve as the primary point of contact for customers seeking support in the area of tooling. They work with the customers (product development teams) to determine the best tooling solution given the customers' designs, target volumes, material specifications, and other requirements. In addition, they serve as the formal liaison between the customers and other members of the precision plastics group. For the most part, the tool engineers are former tool makers or designers who have attained their engineering acumen through skill development and practical experience. However there are a limited number of formally trained engineers who work in this capacity.

Tool designers are responsible for the detailed work of creating engineering drawings for a workable tool. They are skilled in the use of CAD tools and in practice do much of the detailed design work for the tools themselves. In many ways they are analogous to the part designers on the product development teams both in terms of function and background. Most of the tool designers are technically oriented individuals with a limited amount of formal engineering training.

The lead tool makers are skilled trades persons who have a great deal of experience in building tools. These people are responsible for taking the tool designs from the tool designers and turning them into finished tools. In doing this, they direct the efforts of the other skilled trades people in the tooling area including the machinists, EDM operators, NC programmers and others. Within the organization, their function has come to be viewed as a high leverage point in the process for speeding up the tooling process. As a result, a great deal of effort has been invested in this group in terms of skills upgrading and project management training. Within the organization, there is a new term being used that more accurately describes this group: computer aided toolmakers (CATS).

The process engineering group or plastics engineers, as they are frequently called, are responsible for verifying that the new tool functions properly. In this capacity they perform the initial setup of the tool and generate the processing windows that will allow the production of parts which meet the design specifications. For the most part these individuals are former technicians who have a great deal of "hands on" molding experience.

There are several other groups that sometimes get involved in the development of new parts and associated tooling. These groups include the model shop and the measurements shop. However, the groups that have been described in the preceding discussion are the principle players in the process. In the following section, information flows and the methods of interaction between the various functions will be described.

2.5 Procurement Methodology

The interactions and communication paths that have traditionally occurred during the tooling process are shown in a simplified form in Figure 2.5. As shown in the figure, the initial linkages are within the product development team and involve the part engineer, the part designers, and the manufacturing engineers. Early in the "life" of a new mechanical part, very little information is available regarding the part or how it will be made. Therefore, tooling receives little attention. At this point, it is usually only known that the part will be metallic or plastic.

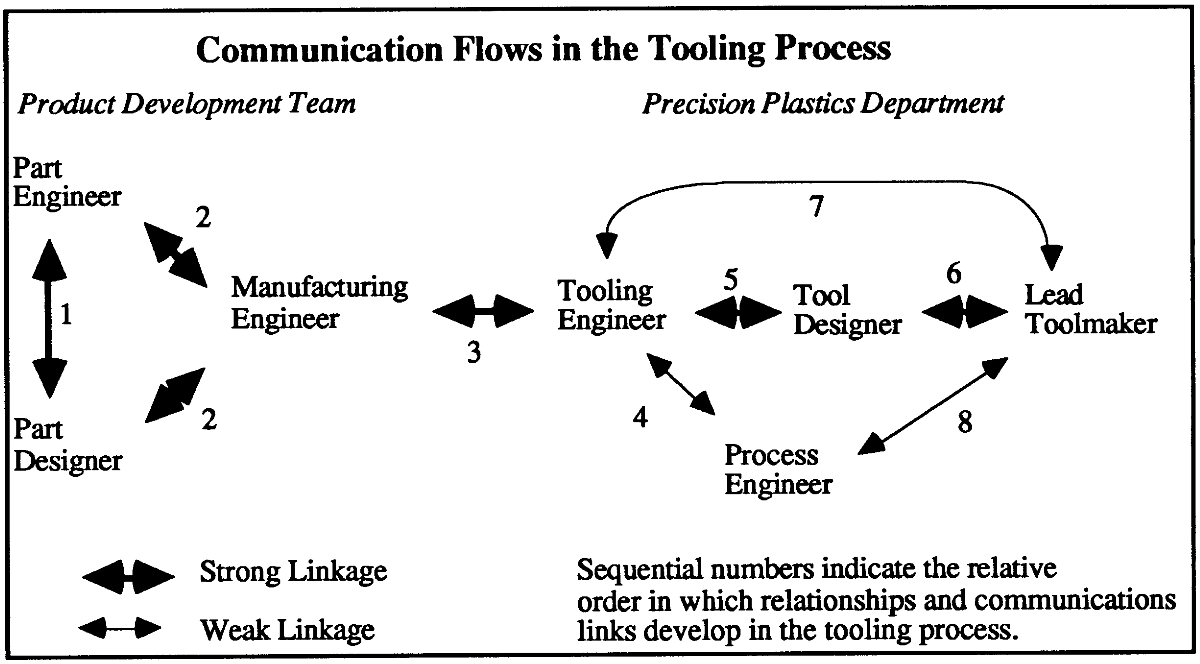

Figure 2.5

Once it becomes evident that the part is to be injection molded and a rough idea has developed regarding the part's size, shape, and target volumes, a dialogue is initiated between the manufacturing engineer and the tooling engineer. This is a two way dialogue and is the first opportunity that the tooling community has to provide input to the development process. At this point, the objective is simply to verify the feasibility of using injection molding as a manufacturing process for the part, to estimate the number of cavities required to produce sufficient volumes of the part, and to get an order of magnitude estimate for what the tool might cost. In order to do this, estimates are made of certain parameters such as mold cycle time. Mold cycle time and other parameter estimates are usually done on the basis of experience and past history with similar parts.

In practice there is no formally established procedure used universally by the Precision Plastics Department to make these estimates.

The dialogue between the manufacturing engineer and the tool engineer is the first stage during which tradeoffs begin to be evaluated. These tradeoffs include such issues as initial tool cost versus production part cost, tool cost versus tool life, tool cost versus part quality, financial risk versus tool cost, part variation versus the need for multicavities, as well as other issues. In considering these issues a number of factors begin to be considered. Some of these factors are specific to the part being made such as surface finish requirements, raw materials, requirements for painting/secondary finishing, tolerances, part complexity, size, need for prototype parts, and the probability of future changes to individual part features. Others are operational factors such as where the part is to be made, how many production locations will exist, the injection molding machines available, projected volumes, product launch volumes required, resources available, budget constraints, planned program life, and project schedules/time lines. While not all of these factors are dealt with immediately, they will be addressed as the development project proceeds and the milestones are reached that signify the need to begin tool construction. In seeking to address some of these issues a relationship begins to grow between the tool engineer and a process engineer. Initially this is a one way relationship in which the tool engineer seeks expertise in particular areas from the process engineer.

Once a workable design has been achieved, even though there is future risk that it may change, the drawings[6] are released to the tool room to begin design of the tool. The tool engineer is responsible for determining the basic concept regarding how the tool is to be constructed and provides that information to a tool designer. Because the tool engineer may work with a multitude of parts at any given time, but designers will normally focus intensely on only one or two tools at a time, the engineer will interface with several designers at any given time. As questions arise or problems are unearthed

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[6] As noted earlier, the environment within the subject company has encouraged the movement towards a paperless design process. Thus, the "drawing" is really an electronic CAD file.

during the detailed design phase, information flows back and forth between the tool designer and the part designer via the manufacturing engineer and the tool engineer.

The tool design does not need to be complete prior to the lead tool maker commencing work. It is not unusual for part of the design, the mold base layout and construction details for instance, to be passed on to the lead tool maker from the tool designer. In fact, for very complex tools, due to the lead times involved for obtaining custom mold bases, the tool design is normally passed on to the tool maker in stages. Immediately after receiving the design, the lead tool maker will work exclusively with the tool designer in order to understand the intricacies of the design. As work progresses however, the tool designer's role is diminished and the tool maker will increasingly direct questions and clarification issues to the tool engineer. If required, these are in turn directed to the development team personnel through the manufacturing engineer.

Once the tool is built, it is turned over to the process engineer to determine its functionality and ability to produce parts meeting the design specifications. First run parts are subjected to a detailed measuring process called a Tool Inspection Report (TIR). The purpose of the TIR is to measure 100% of the dimensions on a single part to determine if there are any deviations from the intended design. Later in the process, Statistical Tool Inspection Reports (STIR's) are done to verify that the tool and process are capable of manufacturing parts to the predetermined quality standards. Throughout this inspection and rework process (commonly called tune up and tryout) the tool engineer, process engineer, and tool maker work together to determine which discrepancies should be fixed by altering the process (often a designed experiment will be conducted to try and correct the noted defect without adversely affecting other critical dimensions) or by altering the actual dimensions of the tool.

During tool construction as well as during tune up and try out, the design team may be making design changes which affect the part and consequently the tool. Traditionally these changes are forwarded to the tool maker via the same information channels that have already been identified. Changes can either come in the form of a continuous trickle of changes or as batches of changes. How the change process is managed is usually decided jointly by the manufacturing engineer and the tool engineer. Once the change process has been completed and the specified production quality levels are consistently met as verified by statistical sampling, the responsibility for the tool shifts from the manufacturing engineer to the operations department at the location(s) the mold is to be run.

While this discussion is illustrative of the general process within the subject company, the process wouldn't differ much in terms of communications flows were an outside tool supplier involved. Communications regarding the part design would still flow through the manufacturing engineer. Outside suppliers are frequently used by Kodak and the Precision Plastics Department on a subcontract type basis. These suppliers are used for specialized work or to reduce queuing delay for certain pieces of equipment during periods of heavy activity at Kodak.

2.6 Evaluation of Current Process

The process outlined in the preceding sections has several notable strengths and weaknesses. These have been identified in Table 2.6 and are discussed in more detail in this section. Where appropriate, comparisons will be made between the Kodak process and the process followed by a Japanese competitor.

Summary Assessment of Current Process

Strengths	Weaknesses
Simple linear process	Slow process
Flexible with regards to design changes	Costly tools
Produces a durable, high quality tool	Attention focused on tool, not the parts
Maintains a close proximity to customer	Tendency towards poor documentation
Ensures a continued "in-house" expertise	Inefficient use of resources

Table 2.6

The prime strengths of the process as shown in Table 2.6 are its simplicity, its closeness to the customer, and the fact that it has historically produced a good output in the form of generally long lasting, quality tools. The straightforward, simple nature of the process gives each person in the process a set of responsibilities and should difficulties be encountered, it is clear whom to speak with. With regards to being close to the customer, having the ability to meet the complete spectrum of tooling needs within the company provides for a convenient resource that the development teams can draw on as their needs evolve. While an outside company may not want to provide their time and advice unless there is a firm commitment for future business, the internal organization (lacking the same profit motive) can provide this. Furthermore, when new projects are under consideration, the common link to the parent company reduces security concerns around proprietary issues.

Despite the identified strengths of the process, it receives frequent criticism from the parties involved for its shortcomings as well. As noted in Table 2.6, the process is perceived as being slow by the product development teams. Much of the effort that has focused on this problem has dealt with the issue of actual tool manufacturing and have concentrated only on the time involved in tool design and actual tool build. While gains have been made in reducing this time in certain cases, such as when part and tool design changes are consciously suppressed, it is an event focused approach that ignores other aspects of the tool life cycle. The mechanisms of communication flow that give the system its simplicity take their toll on speed when questions arise downstream in the process or when a continuous stream of changes clogs the system with work. This problem is exacerbated by a system that focuses attention and responsibilities on the tool but not on the real goal which is the parts the tools produce. Furthermore, communications between different groups in the organization is restricted by the linear nature of the process.

The cost of the tools produced by Kodak is a common complaint voiced by the product development teams. The comparison is usually with suppliers from the Far East. It is not clear that this is a legitimate complaint for several reasons. First, the Kodak cost accounting system does a poor job of capturing actual costs for any individual job[7] so it is difficult to make comparisons. (It is also difficult with such a system to make accurate bids for tooling jobs.) Second, for those cases where costs are compared with competitors, the comparisons are rarely based on the same criteria. In these cases, the data must be converted to a unit price for parts including the cost of tooling amortized over some target volume. The examples where the author has seen this done showed inconclusive results and were usually flawed in that they did not account for the time value of money.

Given a prima facie case that KEMD tooling is more expensive than competitors tooling, a quick comparison with a Japanese based competitor begins to highlight areas that may account for this. In the case of Kodak, there is little coordination across individual projects in terms of scheduling for tool construction needs. Jobs are generated, rough schedules are established, but deadlines are not rigidly adhered to. This process creates a highly variable flow of work through the tool room. As a consequence, the shop will cycle from periods of low activity when resources (both human and machine) are underutilized to periods of extremely high activity characterized by queuing delays, expediting for both original work as well as changes, and increased cost for overtime work and outside contracting. Furthermore, as noted earlier, Kodak tends to produce tools that are very durable and long lasting regardless of the volume of parts expected to be produced. All of this tends to drive up the cost of the tooling supplied by KEMD.

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[7] The cost accounting issue has appeared annually in LFM theses done within the Kodak Equipment Manufacturing Division. While it is not the subject of this particular work, the author strongly encourages the interested reader to refer to the earlier theses. In particular the following theses should be consulted: "Designing Measurement Systems in a Manufacturing Environment" by Michael Blatz, LFM 1993; "Measuring Customer-Driven Manufacturing Process Improvement in a Multidivisional Corporation" by Jonathan A. Rennert, LFM 1993; and "Improving the Strategic Contribution of New Technology - Learning From a Sheet Metal FMS" by James C. Leonard, LFM 1991.

The tooling process in a Japanese company engaged in the manufacture of similar types of equipment is similar in its linear step by step approach. The Japanese company also uses outside suppliers in much the same way Kodak does, as supplemental capacity. However, the Japanese tooling process differs in several important respects. First, there is a schedule established early in the product development process which actually dedicates blocks of time in the tool room for that particular project team. This schedule is then strictly adhered to resulting in a continuous loading of the shop and efficient use of resources. A second difference is that time and resources to incorporate changes to tooling is planned in advance and changes are done in batches after sample parts from the tools have been examined. The time to incorporate the changes is prescheduled with the tool room as well. Finally, the Japanese company tends to make tools with a shorter life span than Kodak, reducing the initial cost. The intent is not to argue that a linear process is correct but rather to illustrate that the process currently in use at Kodak, coupled with the organizational policies that have been in effect concerning scheduling and planning, result in a less efficient system than an organization employing a similar process but with a different set of policies.

2.7 Assessment of Opportunities for Improvement

During the course of this project, a team was formed to look at the tooling problem and to marshal resources to tackle individual opportunities. This team consisted of members from the Precision Plastics Department, a product development team, and a continuing engineering team. While it was recognized that speed was an issue, time to make tools was considered to be a cost driver and therefore the overall focus became to seek ways to reduce tool cost. From the outset a variety of options were proposed; rated according to importance and probability of having a positive impact; then assigned to specific coordinators to oversee follow on work in the particular area.

While many of the opportunities were seen as promising, two were selected as the focus of this project: exploring the possible use of family tools as a cost saving alternative and exploring the use of teams in the tooling process. In the case of family tools, the issue was controversial within the organization and it was felt that an outsider would be in a good position to provide an objective assessment of the subject. The team concept was somewhat different in that it was a direction in which the organization was trying to move but was making slow progress. Because the team concept is an opportunity for which the payback and costs are difficult to quantify, the emphasis of this effort was on understanding the "softer" organizational impacts of this change. In the chapters that follow, this work and the associated results are explained.

3 FAMILY TOOLS

3.1 Determining Capacity Needs and the Piece Price Dilemma

One of the questions that needs to be addressed when the tooling strategy for a new plastic part is under consideration is: What is the minimum tooling needed to meet required demand for this part? Typically this is measured in terms of the number of mold cavities required for the part and is driven by one of several factors or combination of factors including:

Program lifetime volumes
Number of parts required per product (unit)
Program production schedule
Number of shots during mold life
Mold cycle time
Mold down time
Mold yield
Mold press availability

There are actually two parts to this problem. The first part is to determine the minimum capacity required to meet lifetime capacity needs. The second part is to determine the minimum capacity required to meet peak demand. As an example, assume for a moment that the consumer product being built is a camera and one of the parts in it is a lever arm. If there is 1 lever arm per unit and the program is expected to produce 2.5 million units over the life of the program (1.5 million in year one and 1.0 million in year two), the manufacturing engineer needs to plan for a total 2.5 million levers. If each cavity is capable of producing 1.5 million parts before it is worn excessively and must be replaced, the manufacturing engineer would need a minimum of two cavities over the life of the program.[8] This is the minimum capacity to meet lifetime volumes. Next, the engineer would need to consider some of the other factors. Assuming that the press

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[8] How these are procured (either both cavities in the same mold base, or a single cavity tool initially, to be replaced later in the life of the program by another single cavity tool) depends first upon peak demand needs, and second upon the financial attractiveness of each alternative. The financial analysis should account for the capital cost of the tools, the piece price of the parts produced, and the time value of money.

functions 70% of the time, 24 hours a day, 5 days a week, 52 weeks a year and the expected cycle time of the part is 30 seconds, some quick math reveals that to produce 1.5 million parts in year one, would require a minimum of 3 cavities. This is the capacity required to meet peak demand which, in this example, occurs in year 1.

In reality, the above analysis is confounded by the fact that the inputs are often merely best guesses. Program volumes are based on marketing forecasts and are difficult to predict with precision. Often the actual cycle time varies from the estimate because the manufacturing and plastics engineers are trying to estimate parameters of a part that in all likelihood is not yet designed. Furthermore, press availability is rarely so simple to determine and is contingent upon production requirements for the other parts of the product as well as other products the molding department may be supporting. However, the example does illustrate the idea that there is some minimum required capacity simply to meet the program needs and production schedules and that those capacities can be estimated by the engineers involved.

Once the basic tooling requirements have been established to meet the program requirements, another factor must be considered which is the effect that the number of cavities has on the piece price of the item being produced. The greater number of cavities per mold the lower the price per part.[9] This is simply because more parts are being produced per unit time per machine resulting in a more efficient use of resources. The effect is particularly dramatic in molding facilities with a high labor and burden rate structure or in facilities which are constrained by molding machine capacity (i.e. have insufficient machines to meet demand). However, the reduced piece price comes at the expense of a higher initial tooling cost, possibly a higher inception cost,[10] and a higher financial risk should the product fail in the marketplace or require significant changes late in the development cycle. This presents the manufacturing engineers with a dilemma

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[9] This analysis ignores the fact that due to the complexity of some parts, the maximum number of cavities per mold is often dictated by constraints on the ability to construct the mold.

[10] Inception costs, for the purposes of this analysis are the costs associated with transferring a product's production system from a controlled lab environment to the factory floor.

regarding how aggressively they should pursue a reduced unit manufactured cost (UMC). Intuitively, the objective should be to reduce the overall program cost, but given the many uncertainties pointed out, it can be difficult to assess what the costs will be.

It is clear that a higher initial tooling cost translates directly into a higher front end load (FEL) cost since tooling is a major portion of the development cost. However, it is less clear what the effect is on the inception costs because little work has been done in this area to study the effects. It is known that there is some variation in part parameters from shot to shot even within the same mold cavity. It is also known that parts will vary between different cavities producing the same part. Theoretically, this accumulated variability can result in a higher part scrap rate, the need for a wider tolerance on the parts being produced, or costly rework of the mold to reduce the intercavity variation to acceptable limits. Because this effect is not well understood, the costs of part variation are usually not considered when weighing the tradeoffs surrounding multi-cavity tooling.

Exposure to financial risk is of great concern especially when there is a wide variance between the high and low projections of market demand, when the opportunity cost of capital is high, or when there is a significant probability that the product will change late in the development cycle. When these conditions exist, purchasing additional cavities to obtain a reduced lifetime piece price may not be the most prudent strategy. When dealing with unknown volumes (either due to uncertainty surrounding product acceptance or due to actions of industry competitors) the preferred strategy would be to purchase the minimum tooling required to meet the expected value of demand. Similarly, when the opportunity cost of capital is high, a strategy of deferring costly initial investments can reduce the overall cost of the program. Product changes late in the development cycle, which affect tooling already made or being constructed, can have a particularly sinister effect on overall cost. In some cases this has added 50% to the cost of the tool. This problem is exacerbated when many cavities must be altered since it increases both the cost and the time required to get the mold back into production.

The tradeoffs and risks described create the crux of the piece price dilemma. The low piece price offered by putting many cavities in a tool is desired, but not the cost associated with that tooling. This creates the opportunity that will be explored in this chapter. In the following sections, the opportunity that family tools provide will be described along with the benefits and barriers to use. Following a discussion of the proposed criteria for using family tools, an actual financial case example will be presented. Finally, some suggestions for easing the introduction of the use of these tools will be presented.

3.2 The Opportunity

Purchasing excess tooling capacity in the form of extra cavities to gain a reduced piece price can be a waste of financial resources. In an ideal situation, the investment in tooling would be the minimum required to produce the expected lifetime volume requirement. If the tooling is still usable once the last required part is manufactured, it implies that too much money has been invested in the tool, and the return on that investment will probably never be realized. However, this waste is often justified based on piece price considerations and, presumably, the need to minimize the total waste of resources in the entire production system. Justifying excess tooling capacity on the basis of a lower overall fully amortized piece price implies that the wasted capacity built into the tooling is more than offset by the savings generated from greater molding machine utilization.

The optimal strategy would allow the manufacturing engineer to get the benefits of tooling a program for the actual capacity required while still maximizing machine utilization (and thereby getting the lowest piece price). There are several strategies that would allow the manufacturing engineer to have the proverbial "cake and eat it too," reaping the benefits of a lower front end tool cost and still getting the low piece price desired. One such strategy would require a capital equipment base which is optimized to accommodate molds of few cavities. In most cases, companies involved in injection molding already have an installed equipment base and are not in a position to change their production system. A second strategy, and the subject of this discussion, is to build what are commonly called family tools or family molds.

Family molds are basically multi-cavity tools which produce two or more unique parts. A common use of family molds can be found in plastic model kits where a variety of parts of different shapes are attached to the same runner system. It should be noted that some tools fitting our definition of family tools are designed to run only one part at a time. This is done by "blocking off" the flow of plastic in the runner system to all but the desired part cavity. Such tools are not what are meant by the term family tools as used in the context of this document. Instead, the author is referring to tools which meet the criteria at the beginning of this paragraph and in which all the cavities are used at once. Family tools are not a new concept, but because of some unique problems which will be discussed in more detail, have not enjoyed widespread use. However, increased competition and the continuing advances in technology are providing the foundations for change and may drive the increased use of family tools as a strategy even in non-traditional applications.

To aid further discussion regarding these molds, a common convention is required to identify a mold's particular composition. For example, a conventional eight cavity mold would have eight cavities of the same part. However, an eight cavity family mold may have eight parts with one cavity each, two parts with four cavities each, etc. To avoid confusion, a three part numbering system is proposed to identify a family mold's makeup. The first number identifies the total number of unique parts the mold produces, the second number identifies the number of cavities for each part,[11] and the last number

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[11] This numbering system would seem to imply that family molds have an equal number of cavities per part. This is clearly not the case and it is easy to conceive of exceptions (i.e. a four cavity mold with two unique parts, the first part having only one cavity and the other part three cavities). In practice however, this could be accommodated by using a symbol such as the letter "u" in the second position to indicate exceptions. (Continuing the previous example, the mold would be a 2-u-4 family mold.)

identifies the total number of cavities in the mold. Using this convention, a 2-3-6 family mold would have six total cavities making two different parts with three cavities each.

The assumptions that underlie the argument that an opportunity exists for using family tools are threefold. First, there is a pre-existing capital base of injection molding equipment that is of a tonnage not optimized to single cavity molds and that the company is unwilling to replace. Second, the organization seeking to use this approach is engaged in the manufacture of a variety of small to medium sized plastic parts for which multi-cavity tooling is attractive on a piece price basis. Finally, the volumes required for production are low enough that multi-cavity tooling is not necessary. If these three assumptions are met, then family tools should be investigated as an alternative to traditional tooling strategies.

3.3 The Benefits

The most obvious benefit of using family tools as part of an overall tooling strategy is the potential to reduce the initial investment or FEL of the product by building fewer tools. However, there are a number of other benefits worth exploring including the potential for reduced machine setups, reduced part handling, reduction in intercavity variation, and reduced material cost. Not all of these benefits will necessarily be realized with every decision to use family tools, but the potential does exist for spillover benefits in areas not traditionally looked at for cost saving opportunities.

For typical 35 mm camera programs, a good rule of thumb for estimating tooling cost is that tools will generally account for 40% of the development cost of the camera.[12] With tools being such a significant portion of the FEL, there is a great deal of pressure to find lower cost alternatives to traditional tooling. Family tools provide such an opportunity. Rather than pay for excess capacity, only the minimum capacity required to meet demand is purchased resulting in two benefits already discussed: less tooling

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[12] This is a widely accepted rule within the consumer imaging department. There is no evidence however that this is an industry wide benchmark.

capacity waste and a lower financial risk early in the program. Family tools can also open up the possibility for tooling to be a "pay as you go" proposition in that single cavities of several different parts can be combined into one mold base and used for production until it is clear that the product will be a success and that more significant follow on tooling will be justified.

Reducing the front end load of a product program has additional value in that it opens up a new range of product opportunities that may not otherwise be profitable. Some companies traditionally have only been able to justify programs by assuming large volumes across which they could amortize the large FEL. By reducing development costs it becomes possible to justify products on lower overall volumes. Considering the trends toward "mass customization,"[13] the ability to develop and sell products for niche markets may become more important in the future. Closely tied to this is the idea that tomorrow's consumers are likely to be a more fickle group accustomed to products that satisfy their needs more completely.[14] The ability to make rapid product changes at a low cost will be crucial in order to satisfy these customers. Family molds may provide a means to do this and gain a competitive edge.

Family tools also require fewer machine setups and should result in less required machine time. This advantage can be demonstrated by a quick example. Assume that four unique gears are to be made in a lot size of 30,000 each. The cycle time for each mold is 15 seconds. We will consider two cases. In the first case, each gear is made using a traditional four cavity mold. In the second case the gear is made using a 4-1-4 family mold. The setup time for each mold is 2 hours. This includes actual mounting time of the mold in the press, time to bring the mold to a uniform temperature, and time to bring the mold parameters on target so that good parts are being produced. The results of this example can be seen in Table 3.3-1.

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[13] Joseph B. Pine, Mass Customization - The New Frontier in Business Competition, Harvard Business School Press, Boston, 1993, page 6.
[14] Ibid., page 31.

Traditional Multi-Cavity Vs. Family Mold Machine Utilization Comparison

Case 1						
Mold	Cavities	Cycle Time (sec)	Set Up Time (hrs)	Set Up Quantity	Run Time (hrs)	
Gear A	4	15	2.00	30,000	31.25	
Gear B	4	15	2.00	30,000	31.25	
Gear C	4	15	2.00	30,000	31.25	Total Machine Time (hrs)
Gear D	4	15	2.00	30,000	31.25	
			8.00		125.00	133.00
Case 2						
Mold	Cavities	Cycle Time (sec)	Set Up Time (hrs)	Set Up Quantity	Run Time (hrs)	
Gear	4-1-4 FM	15	2.00	30,000	125.00	127.00

Table 3.3-1

By using a family mold in this situation, setups are reduced and the machine time required to produce the same size lot of parts is decreased by 4.5%. The benefits of expanding machine capacity must be traded off against some of the disadvantages such as a need for a sorting scheme which will be discussed in Section 3.4. It should also be noted that not all family molds will automatically result in increased machine usage. For instance, since the family mold can only cycle as fast as the slowest part being made in it, if the cycle time of one of the gears was much longer than the others it is conceivable that the use of a family mold would actually result in a decrease in machine utilization. This illustrates clearly the need for specific criteria against which to measure whether family tools should be used in any particular circumstance. Furthermore, molding shops that aggressively pursue quick mold changes on their molding presses would not be as likely to gain this benefit of increasing machine utilization through setup reductions.

Two benefits from family tools have application only under particular circumstances. The first is a reduction in part handling and the ability to "fit" better with certain inventory schemes such as just-in-time (JIT), the second is the ability to precisely match colors between parts. In the first case, if several parts of a particular subassembly can be made in a family tool, then they could be left on the runner system and sent to the assembly area as a "kit". This reduces the amount of effort expended in material handling and inventory control. Furthermore, since the parts are produced at the same time rather than sequentially, part sets can be sent to the assembly area in smaller lot sizes. Given the example from Table 3.3-1, rather than waiting 133 hours until all 30,000 part sets have been run in the traditional multi-cavity molds, with family molds the part sets could be sent in discrete lot sizes as needed (i.e. 5,000 sets every 22 hours). For parts which need the same color characteristics, family molds might be a particularly attractive alternative. When a set of parts can be made from a single shot of plastic, they will have exactly the same material and color characteristics and no matching is required.[15]

Family molds can also be helpful in driving a more disciplined approach to raw material selection and management. Because parts selected for use in family molds must be made of the same material, as family molds become more prevalent they will force an evaluation of how many material varieties are acceptable. For example, one product encountered during this study was comprised of 40 unique plastic parts made of 13 different materials. While there was a legitimate design rationale for using such a wide variety of materials, it was apparent that the number of materials chosen for use could have been reduced.[16] For the molding department, a wide variety of materials means the potential for increased inventory costs as well as increased waste, setup time, and machine maintenance due to the need to run different materials through the same press. Reducing the breadth of materials used and increasing the volumes used of individual material types can also equate to material cost savings in the form of volume discounts. The benefits of rationalizing raw material choices needs to be evaluated in each individual case but represents another area not traditionally looked at for cost savings.

One less obvious effect of using family tools is that if fewer cavities have to initially be built and "tuned up", it may be possible to accelerate the tool build cycle. Traditionally, tooling has been a critical path item in the product development process, so a savings in tooling time can have the dual effect of reducing the cost of engineering

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[15] Caution should be exercised in deciding to use family tools for cosmetic parts especially where extremely fine or difficult to produce finishes are specified. For more information, see the sections regarding Barriers and Criteria for Use.

[16] In this example the reduction would have come from specifying that some parts be made out of materials of higher specifications (and thus higher cost) to reduce the number of individual plastics required.

support (by allowing people to leave the program earlier) and reducing the time required until the program begins generating a positive revenue stream.[17]

It has not been the intent to promote family molds as the panacea for reducing molding costs and, as has been emphasized, not all manufacturing operations will realize the same benefits from their use. However, a prima facie case can be made that family molds do have the potential to offer a number of benefits both in general terms and in specific situations if the barriers to their use can be overcome. A summary of the potential benefits of family mold usage is shown in Table 3.3-2.

Potential Benefits of Family Molds

- Reduced Front End Load
- Greater access to niche product opportunities
- Reduced tooling "waste"
- Reduced financial risk
- Reduced mold setups
- Increased machine efficiency
- Reduced inventory costs (parts and raw materials)
- Reduced intercavity part variation
- Reduced appearance variation between parts (color, material characteristics, etc.)
- Faster tool build

Table 3.3-2

3.4 The Barriers

Although family tools offer potential benefits, there are a number of barriers which must be overcome if they are to gain greater usage in non-traditional applications. The barriers can be divided into three groups: cultural, managerial, and technical. Each of these will be discussed in the following sections. The intent is to identify the specific

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[17] For more information on the effect of receiving a revenue stream earlier, refer to Section 4.3.

issues, discuss their causes, and begin framing possible solutions for overcoming them. In developing this section, a cross section of people at the subject company were interviewed regarding their perceptions of problems with family tools because there is very little documentation regarding actual problems. Furthermore, it is the perceptions that must be overcome before family tools can gain enough acceptance to be tested as a strategy.

Cultural Barriers

There is a great deal of resistance to the use of family tools in camera manufacture at Eastman Kodak. This resistance seems to be widespread, and it is not isolated to one particular area but comes from all areas including some of the manufacturing engineers, tooling engineers, and the operations personnel in the molding area. One obvious reason for this resistance is the fear of problems resulting from some of the managerial and technical challenges surrounding the manufacture and use of family tools. However, it appears that there are a number of other reasons for this resistance including problems experienced with family tools built in the past, a perception of injection molding as an art rather than a science, and a long history of molding high volume items with multi-cavity molds. Collectively, this leads to a negative bias towards family tools.

In discussions with the molding facility regarding family tools, it is invariably pointed out that the tools that are the hardest to run are the existing family tools. They are pointed to as taking the longest to setup, being the most difficult to make engineering changes to, and having the narrowest processing window. Fortunately, family molds do not have a lock on the market for being difficult and there are abundant examples of traditional multi-cavity tools that fit the same difficulty profile as family tools. When pressed further on family tools, the critics will concede that there are some that do run consistently with no problem. During an interview regarding this subject, it was enthusiastically pointed out, in reference to a 2-4-8 family mold for gears, that "It can't make a bad part!" While it is true that there have been difficulties in the past with some family tools, it is also true that they can and do run with a high degree of success. It is also true that there are more aids available now (i.e. process control and mold analysis tools) to ensure their success than ever before. Despite this, the general reaction to family molds is to focus on past problems relative to traditional multi-cavity tooling. This attitude fails recognize that the difficulties involved in a new method or technology should not be evaluated against the difficulties inherent in current methods, but rather against the relative value of the benefits that could be derived by using the alternative method or technology.

Because injection molding is a complex process with many variables, it has proven difficult to accurately model. Traditionally, programs for mold flow analysis have been limited to two dimensional approximations and have not been easy to use.[18] In many ways, the inability to predict with 100% confidence the performance of a particular mold design has reinforced the belief that molding and the building of molds involves a high degree of art in addition to science. Folklore within the organization is abundant and examples are cited of tools that are apparently identical but when mounted into the same molding press run with slightly different process parameters. These examples are referenced when critics seek to illustrate how difficult it will be to put different part geometries into the same mold base. Although these complaints may have had some validity in the past, they ignore the advances that have been made in the modeling of injection molding and result in a mind set that is very difficult to overcome.

The cultural issues just described, collectively represent a "prove it to me" mentality. The keys to dealing with this cultural challenge are to understand the factors that make family molds difficult to deal with, to carefully select candidates for inclusion as family molds with an aim of minimizing problems, and to make use of the best tools and diagnostic aids available to maximize the chances of success. Success during the early trials of such a change should provide the breeding ground for future successes.

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[18] Matthew H. Naitove and John De Gaspari, "Mold Analysis," Plastics Technology, April 1992, page 67.

Although family tools are still viewed skeptically by many people, if proposals to utilize them are approached in a prudent manner such that the benefits are clearly displayed, more people will begin to express the attitude of one plastics engineer who summed up the issue by stating, "If it's what we need to do to beat the competition, then let's do it."

Management Issues

The use of family tools is accompanied by several unique management challenges. Interviews with a number of personnel familiar with their use revealed concerns in four areas: inventory management, production scheduling, engineering change management, and part sorting. With the exception of sorting, all of the concerns really only become issues in the case of unexpected events.[19] For these issues, the potential problems need to be identified and contingency plans prepared. On the other hand, the need to sort parts is a direct by-product of using family molds and trying to combine different parts into the same mold base. This issue may require a change to the production system resulting in some additional costs that need to be traded off against the benefits derived through the use of family tools.

Inventory Management

One of the handicaps of family tools is that parts built through their use are produced in constant ratios. Consider the 4-1-4 family mold for making gears A, B, C, and D from Table 3.3. Ideally, all of the gears should be required in the same production quantities. It should be obvious that if an order for 10,000 units of gear A is received, 10,000 units of gears B, C, and D will normally be produced as well. If the finished product uses two of gear A for every one of the other gears, then this particular family mold would be an inappropriate grouping. In such a case, an alternative grouping

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[19] This assumes that under normal circumstances a tooling strategy would not be adopted that would create problems during steady state operations with regards to inventory management, production scheduling, or engineering change management.

strategy could be considered. In general, however, this problem can be resolved in the planning phase when part requirements and tooling strategies are being considered.

The fact that parts in a family mold are produced in fixed ratios creates problems when the demand ratio for those parts is changed for some reason. Two possible scenarios that were repeatedly identified in discussions with personnel regarding family tool disadvantages would be if parts were lost in shipment or if a discrepancy is discovered in one of the parts forcing a need for replacements to be made. Both of these situations should clearly be exceptional cases. In the first case, the answer is very simple: don't lose parts! Unexplained losses in transit from the molding location to the assembly area are indicative of deeper inventory problems that should be vigorously attacked and eliminated regardless of what tooling strategy is employed. In the second case, if the parts are under either product or process control, any deviations from normal in one of the cavities should be rapidly detected and corrected before more parts are run. This would be true whether the parts were being made in a family tool or in a traditional multi-cavity tool.

A less obvious but similar inventory problem would be if one of the parts being made in a family tool, which was originally designed for a specific product, were to be used in a related or follow on product. This would create additional demand for one particular part but not for the other parts in the tool. The new demand would be in conflict with the preset ratio of parts that the tool is capable of producing. Furthermore, if the volumes are significant enough they could exceed the theoretical maximum number of shots the tools is capable of accommodating.[20] This issue is unique to family tools but should not pose significant problem if long term product planning is a normal part of the organization's operating procedures. Those parts with a high probability of being used in more than one program would therefore be required in greater volumes and may be ideal

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[20] Recall that one of the purposes of family tools is to minimize the amount of "wasted" cavity capacity by only building enough capacity to accommodate a particular program. Ideally the cavities in a family tool would be too worn to be used on a follow on program.

candidates for traditional multi-cavity tooling. On the other hand, if the goal is to minimize the up front development costs and minimize financial exposure early in a program when it is not clear how successfully the product will sell, it may be desirable to use family tools and build additional cavity capacity later, at the time it is required.

Production Scheduling

Family tools are a concern for production scheduling as well. There are two issues to consider. The first is what contingency plans are required should one of the cavities in a family tool break or become damaged? The second is the concern that family tools don't allow for the same capacity expansion that traditional multi-cavity tooling does.

When a cavity becomes damaged in a traditional multi-cavity tool (but the tool can still operate in a press), production can often still be met unless the damaged tool becomes the production bottleneck. For example, for a four cavity gear mold, if one of the cavities becomes damaged: the runner system to the damaged cavity can typically be blocked off, the mold rebalanced for the remaining three cavities, and production can be resumed. In this case the piece price would increase a certain amount because only three parts would be produced rather than the usual four. The mold could then be run until sufficient inventory is built up to allow the mold to be removed from production for the period of time required to repair it. In the case of a single cavity tool or if blocking off the damaged cavity won't allow enough production to meet demand, the tool has to be repaired immediately.

In the situation just described, family tools are more difficult to deal with and what should be done is highly dependent on the particular situation. If a family tool cavity is damaged and it is the only cavity capable of producing a particular part, it makes no sense to block off the cavity and continue production of the other parts in the tool. If this is the case, the only option is to take the mold out of service and repair it immediately. On the other hand, if it is a family mold with at least two cavities producing each part, such as a 2-2-4 family mold, it may be possible to block off one cavity of each part and still meet production demands. Unfortunately, it becomes very difficult to balance these molds and the effort required needs to be weighed against costs of alternative strategies and the risk of not meeting demand.

There are two strategies that can be considered to minimize the effect of a production scheduling problem. One such strategy would be to carry more inventory of parts made using a family tool. The amount of inventory required should be proportional to the amount of time that would typically be required to repair or replace the damaged cavity. The costs of doing this need to be weighed against the expected advantages of using family tools in the first place. It is important to realize that each part will, in all likelihood be unique and require a contingency plan tailored to the particular situation. A variation of this strategy would be to carry an "inventory" of semi-finished tools. This could be done in practice by roughing out cavity blocks for those parts that are time consuming to make a mold for and have them on hand in the event of a damaged cavity. This strategy might prove to be a low cost solution since much of the value added in making the mold is in the finish work and the fitting of the mold cavities. However, having the rough cavity blocks on hand could save a great deal of time in the event of an emergency. Depending on the circumstances, this could reduce the contingency part inventory required.

Some development programs require a substantial engineering model (prototype) effort which forces the building of preproduction engineering tools. For these programs, the engineering tools could be used as part of a contingency plan in the event of a damaged family tool. The draw backs are that engineering tools are typically single cavity "soft" tools. Thus, using them to meet production needs would result in a higher piece price for those parts produced in this manner. Furthermore, "soft" tooling has a significantly shorter life than prehardened or hardened tooling and would only be able to provide limited emergency production before the tool is worn excessively.

The other major production scheduling issue is that family tools do not allow as much upside capacity growth should consumer demand exceed expectations. This is true for the short term when the goal is to temporarily boost production as well as for overall lifetime volumes. One method of dealing with this dilemma is to develop a tooling strategy which ensures that the parts made using family tools are not the bottleneck parts (from a capacity perspective). An alternative method would be to evaluate market forecasts and build in an appropriate cushion. In this case, the appropriate question to ask would be: are market forecasts usually high or low and by how much? The obvious disadvantage of this strategy is that building excess capacity is wasteful and defeats the purpose of using family tools in the first place.

Engineering Changes

Engineering changes, once production tooling has been built, are troublesome regardless of what type of tooling is used. In the case of family tools, however there are two issues that heighten the problem: engineering changes have the potential to disturb the balance of the mold and engineering changes typically will cause excessive scrap. The issue of balancing will be addressed in more detail in the next section on technical issues. However, the important issue is that changes to a family mold are not a trivial matter and can take more time than a change for a comparable number of cavities in a traditional tooling scheme. The additional time required is both to rebalance the mold as well as to reestablish operating process parameters during the subsequent tryout and tune up phase.

The second problem created by engineering changes is closely related to the inventory and production scheduling issues previously discussed. Assume that a production lot of 50,000 part sets has been run on the 4-1-4 gear family mold used in an earlier illustration before it is discovered that a change is required to one of the cavities, cavity "A," in the tool. Once the change has been made, the tool rebalanced, and the 50,000 parts associated with cavity "A" scrapped, there is a need for 50,000 replacement parts to be run. However, to get the 50,000 parts from cavity A, 150,000 unneeded parts would be produced in cavities B, C, and D.

There are several actions that can be taken to try and minimize the effects of engineering changes. For programs that have an extensive engineering model program, it would be expected that most problems would be resolved during the prototype phase and prior to committing to building production family tools. However, for some products, the cost of such a program is prohibitive. In this case, one method is simply to limit the selection of parts targeted for inclusion into family tools to those that exhibit a low probability profile of requiring a change. For products such as cameras, there should be a good history of engineering changes that have been required on various part types which can be used to aid the manufacturing engineer as a decision tool. A second method would be to try and force the changes onto mating parts that are not included in family tools.

Regardless of what approach is taken, attention should be focused on minimizing the need for engineering changes after the decision has been made to begin production tooling. Changes at that point in a program are costly from both a time and dollars standpoint regardless of the tooling strategy chosen. Probably the best way of doing this is by using concurrent engineering principles throughout the design phase of the product. This requires involving tooling designers as well as manufacturing and design personnel so that problems can be identified and worked out in advance of a commitment to hard tooling.[21]

Sorting

One basic issue with family tools is that two or more different parts are being made in a mold at the same time, and at some point in the process these parts need to be separated from each other. With traditional multi-cavity tooling, the parts can be ejected and collected in a number of ways. The simplest is to simply let the parts fall out of the

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[21] This topic is explored further in Chapter 4.

mold to a collection bin or conveyor located beneath the injection molding press. The parts may be on runners and have to be removed by hand or they may be separated from the runner automatically. A method for part removal that is gaining increased usage is to employ some type of robotic system to remove the parts from the mold and place them in trays or on a container. Regardless of the system used there is no need for a secondary sorting operation in a traditional tooling scheme.

Part removal and sorting for family tools can be accomplished by many of the same methods used in traditional tooling schemes. In addition there are a few other options worth investigating. The choice of which method to use will be highly dependent on the particular situation and on the cost structure at each individual molding facility. For instance, if the parts are being made in a low wage country such as China or Mexico, sorting by hand may be the most economical method available. Conversely, in the United States hand sorting may be a less economically attractive solution than a pick and place type robot unless the mold cycle times are high and the machine already requires a full time machine operator. In the following paragraphs, several alternative schemes for dealing with the sorting issue will be briefly introduced.

The simplest, least capital intensive method for sorting parts is hand sorting. The parts can be automatically degated, ejected from the mold, and allowed to fall into a bin for sorting at a latter time, or they can be sorted "real time" as they are made by a machine attendant. The major drawbacks to this method are that it does require dedicating personnel to the task, and if the parts in the family mold are similar such as in the gear example from Section 3.3, there is a potential for errors in sorting especially if the production rate is high. A variation of hand sorting that could lessen the probability for errors would be to eliminate the automatic degating, and leave the parts attached to the runner system. In this case, the operator would either remove the parts by manually breaking them off of the runner or by using a specially designed degating fixture. Although probably providing increases in sorting accuracy, any hand sorting scheme would most likely take additional time. However, as long as the operator could keep pace with the cycle time of the mold, manual degating and sorting could be a reasonable solution.

If labor costs are high there are several machine based approaches which could be employed. One method would be to automatically degate the parts and have them automatically sorted as they fall into bins. This could be accomplished by spacing the mold cavities far enough apart such that different parts fall into different bins. The primary disadvantages to this approach are that a more extensive runner system would be required, increasing both the material cost of the parts as well as the cycle time of the machine; there is also no way to ensure that parts won't occasionally get "hung up" during the ejection process and be thrown into the wrong bin. Dividers or ejection chutes actuated by air cylinders could be employed to solve both of the previous problems. Conceptually, when the mold opens, the separator system mounted beneath the press would actuate and intrude into the area of the mold opening. The parts would then be guided to separate collection locations upon ejection. In general this would be a low cost solution involving an actuation system and a detector system to ensure that the separator was out of the way prior to beginning each mold cycle.

Automatic picker robots could also be employed as a means to remove the parts from the mold and ensure that they are sorted. Pickers are being employed more frequently due to their ability to protect the molded parts from damage incurred when the parts are simply allowed to fall into bins or onto conveyors. Pickers, in combination with sensors on the end effecters, have the added advantage of ensuring that parts are completely removed from the mold thus preventing costly damage that would occur if the mold were to close on a partially ejected part. Once picked, the sorting task would be completed by depositing the parts onto separate trays or conveyors. One concern with pickers is that since most work on a suction vacuum system, a relatively flat surface on the part is required in order to pick it. For very small parts, end effecters with a small suction area would need to be designed, increasing the picking system cost as well as the machine setup cost if the end effecters need to be changed for each mold. An alternative would be to leave the parts on the runner system and pick everything at once. The parts could then be separated in a secondary operation; either manually or by an automatic degating fixture (which would again increase the cost of the system).

Other possible solutions could involve hybrid systems or simply leaving the parts on the runner system. One hybrid system alternative might involve automatically degating and ejecting some parts while leaving some on the runner system for manual degating by the operator. This might be a excellent solution for a family mold with two unique parts such as a 2-2-4 family mold, two parts would fall into bins and two would be degated by hand reducing the chances of inadvertently mixing parts. If all the parts in the family mold belonged to the subassembly it may be advantageous to leave them attached to the runner system and allow the assembly personnel to degate them. This may add additional time in the assembly process, but this drawback would need to be weighed against the benefits of using family tools and providing parts to the assembly area in a "kit" type arrangement.

Although sorting is an issue that must be addressed when considering the use of family molds, the previous discussion should provide some indication of the range of possible solutions that could be employed to overcome this particular barrier. In each case, the individual situation needs to be taken into account to find the most economically attractive solution that will mesh with the existing production system.

Technical Issues

The technical issues surrounding the use of family molds range from simple issues such as material restrictions (i.e. all the parts in the mold must be made from the same material), to very complex issues such as how the mold should be balanced. Fortunately, most of these technical issues can be dealt with through the use of careful selection criteria or by employing computer aided diagnostic tools. In this section the intent is to introduce the issues and provide some insight as to how they can be solved.

Material Restrictions

The most obvious restrictions surrounding the use of family tools revolve around material issues. Since all the parts in a family tool are made from the same shot of plastic, they must all be made from the same material. The impact is that each part will have the same engineering properties and color. There are a wide variety of plastics available to meet the particular engineering needs (tensile strength, modulus, hardness, melt temperature, etc.) of the part in its use environment. Restricting the variety of materials that can be selected for use in parts manufacture in order to bundle parts together in family tools could result in parts that are not completely optimized for their specific use environment. While there is no inherent harm in an "over engineered" part, it carries with it a potential cost penalty in terms of material and processing cost. However, manufacturing more parts out of a single material may provide volume discounts on the raw material, leading to some savings as well.

Parts that are molded in particular colors due to cosmetic or aesthetic reasons probably would not be good candidates for family tools if producing the product in a single color would result in decreased customer satisfaction. Color also becomes an issue with family tools if parts are molded in particular colors for ease of assembly. An excellent example of this is gears. Gears of similar size that are not obviously different are sometimes molded in different colors to facilitate rapid identification of the various parts by the assembly operators. This is not a trivial concern and the impact on the final assembly process should be carefully evaluated when considering molding parts of this nature in a family tool.

Once a mold is designed and built it is often difficult to change the material that the part is made from. Since different plastics experience different shrink rates during processing, a change in material could result in a dimensional change of the part. This can sometimes be accommodated by changing the processing parameters or modifying the mold. However, the problem is compounded for a family tool where the balancing of the mold is extremely critical. In this case, even if the shrinkage problem can be overcome, it may not be possible to rebalance the mold without significant alteration if other properties such as the material flow rate have changed. The inability to easily change the raw material used in a part's manufacture should not be a barrier to use of family tools if prudent material selection is performed in advance. In those cases where there is a sufficient probability that the material may need to be changed, prototypes should be made and tested to verify the design objectives.

Mold Balancing

In multi-cavity tooling, it is important for all cavities to fill at the same rate. If the mold is not designed for an even fill rate, defects such as incomplete shots or over packing can occur.[22] Frequently, the balancing of the mold is obtained naturally by ensuring that the plastic flowing to each cavity must travel the same distance, as in Figure 3.4-1. Because the parts are of equal size, they then should have the same fill rate. In a family mold, natural balancing is difficult to achieve because the parts are not necessarily of equal size. Even if they are the same weight, different part geometries can have a substantial impact on fill rates. The ideal situation would be to combine parts into family molds that are approximately the same weight, the same nominal thickness, and have similar flow lengths that the molten plastic must travel. In the event that these conditions cannot be satisfied, there are a number of factors that can be used to influence the fill rates including the runner geometry, runner length, gate type, gate size, cooling rate, venting and a number of others beyond the scope of this paper. In general, most balancing problems are solved through runner design. However, to maximize the chances

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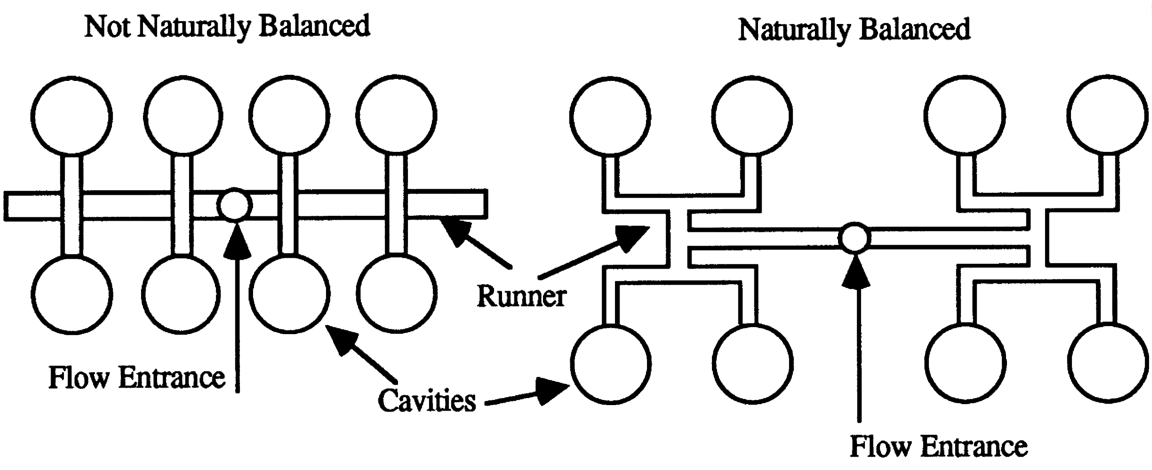
[22] Irvin I. Ruben, Injection Molding Theory and Practice, John Wiley and Sons, Inc., New York, 1972, page 104.

of success, the proposed mold design should be modeled prior to actually beginning construction.



Natural Balancing of Injection Molds

Figure 3.4-1

Computer aided engineering (CAE) software packages can help solve the balancing problem through computer modeling. However, there are many complaints regarding their use. Many are difficult to understand and use, they are not completely compatible with existing CAD packages, they are at best an estimate of what will happen, and they can require additional time on the order of several days to evaluate a design. There is no doubt however that these packages are improving and are of benefit in the design of conventional tooling and especially in the design of family tooling.[23] Accuracy is improving and is now quite good for simple geometries or for materials which are easy to process.[24] Furthermore, users of such systems have verified that gaining experience

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[23] Naitove, page 65.

[24] In general, users the author spoke with felt that the prediction capability of the mold analysis packages is highly correlated to how easy it is to process a particular material. For instance, styrene, which is quite easy to process, is very predicable, where as the predictions for an engineering plastic such as 30% glass filled polycarbonate is not as reliable.

with such systems is one of the keys to unlocking its full potential.[25] Unfortunately, while these technologies are emerging and providing greater benefits, cultural barriers surrounding their use are keeping them from being rapidly adopted. As was identified earlier, the issue of changing people's work habits and applying science to a process that has traditionally been viewed as an art, is a problem to overcome. However, doing so is essential to addressing the mold balancing issue in family tools.[26]

The impact of engineering changes has already been touched on in relation to production and inventory management issues, but from a technical standpoint engineering changes are quite problematic where family molds are involved. With traditional multi-cavity tooling, an engineering change affects all parts in the mold equally, and if the mold was "naturally" balanced prior to the change, then it should still be balanced after incorporation of the change.[27] Because the cavities in a family tool are not the same, a change to one could upset the balance of the entire system resulting in a potentially significant effort to correct. This could involve resizing parts of the runner system, modifying the gates, and altering the process. While it is certainly not impossible to accomplish, changes should generally be viewed as more challenging than equivalent changes in a traditional multi-cavity tool. For this reason, every effort should be made to solve potential design problems in advance through modeling/prototyping or trying to force the required changes onto parts that are not contained in family molds.

Reduced Process Window

Accommodating different parts in the same mold base theoretically results in a tighter processing window. This is due to the fact that each individual part has its own optimal process range within which good parts can be produced. Family molds combine

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[25] Naitove, page 63.

[26] Mold balancing of family tools through the use of CAE software has been done successfully at Eastman Kodak although there have been few attempts and those attempts have not received much attention in the molding community within KEMD.

[27] Although the mold should remain balanced, the processing will most likely change. Shot size, injection pressures, hold times or other parameters will probably need to be reevaluated and optimized to accommodate the physical changes to the mold.

parts with slightly different process parameters and ranges into the same mold base which drives a need to find some overlapping area. The intersection of these processing areas is likely to be smaller than the processing ranges of the individual parts. Within the subject company, molding presses were historically not maintained under process control. However, in the last two years the Precision Plastics Division has undergone a significant upgrade in this area and has made great strides in placing all its molding presses under process control. The results have been very positive, and the division has been able to target those molding presses with high variability and work to upgrade them and bring them under control. It is not clear from the available research or past experience what level of variability is tolerable when dealing with family tools. However, it is clear that the organization is in a much better position to explore this issue now that it has a sophisticated process monitoring capability.

Summary

This section has highlighted several important barriers associated with the use of family tools. Since there is not much published literature available on this class of tools, much of what has been presented and discussed has been derived from the experience of the personnel who will have the task of designing, building, and making these tools work should they be employed as part of a broader tooling strategy on a particular product development effort. In the face of these barriers, the challenge is to devise a prudent selection criteria for the use of this class of tools. This is presented in Section 3.5.

3.5 Criteria for Use

The previous sections regarding the benefits of family tools and barriers to their use have identified some of the issues that must be considered when a decision is being made to use this class of tools. Based on the information presented in these sections and available in the literature, a rough selection criteria can be generated to aid in this decision process. Such a selection criteria is presented in this section. The selection criteria fall roughly into four categories: criteria relative to the part's raw material, criteria relative to the part's geometry, criteria relative to logistical issues, and other criteria which don't fit neatly into the first three categories. Table 3.5 is a summary of the selection criteria.

Family Tool Selection Criteria

Criteria Relative to Part Material

1) Part materials are the same.
2) Low probability that the material selected will need to be changed.

Criteria Relative to Part Geometry

3) Parts are approximately the same weight.
4) Parts have similar flow lengths (shape).
5) Parts have approximately the same cycle time.
6) Parts are not high complexity requiring multiple side draws.
7) Low probability that parts will require engineering changes.

Criteria Relative to Logistics

8) Parts have the same ratio of demand.
9) Parts have a low probability of being used in a follow on program.
10) Parts are use in the same subsystem or required in the same assembly step.

Other Criteria

11) Part functionality is not dependent upon cosmetic criteria.

Table 3.5

The criteria presented in Table 3.5 are not intended to be exclusive or absolute but rather are to be used as general guidelines to aid the tool engineer and manufacturing engineer when they are initially exploring options for how a part or set of parts should be tooled. Criteria 10 and 11 in particular should not be interpreted as rules. Criteria 10 indicates that, all other things being equal, parts which are used to build up particular subsystems prior to final assembly or which are used at the same assembly step may make better candidates for family tools simply because of the sorting and logistic implications involved.[28] Similarly, criteria number 11 is a function of the fact that not much work has been done at the subject company to understand the impact of using family tools for cosmetic parts. It has been done successfully, but until a base of experience has been built up with family tools in general, it may be prudent to exclude cosmetic parts initially as a method of risk reduction.

Five of the criteria presented in Table 3.5 are what can be termed individual part criteria. These five criteria (numbers 2, 6, 7, 9, & 11) can be used as an initial screen to reduce the pool of potential candidate parts that could be built with family tools. For example, if the part has a high probability of requiring engineering changes after the tool design has been approved, that part would be a poor candidate for inclusion in a family tool due to the difficulties inherent in rebalancing a family tool after such a change.[29] The remaining criteria should be used when evaluating whether a group of parts would be good candidates for inclusion in the same family tool.

Criteria 3 and 4 are somewhat problematic in that there is no specific guidance available that can aid in a determination of how much variance should be allowed between part weights and flow lengths. This is an issue which requires further investigation and should be determined by simulation, experimentation, and experience gained through the increased use of these tools. For small parts (part weight is small relative to runner weight) this should not be a significant issue because the individual part runners can be manipulated to accommodate balancing and differences in part geometry. Section 3.8 addresses issues in implementation and the need to acquire this type of data to aid in the decision process.

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[28] As noted in Section 3.4, one option with family tools is that parts can be left on the runner and delivered to the assembly areas as kits. This reduces the need for sorting parts made in a particular family tool.

[29] An example of such a part on a common consumer item like a camera would be the camera frame.

3.6 Case Example

The purpose of this section is to illustrate the use of the selection criteria presented in Section 3.5. To do this, an existing product was selected as a case study to determine if a compelling economic justification exists for experimenting with the use of family tools. In this section, the case will be explained, the assumptions underlying the example will be identified, and the results will be presented. Overall, there is a compelling case for attempting to use family tools under certain circumstances.

The product selected for this case study contained 40 unique plastic molded parts which are identified in Appendix A. The parts were initially screened against the criteria presented in Section 3.5 to determine their suitability for inclusion in a family tool. Seven parts were excluded immediately due to the fact that each one was made from a unique material (or color) that was unlike any other part in the group.[30] Five more were eliminated due to their complexity. Twelve were excluded because their functionality was partially dependent upon cosmetic criteria. One was eliminated due to the fact that it was used in the product four times as often as any other part. Five others were unable to be matched with partner parts due to weight and size ratios or simply because there were no other parts remaining made of the same material. The remaining ten parts became the focus of this example and were grouped into four sets as possible family tool "mates." The groupings are shown in Table 3.6-1.

Potential Family Tool Part Groupings

Set Number 1	Set Number 2	Set Number 3	Set Number 4
Gear A	Mount A	Fastener A	Support A
Gear B	Mount B	Fastener B	Support B
Gear C			
Gear D			

Table 3.6-1

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[30] Although it was not explored, it would be possible to calculate the economic implications of reducing the number of material choices by specifying more expensive materials for some groups of parts in order to create a larger pool of potential family tool pairings.

Once the groupings shown in Table 3.6-1 were complete, the following assumptions were made regarding the example:

- All the comparisons were to be made as if the tools were being used in a low cost labor country typical of where Kodak might be making this product.
- Part of the implication of the previous assumption is that parts made on family tools would be sorted by hand. Additional operators were included in the operating cost of the machine where it was felt appropriate in order to account for the costs of sorting.
- The life of the tools were assumed to be 1 million good parts per cavity. After this, the tool would require replacement. This assumption is probably conservative. In actual practice, the tools could be treated to extend their useful life or reconditioned at least once. In addition, how much the tool actually wears is dependent upon a number of factors including the abrasiveness of the plastic being used, how well the tools are maintained, and the level of detail in the parts being manufactured.
- All the tool comparisons would be made assuming a cold runner design. This is very realistic since most of the original tools for this product were built in this manner.
- The setup time for a molding press with any of the tools is 2 hours. This is the time to mount the mold, connect the heating/cooling lines, bring it to temperature, and begin to produce good quality parts.
- From a production standpoint the most efficient part production policy is perform the minimum number of machine setups and to run the maximum number of parts possible between setups. Because the molding presses engaged in the production of the product used for the case example are only run 5.5 days per week, the "setup volume" is the amount of production that can be made in a 5.5 day (24

hours/day) work week assuming a total yield of 70% (the 70% value accounts for machine utilization and quality losses). The costs of this production/inventory policy were not included in the analysis.

- The volume of parts to be made would be below 1 million per year. This is a necessary assumption since the theoretical volumes per year that can be produced of a particular part in some of the family tools considered, where there is only one cavity available to produce that part, (and given the assumptions that have been made) is approximately 1 million.
- The time value of money was not specifically included in this analysis. To do so would not be difficult but it would require making additional assumptions regarding the life of the product and the actual volumes produced per year. In general, for the cases looked at, incorporating the time value of money makes the family tool option more attractive. This is due to the lower initial investment for the family tool option versus the traditional multi-cavity approach.

The individual parts involved in this case were all actually manufactured in 4 cavity molds. The desire was to look at four cases for each set: a conventional four cavity mold for each individual part, a conventional 2 cavity mold for each part, a family mold with one cavity of each part, and a combination of family molds with two cavities for each part. Actual tool costs were used where possible, and estimates of the actual cost for constructing the tools were made when needed. The estimates for the family tools are considered conservative.

A summary of the important results for each set of parts shown in Table 3.6-1 is included below. For each set, the various tool cost combinations are presented in Table 3.6-2. In addition, Figure 3.6-1 presents a graphical comparison of the total cost of each tooling option over a range of potential life time production volumes. More detailed data for each of the cases considered is included in Appendix A.

Set Number 1 Tooling Combination Costs

Mold Type	Part	Number of Unique Parts	Number of Cavities/Part	Tool Cost ($)
Traditional	Gear A	1	2	18,000
2 Cavity Tool	Gear B	1	2	18,000
	Gear C	1	2	18,000
	Gear D	1	2	18,000
			Total Cost	72,000
Traditional	Gear A	1	4	26,500
4 Cavity Tool	Gear B	1	4	26,500
	Gear C	1	4	26,500
	Gear D	1	4	26,500
			Total Cost	106,000
Gear 4-1-4 Family Mold		4	4	32,000
			Total Cost	32,000
Gear AB 2-2-4 Family Mold		2	4	30,000
Gear CD 2-2-4 Family Mold		2	4	30,000
			Total Cost	60,000

Table 3.6-2a

Set Number 2 Tooling Combination Costs

Mold Type	Part	Number of Unique Parts	Number of Cavities/Part	Tool Cost ($)
Traditional	Mount A	1	2	16,000
2 Cavity Tool	Mount B	1	2	30,000
			Total Cost	46,000
Traditional	Mount A	1	4	24,000
4 Cavity Tool	Mount B	1	4	47,000
			Total Cost	71,000
Mount 2-1-2 Family Mold		2	2	23,000
			Total Cost	23,000
Mount 2-2-4 Family Mold		2	4	35,500
			Total Cost	35,500

Table 3.6-2b

Set Number 3 Tooling Combination Costs

Mold Type	Part	Number of Unique Parts	Number of Cavities/Part	Tool Cost ($)
Traditional	Fastener A	1	2	20,000
2 Cavity Tool	Fastener B	1	2	18,000
			Total Cost	38,000
Traditional	Fastener A	1	4	31,100
4 Cavity Tool	Fastener B	1	4	28,500
			Total Cost	59,600
Fastener 2-1-2 Family Mold		2	2	20,000
			Total Cost	20,000
Fastener 2-2-4 Family Mold		2	4	34,000
			Total Cost	34,000

Table 3.6-2c

Set Number 4 Tooling Combination Costs

Mold Type	Part	Number of Unique Parts	Number of Cavities/Part	Tool Cost ($)
Traditional	Support A	1	2	32,000
2 Cavity Tool	Support B	1	2	23,000
			Total Cost	55,000
Traditional	Support A	1	4	49,400
4 Cavity Tool	Support B	1	4	36,000
			Total Cost	85,400
Support 2-1-2 Family Mold		2	2	27,500
			Total Cost	27,500
Support 2-2-4 Family Mold		2	4	43,000
			Total Cost	43,000

Table 3.6-2d

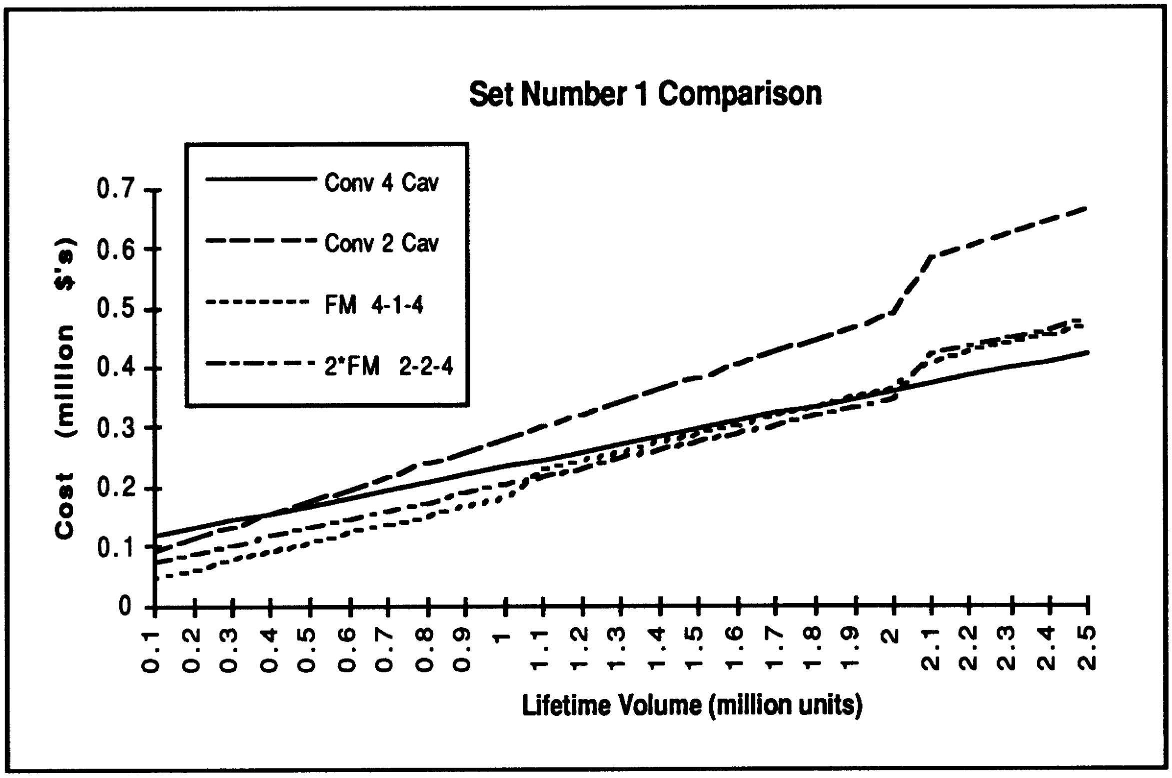

Figure 3.6-1a

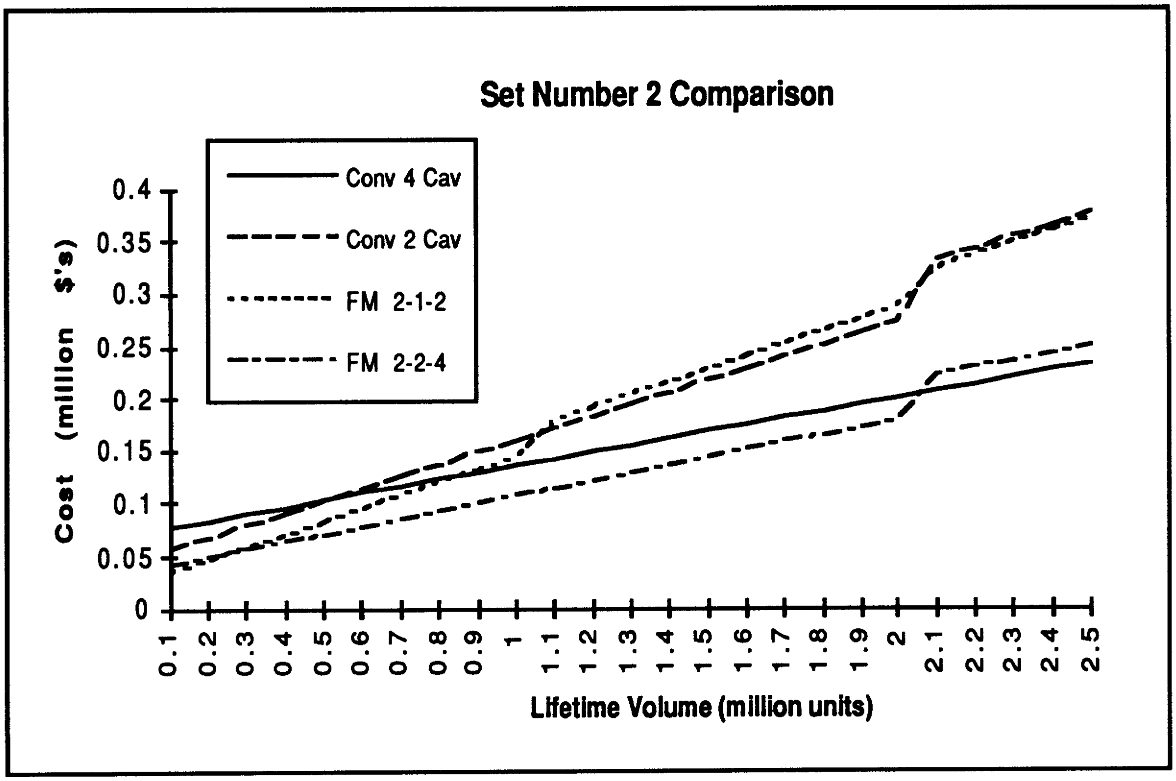

Figure 3.6-1b

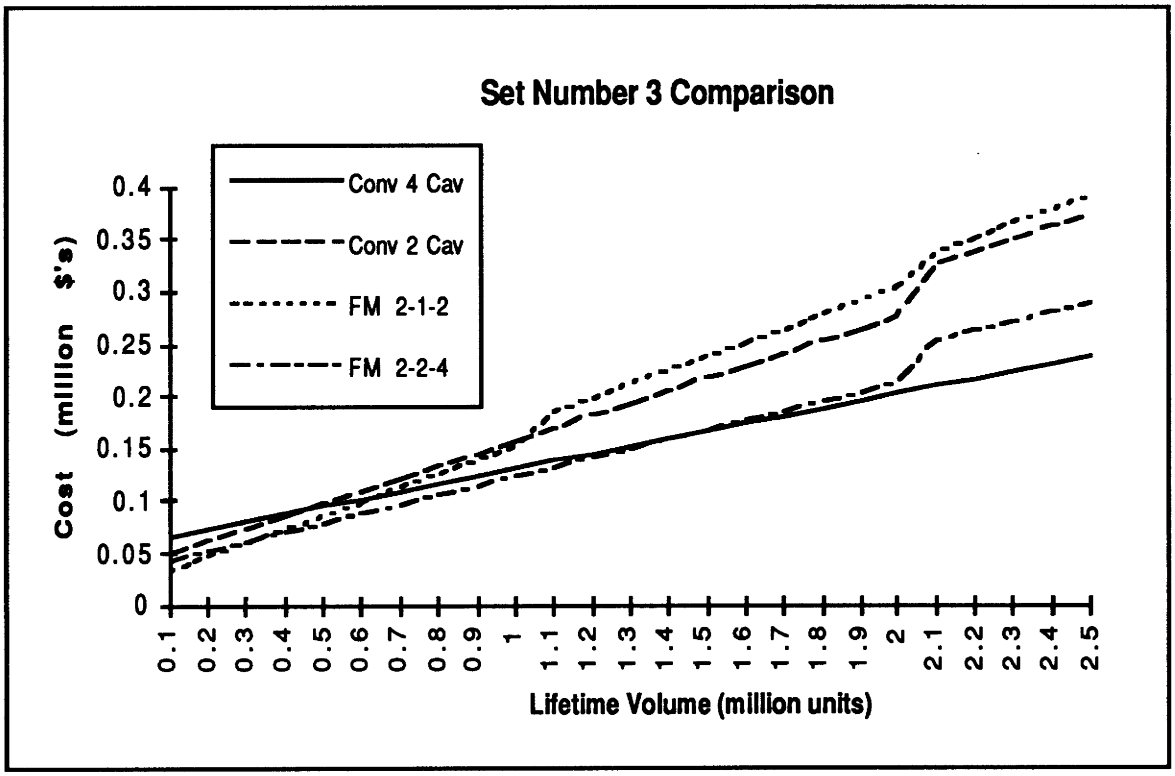

Figure 3.6-1c

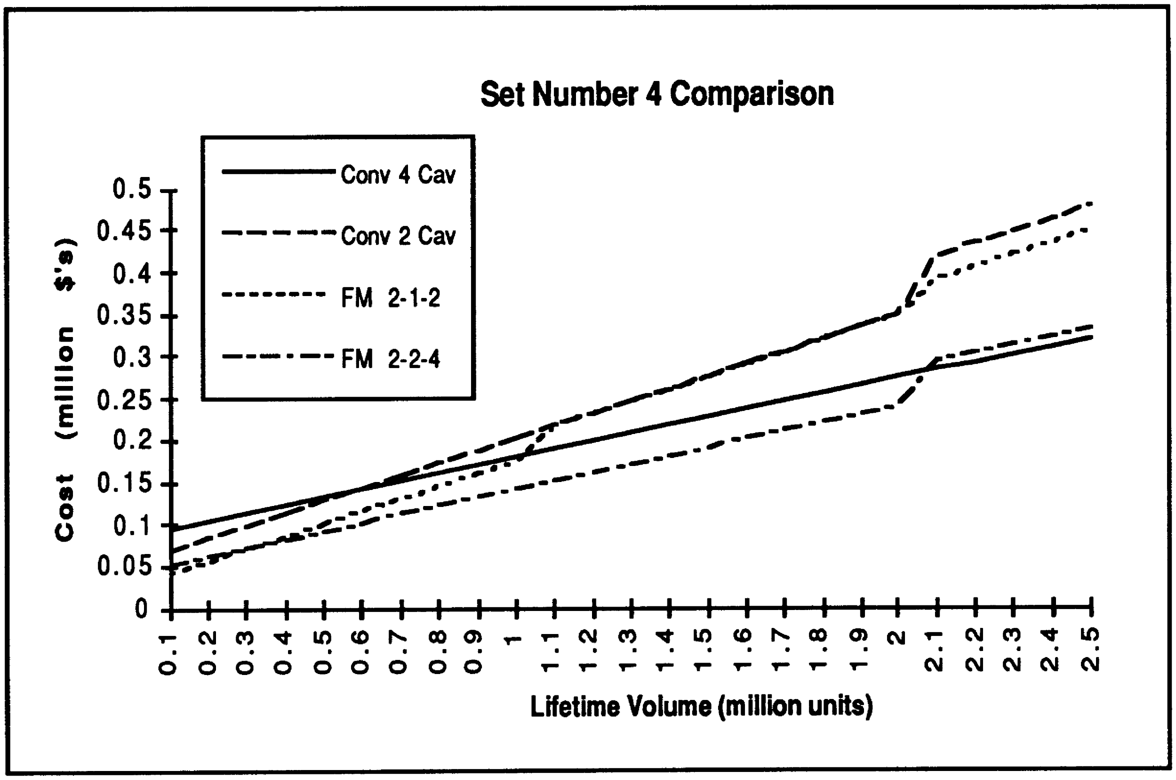

Figure 3.6-1d

The significance of the data presented in Tables 3.6-2 and Figures 3.6-1 is twofold. First, for each case the initial cost for tools for four cavity family molds is less than the cost of the traditional multi-cavity option (four cavities for each part) and second, the total cost for tools and parts at low volumes (less than 2 million units total) is less for family tools. As can be seen from Tables 3.6-2, the total cost for tooling for the 10 parts in this case study using a traditional multi-cavity approach is $322,000 and 10 tools are built. Using four cavity family tools, the cost is $144,500 and only four tools are built. This represents a potential reduction of 55% for the initial investment to produce these 10 parts. Furthermore, as shown in Figures 3.6-1, the total cost for producing parts with four cavity family tools is less than that of the traditional four cavity solution up to approximately 2 million units.[31]

The conclusion that can be made from this case is that family tools have the potential to provide economic benefits in certain circumstances. Specifically, these tools could be attractive in the production of plastic parts for low volume products or products with uncertain future demand where a goal is to minimize the initial exposure to financial risk. In such cases, it would be prudent for those personnel involved in setting the product's overall tooling strategy to consider the use of family tools.

3.7 Proposed Decision Process Methodology

To facilitate decision making regarding whether or not to use family tools in a particular situation, a decision process can be mapped out. Based on the case example and the experience gained in trying to apply the selection criteria of Section 3.5 a decision process has been constructed and is proposed in this section. The decision process is a four step process which may require iteration between the third and fourth steps as shown in Figure 3.7-1.

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[31] The actual break-even volumes for each case can be determined from the data presented in Appendix A.

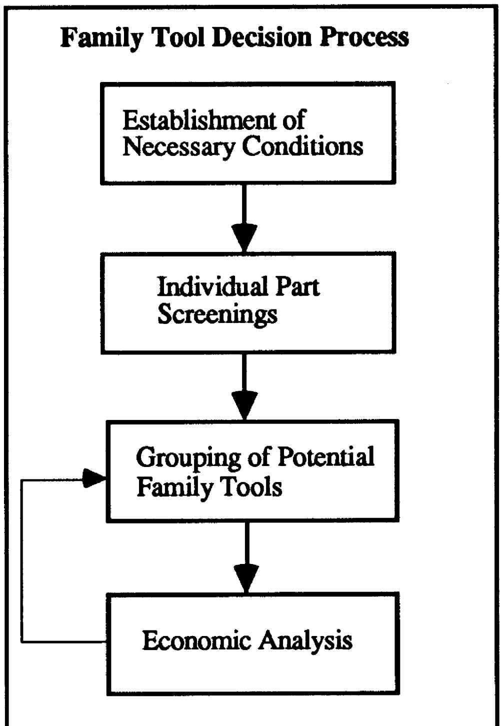

Figure 3.7-1

The major steps of the process are as follows:

Step 1: Establishment of the Necessary Conditions

The goal of this step is to ensure that there is a reason to continue exploring the family tool option for the product under development. The main criteria for determining this are: expected volumes and potential for product growth. Expected volumes are crucial because if the expectation is that the product will be a high volume product, family tools will probably not be an attractive option. As an example, if a rough order of magnitude estimate of product volumes is 10 million units, and a single part cavity is only capable of producing a million parts, then based on the number of cavities required it clearly would make sense to produce traditional multi-cavity tooling from the beginning. The same argument applies when evaluating the potential for product growth. If there is a high degree of confidence that the product's demand will take off in the market place, it would probably make sense to build capacity in advance of demand.

As experience is gained in the use of this class of tools there will probably be other criteria that are determined to be necessary conditions for even considering the use of family tools. This may include such things as the capital equipment (injection presses) available in the production facility. As these items are identified, the decision structure should be modified to include them.

Step 2: Individual Part Screenings

This step draws directly from the selection criteria of Section 3.5. Using the criteria presented in that section, there are 5 tests that each part should be subjected to. A failure of either test is probably sufficient to exclude the part from consideration as a family tool candidate. Several of these criteria are subjective decisions and depend upon the knowledge and expertise of the decision maker to evaluate. The tests are:

- Probability that the material selected will need to be changed? (High probability = failure of test)
- Parts are high complexity or require multiple side draws? (Yes = failure of test)
- Probability that parts will require engineering changes? (High probability = failure of test)
- Probability of parts being used in a follow on program? (High probability = failure of test)
- Part functionality is dependent upon cosmetic criteria? (Yes = failure of test)

Step 3: Grouping of Potential Family Tools

During this step, potential groupings of parts into family tools are made. The pool of parts from Step 2 should be evaluated using the remaining selection criteria from Section 3.5. Parts should be grouped as follows:

- By material type.
- By ratio of demand.
- By size and weight.

- By cycle time.
- By assembly line needs.

Step 4 - Conduct Economic Analysis

During this step, the groupings created during Step 3 should be evaluated from a cost perspective against the alternative tooling schemes available for each part. Every attempt should be made to use actual cost estimates for each tool possibility, as well as for labor and machine time costs at the planned point of production. Throughout this analysis, it should be remembered that the goal is not to get the lowest cost for each individual part, but the lowest cost for the set of parts considered for each grouping. Appendix A shows an example of this type of analysis. As this analysis is done, it may become apparent that some groupings do not present any significant financial advantage, and alternative groups should be considered. In this case, the process would iterate back through Step 3 to regroup certain parts and repeat the economic analysis.

This process was applied in the case example presented in Section 3.6 and, from a conceptual standpoint, seemed to work well. However, in this case the method was being applied to an existing product where there was a good deal of "hindsight" knowledge about the individual parts, their complexity, the tooling costs, and the part volumes involved. Application to a new product and the actual construction of tools would provide valuable feedback to the usefulness of both the tools and the decision process. "Automation" of the decision process through the use of a computer application could be accomplished. However, because of the amount of subjective input required in steps 1, 2, and 3 of the process, it was felt that the only portion of the process that would benefit from this would be Step 4. Step 4 involves a number of numerical calculations and, as seen in Appendix A, can be readily accomplished on a simple spreadsheet.

3.8 Issues in Implementation

Section 3.7 alluded to the fact that the use of family tools in a new product, and the process of convincing decision makers of their suitability could be quite different than the experience of analyzing its applicability to an existing case. During the phase of this research when the decision methodology was being applied to a current program, three issues in implementation were encountered that are worthy of mentioning. The first is the relationship between the internal units within the company, the second is the attitudes encountered in dealing with the change to family tools, and the third is the risk associated with attempting to use family tools.

The relationship between the product development team and the internal supplier of tools in the organization is much different than that of the development teams and outside suppliers. This can be a two edged sword. An external supplier has a stronger incentive to please the customer. If the customer is insistent and wants tools built in a particular way, an external supplier is likely to do it rather than face the prospect of losing the business to another supplier. This could happen even if what the customer wants is not correct. The internal supplier however, because of their ties to the same organization and the fact that internal company policy strongly encourages development teams to use the internal supplier, is more likely to vigorously resist building tools that are felt to be a poor choice. The dilemma created for the development team is understanding when the internal supplier is balking because the tooling choice really is a poor idea and when the resistance is due to organizational inertia. The latter form of resistance can arise out of a mental model developed through years of building a particular class of tool successfully and coming to believe that all tools should be built that way. Such a mental model was alluded to in Section 1.2 and appears to exist in the organization studied.

In general, it seems that the attitude toward the use of family tools is negative within the tooling organization. The reasons for this were described in Section 3.4 and any plan for widespread use of family tools will have to address how to overcome the negative attitudes. During the course of this research, this issue needed to be dealt with as well in order to gain cooperation for the work. In hindsight, there were three actions taken which seemed to increase people's comfort with the prospect of building and using family tools: providing information about the unknown subject,[32] involving the people who will need to implement the idea early in the discussions regarding the change, and using data and estimates that they are comfortable with.[33] These actions seemed to lessen people's resistance to accepting the economic analysis. Those people who were not involved in the process would tend to discount the expected economic benefits.

Risk reduction should be an important issue when considering the widespread application of family tools to a new product especially given the lack of experience with these tools in the organization. Four actions are suggested to reduce the risk of failure in moving to these tools:

- Establish guidelines and a selection criteria for inclusion of parts in family molds. Initially the focus should be on simple, non-cosmetic parts in order to maximize the probability of success. This has been done and is presented in Sections 3.5 and 3.7.
- Use simulations to model the injection molding process for the proposed mold designs in order to resolve potential problems prior to actually building tools. As discussed in Section 3.4, organizations that have made it a practice to use such simulations as a standard part of the tool design process have improved their ability to make the tool right the first time and avoid costly changes late in the cycle.
- Build engineering model tools using the family tool concept whenever possible. Because of the low volumes typically involved in the prototype phase of a

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[32] This was especially important because little information is available regarding these tools and no attempts have been made to summarize and capture what is known.

[33] During the course of this research, the author drew heavily on the knowledge and expertise residing in the Precision Plastics Department. Estimates for tool costs, cycle times, personnel required for sorting, etc. were made by the people who were skeptical of the idea and were then incorporated into the economic analysis. It was felt that this approach would result in an analysis more acceptable to the organization.

development program, this is a very low risk method of testing a family tool design. If the tool fails to perform to expectation, rework can be avoided by blocking off the individual cavities and producing the desired quantity of tools individually. The knowledge gained through this sort of experimentation can be fed back to everyone involved in the process to facilitate better designs and decision making.

- Document successes and failures surrounding the use of family tools. Currently, very little documentation occurs regarding tooling successes and failures. The information obtained through this sort of reflective analysis should be captured and made available to others in the organization for whom family tools might be an attractive option. This information should also be used to update the selection criteria for determining family tool part groupings.

Nothing can fully guarantee that a particular tool will work. However, if the decision to use family tools is well thought out and prudently executed, the risk of failure should be minimized.

4 THE MINI-TEAM CONCEPT

4.1 The Organizational Dilemma

Within the Equipment Manufacturing Division, a structured product development methodology has been introduced. This process, which was referred to in Section 1.2, is called the Kodak Equipment Commercialization Process (KECP). It is designed to "deploy the voice of the customer, to develop superior and robust designs and manufacturing processes, and to implement manufacturing, operations, and business plans."[34] Integral to the success of this process are several guiding principles one of which is Simultaneous Engineering. This is defined as follows:

> "Simultaneous Engineering is the development of a marketing plan, hardware, software, consumable materials, service, and manufacturing processes all at the same time by multifunctional, collocated teams, formed early in the process. Team members are empowered and responsible for making trade-offs , as well as cost, schedule, and performance commitments."[35]

Embedded in the Phases & Gates structure of this process are milestones for the development of tooling to manufacture parts. Despite this, it should be clear from the discussion of Chapter 2 illustrating the linear tooling process, that the vision of simultaneous engineering described above has not been extended to the realm of tooling development. One could argue that it is not practical to include tooling personnel in the multifunctional collocated teams that are created to develop a new product. However, it will be argued in this chapter that including tooling personnel early in the process has the potential to provide benefits and should be done. This leads to an organizational dilemma: if including people full time in the project is beneficial but not practical, how

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[34] Kodak Imaging Group, Kodak Equipment Commercialization Process User's Guide, Eastman Kodak Company, Rochester, NY, 1993, Overview page 1.
[35] Ibid., Overview page 2.

should the team be structured to achieve the goal of simultaneous engineering? In this chapter, this issue will be addressed from the standpoint of tooling development. In the sections that follow, the opportunity will be described, an attempt will be made to quantify the potential benefits, and the barriers will be discussed. In addition, an implementation attempt will be briefly described along with an analysis of the major lessons learned from that experience and resulting recommendations.

4.2 The Opportunity

The tooling phase for some product development programs with a relatively high percentage of plastic components can represent a substantial portion of the overall development time, in some cases upwards of 25% of the time. Often, the design and manufacture of this tooling becomes a critical path item in the development process. Thus, delays in the tooling process can add both cost and time to bring a product to market. Conversely, reductions in this process because it is on the critical path can cut cost and accelerate the time to market. The tooling process discussed in Chapter 2 was essentially a linear process with little overlapping of activities between part design and tool design. As a result of its linear structure and the current nature of communication flows in the organization, there is an opportunity to speed development time if the communications structure can be altered to allow downstream activities to begin earlier and achieve some level of concurrent engineering.

The opportunity for speeding tooling development through concurrent or simultaneous engineering has not gone unrecognized in the organization. However, to date most of the efforts to apply concurrent engineering to tool construction has been concentrated within the tooling organization itself.[36] As an example, it is no longer unusual for tool makers to begin tool construction while the tool design is still in work.

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[36] There have also been attempts in a few programs to integrate an experienced tool designer into the development team before the part designs are finalized. This is done for a period of time to allow the tool designers to get a head start on the design of tooling for long lead time parts. These attempts have mostly been experimental and have not yet become a standard operating procedure.

While this provides limited benefits, it does not fully exploit the opportunity. In order to fully realize the benefits of this opportunity, the people building the tool (the tool designer and tool maker at a minimum) need to be linked directly to the part designers and product engineers. Recall from Sections 2.4 and 2.5 that in the current system the tooling personnel are buffered from their counterparts on the development team by the tool engineer and the manufacturing engineer. Intuitively, this system seems inefficient since it slows the communication flow.

To exploit the opportunity observed, a concept called the "mini-team" concept is proposed. Underlying this concept is the assumption that there are a few pacing items on any tooling project that overwhelmingly determine the critical path. This assumption has been verified in conversations with camera development team members. For a product such as a camera, the pacing items are the frame and the encasements. Occasionally, another part or two will also be identified and these are generally recognized early in the new product's development cycle. The second assumption is that overlapping activities involved in part development and tooling development is possible. There are numerous examples in the literature to support the validity of this assumption, however, AT&T is specifically cited as an example of a company which has successfully done this.[37] Finding opportunities for overlapping activities can be facilitated by having a team in close communication and giving them the support to experiment.[38]

The central idea behind the mini-team concept is that for pacing parts there should be a free flow of communications between all the principle parties involved in the design and manufacture of both the part and its associated tool. For this to happen, a team should be formed at the beginning of the product development effort for each pacing part. All the members of this team do not need to be fully integrated into the overall product development effort but should be considered almost as a "sub product development

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[37] Bernie D Tull, "Quality and Productivity in Injection Mold Tool Construction: A View From Manufacturing", AT&T Technical Journal, July/August 1992, page 61.

[38] Preston G. Smith & Donald G. Reinertsen, Developing Products in Half the Time, Van Nostrand Reinhold, New York, 1991, page 161.

team." This team will be responsible for delivery, by a specified date, of tools capable of producing parts to the level of quality targeted in the product specifications. The specifics of the team and its function will be described through an example in Section 4.5.

4.3 The Benefits

The benefits of reducing cycle time for product development have been enumerated in various works on the subject.[39] Those directly attributable to simultaneous engineering are the time and cost savings which come from the improved communication between the parties involved in the design and manufacture of the product, since this typically reduces design changes.[40] From the perspective of tooling, there are three primary benefits from simultaneous engineering that can be estimated for the sake of quantification. These benefits are: the opportunity for increased revenue by reducing time to market, the reductions in development cost which are directly related to project engineering support, and the reductions in tool cost. The latter of which is due to improved input into the initial part design and the reduction in engineering changes to the tools late in the program.

Reductions in tool cost are the most obvious benefits because they are very visible costs in the system and are captured by typical costing and budgeting systems. If a change is made to a tool late in the development cycle for instance, there is a cost associated with the actual rework. These changes are so pervasive that within the company studied, it is common practice to allow a percentage of the tool budget as a cushion. However, there is a cost associated with the time to perform the rework that is not captured in the simple cost of rework. This cost is potentially larger than the physical rework cost and includes the costs of delay and disruption to the project schedule.

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[39] See for instance: Clark and Wheelwright, Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality, 1992; Rosenau, Faster New Product Development, 1990; and McGrath, Anthony, & Shapiro, Product Development: Success Through Product and Cycle-Time Excellence, 1992.
[40] Milton D. Rosenau, Faster New Product Development, Amacom American Management Association, New York, 1990, page 130.

Models linking lead time to economic implications have been presented in recent management science literature.[41] Relying on a number of assumptions, such a model can give an estimate as to the effect of reducing or lengthening the development time for a particular program. In the general case, a delay in getting a product to market can have the effect of shifting the product revenue stream in time, changing the magnitude of the revenue stream (for instance through lost sales), and increasing the development cost of the program (resulting from a need to retain program support on the payroll until the product has been launched and turned over to continuing engineering).

To illustrate the potential magnitude of the effects discussed, consider the following simple example summarized in Table 4.3-1. Assume there is a product development program which is expected to generate sales of 2 million units over a 2 year period after the product is introduced to the market. The revenue per unit, size of the development team, annual support cost per person, total development cost for the product (Front End Load), opportunity cost of capital, and product margins are all known and are as shown in Table 4.3-1.

Example Case- Impact of Time on Profitability

Parameter	Units	Value
Program Life	Years	2.00
Program Volume	Units	2,000,000.00
Revenue per Unit	$'s	50.00
Development Team Size	Persons	22.00
Average Annual Support Cost per Person	$'s	75,000.00
Front End Load	$'s	8,000,000.00
Opportunity Cost of Capital	%	10.00
Product Margins	%	15.00

Table 4.3-1

Given the information presented, if one makes a simplifying assumption that sales are a constant rate throughout the two year period[42] then it becomes a simple mater to

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[41] Karl Ulrich et al., "Including the Value of Time in Design-for- Manufacturing Decision Making", Management Science, Vol. 39, No. 4, April, 1993, page 431.

[42] This is not a necessary assumption but one must know the profile of sales over the selling horizon. Assuming a level sales rate greatly eases the calculations required for this simple illustration.

generate the present value of the potential revenue stream at the original time of product introduction by using standard financial annuity calculations.[43] To estimate the impact of a program delay on profitability, consider two cases: in the first case, the sales profile and associated revenue stream remains unchanged but is shifted further out in time; in the second case, customers who would have purchased the product had it been available chose instead to buy a competing product (thus, the sales that would have occurred if the product were available, are lost).[44] The results of this analysis are a minimum case scenario and a worse case scenario shown graphically in Figure 4.3 and in table form in Table 4.3-2.

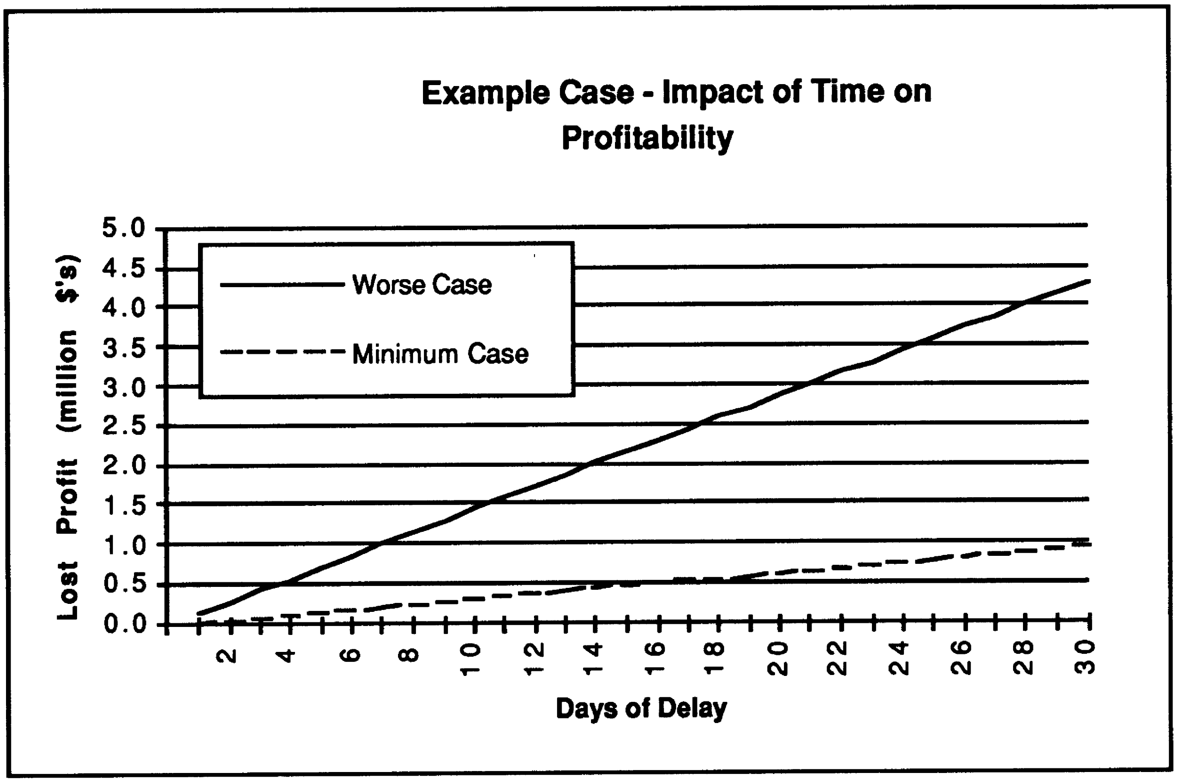

Figure 4.3

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[43] Richard A Brealey and Stewart C. Myers, Principles of Corporate Finance, McGraw-Hill, Inc., New York, 1991, pages 33-41.

[44] In both cases it is further assumed that the development team continues to function throughout the delay period thus increasing the cost of development.

Cost of Delay		
Days of Delay	Minimum Case	Worse Case
1	$31,534	$143,661
2	$63,061	$287,285
3	$94,581	$430,871
4	$126,095	$574,419
5	$157,601	$717,931
6	$189,101	$861,404
7	$220,594	$1,004,840
8	$252,081	$1,148,239
9	$283,560	$1,291,600
10	$315,033	$1,434,924
11	$346,499	$1,578,211
12	$377,958	$1,721,460
13	$409,410	$1,864,672
14	$440,856	$2,007,846
15	$472,295	$2,150,983
16	$503,727	$2,294,082
17	$535,152	$2,437,144
18	$566,571	$2,580,169
19	$597,983	$2,723,157
20	$629,388	$2,866,107
21	$660,786	$3,009,020

Table 4.3-2

In this particular example, a short delay of approximately a week in bringing the product to market could result in a lost profit of between a quarter of a million to a million dollars. This example is conceptually simple but serves to illustrate why there is a strong incentive to reduce the time to market. Furthermore, the example demonstrates that the costs associate with shifting a revenue stream can be quite substantial in their own right and should be considered even if lost sales is not a concern.

4.4 The Barriers

If simultaneous engineering using teams can produce the benefits described in Section 4.3, it seems logical to question why it has not been done and what the barriers are to its implementation. This is a broad subject that has been the primary subject of numerous full length books. However, in this section a few of the barriers that were discovered through observation and interviews of personnel within the subject company will be presented to illustrate the variety of issues that need to be overcome in order to move team based activity from a concept to a reality.

One of the principle barriers to be overcome is simply the lack of strong leadership figures that actively encourage and facilitate the formation of teams to speed the development of tooling. Within the organization, there was no single person at a high enough level to cut across organizational boundaries who actively championed this concept. This is not an uncommon problem with team based activities in general. "Many companies have difficulty establishing strong teams because the entrenched establishment resists the whole concept and there is no one to champion its cause."[45]

Management reluctance to support this type of activity is understandable when one considers the difficulty in quantifying the benefits that teams can yield. As illustrated in Section 4.3, some of the largest benefits are not clearly captured through standard budgeting and accounting schemes. Compounding this problem is the fact that just what it takes to achieve those difficult to quantify benefits is not clear either. The cost of committing resources in the form of people and their time, however, is a clearly visible cost. Furthermore, these are costs that can be avoided by not establishing teams and sticking with the traditional linear system of tool development described in Chapter 2.

Closely associated with the cost of concurrent engineering is the risk associated with trying to overlap upstream and downstream activities in the development cycle in an effort to compress the overall development time. When functions are overlapped, downstream activities are begun based on unfinalized information outputs from upstream activities (in the case of tooling, the building of the tool may begin before the part design is completely finalized). Changes upstream however, can have serious impacts on the system. If the changes substantially impact the downstream activities, this may result in increased rework downstream and may actually result in an increase in overall

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[45] Bernard N. Slade, Compressing the Product Development Cycle, Amacom, American Management Association, Boston, 1993, page 145.

development time. The alternative of waiting until the part design is finalized prior to beginning tooling as described in Chapter 2 is a low risk approach but it results in a development time that is only as good as the linear system.

Team member's individual reluctance to commit to a concurrent engineering process can also be an effective deterrent to its success. In interviews with development team members, a recurring theme was an unwillingness to share incomplete information with their counterparts in the tool room. However, sharing of preliminary information is a key requirement for concurrent engineering to work. The "perfectionist mentality, an attitude of 'I won't give you anything now, because I know I'll have to change it later and I will take the blame for it,' is anathema to integrated problem solving."[46] Concurrent engineering efforts can be just as easily derailed, by an unwillingness by downstream team members to act on incomplete information from their upstream counterparts. Two key elements to this problem are an understanding of risks, and trust among team members.

With whom control rests is another troublesome issue that teams present and was another common theme from interviews conducted with personnel in various parts of the organization. From the perspective of managers, "giving up" resources by committing people to a self directed team is giving up the flexibility to utilize that individual in some other way. This loss of control may be impossible in an organization whose technically skilled work force is small. From the perspective of the team members, it can be disconcerting to not know who is in charge.

The lack of communication tools can be a major impediment to team based simultaneous engineering of injection molds. In fact, communication is viewed by some as the key to this concept's success.[47] Ideally, one would want team members collocated

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[46] Kim B Clark & Steven C. Wheelwright, Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality, The Free Press, New York, 1992, page 184.
[47] Tull, page 63.

since proximity greatly enhances communication.[48] However, this would be unrealistic for the mini-team concept proposed because the time commitment required from individual team members will vary greatly depending upon where in the development process the particular part or tool is. As a result there is a need for an effective communication tool that everyone can access and use as a focal point even if the members of the team are remotely located. One company has successfully used electronic data links to allow multiple parties at different locations to view a computer graphics image during design reviews.[49]

As noted at the beginning of this section, there are many barriers to the implementation of a concept such as the mini-team proposal. However, within the organization studied, the particular barriers referenced seemed to be the most significant based on simple observations of the organization and on data gathered through interviews with people who would potentially be mini-team members. In order to test the concept, the barriers identified are the minimum that need to be overcome.

4.5 The Attempt

To test the value of the proposed mini-team concept, an attempt was made to apply the concept on a development program that was in progress during the time of the research. A part was selected which was felt to be a major pacing component on this particular product. A team was formed (consisting of a part engineer, part designer, manufacturing engineer, tool engineer, and tool designer) and was tasked with developing the part and its associated production tool.

In the absence of a clear champion of the concept within the organization at a high enough level to cut across organizational boundaries, a steering committee was formed consisting of the department head from the Precision Plastics Department, the supervisor

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[48] Smith, page 146.

[49] Tull, page 63.

of the tool room, the lead manufacturing engineer from the development team, another senior engineer from the development team, and the department head from the model shop.[50] The intent was that this group act as a collective champion of the concept and together the committee members would address issues that the mini-team identified as roadblocks to success during the development process. In addition, the committee members involved would be able to get feedback from the people they had chosen to participate as members of the mini-team as to the perceived effectiveness of the idea.

There were no preconceived expectations about what the team should or should not accomplish. No mandate was given to the team about how they should function or how frequently they should meet beyond identifying one of the mini-team members to coordinate the kickoff meeting and informing them that they had the support of the steering committee should they encounter any roadblocks. The intent was to allow the mini-team members to structure themselves as they felt necessary, and allow the team the freedom to decide how they should proceed as a group. Aside from the mini-team members themselves, the only person who attended the meetings was the author who was a silent observer during the proceedings.

During the initial meeting, which lasted slightly over an hour, the manufacturing engineer took the lead role in moderating the meeting and introduced the subject of a team structure and the goal of trying to figure out as a team how to work together most effectively for the duration of the project. Over the course of the meeting, there were four main issues that were addressed: future meeting structure, control, interfaces, and communications. All of these were process related issues that centered on how they would interact as a group. In each case a consensus was reached that seemed to be acceptable to all the participants. Meetings would be held informally on an as needed basis as issues arose regarding the part. The exception would be formal design reviews which would be scheduled well in advance. It was also suggested that design reviews be

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[50] Initially, it was felt that a representative from the model shop might be a part of the mini-team concept to aid in prototypes. Ultimately, it was decided that this would be an unnecessary expansion of the mini-team.

held for the tool and its design as well as for the part. This has not been done in the past and was seen as beneficial in getting input from the product designers on the tool as well as keeping the entire team involved in the tool build, something also not traditionally done. The preference during the meetings was to focus discussions on the part through the use of a CAD terminal.

Control, interfaces, and communications were three issues that received the bulk of the attention but were so closely intertwined as issues that it is almost impossible to separate one from another. The team members felt it was important for them to understand individually who they should communicate with and when it was incumbent upon them to include others. As an example, the part and tool designers wanted the flexibility to communicate directly with each other as issues arose without having to first check with the engineers as was done in the traditional linear process. They felt that this increased communication would enable them to make decisions faster on design issues. After a good deal of discussion regarding each member's individual concerns, a decision was made to allow team members to use their judgment on who to involve in such situations and to fill other team members in after the fact if necessary. During the discussion it was brought up and clearly recognized that trust would have to be a key element to make the concept work.

To try and gain some appreciation of the impact of the mini-team concept, the participants were interviewed before the kickoff meeting, after the kickoff meeting, and after a follow on design review. In addition, several meetings were observed over the three month period that the author remained on site. Additional information was gathered by the author via telephone conversations regarding the status of the group. Although the observation time was short compared to the overall expected "life" of the team, enough data was obtained to draw some generalized conclusions about team members perceptions of the concept, the efficacy of the concept, and the implementation approach chosen. These are discussed in the following section.

4.6 The Results

It is impossible to make a definitive determination at this point if the concept has had a positive impact on cost or speed of tool development in this particular implementation. If the concept does provide cost and speed benefits, they will really only become visible once the tool is being built. If there is a positive impact it should manifest itself by resulting in an easier-to-build tool, requiring fewer changes during the tool build, and the required changes should be of a lower impact nature requiring less rework than has been historically observed. However, there is a perception on the part of the participants from the tool room that the up front time invested simply understanding the part, becoming familiar with its various features as they are being created, and understanding how the part interfaces with other parts in the product will eliminate that portion of time that used to be spent trying to figure out the drawings and CAD files immediately after drawing release.

There were a number of positive short term impacts centered around the team members perceptions of the concept, team members understanding of each others needs, and the information exchanged in the meetings. Prior to the kickoff meeting, four of the five members of the team were skeptical of the idea and felt that it was only going to impede their ability to perform their jobs as they saw fit[51]. The skeptics were especially concerned that the team was going to become a bureaucratic burden that would impose more control on their communications flow than they currently felt. However, after the initial two meetings, the members, while still somewhat skeptical that the concept would work over the long term, were all pleasantly surprised that their ability to communicate had actually improved. Each member perceived that knowing up front who the other people were that would be involved in producing the part and the tool was important.

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[51] After the initial meeting, 3 of the 4 members who had originally been resistant to the idea felt that it was a concept that may be beneficial. The remaining individual, while willing to go along with the idea felt that there would be no difference in the end result.

One member specifically indicated that knowing who to call was a key element of getting him to seek input when he has a question. In the absence of knowing who to talk to, the tendency is to continue on and let some issues get worked out later even if that approach is suboptimal.

Four of the five members felt that having the team and discussing each other's concerns up front resulted in a better understanding of what each person needed from the others in order to perform their function more effectively. In particular, the development team members were all surprised at the importance that the tooling members placed on having a preliminary part design to look at even if there was a high probability of changes. In the minds of the tooling personnel, having anything which would give them an idea of the size, functionality, and design challenges involved in the part was better than nothing. They also felt it would allow them to offer up suggestions early in the process that would make the part more manufacturable from a tooling standpoint. They voiced a concern that in the past, they had received designs that were difficult to make changes to because of the ripple effect such a change would have on other mating parts. If these changes were suggested early in the process when the mating part designs were not yet complete, these changes would be much easier to make.

The overall skepticism of the team members regarding the concept has remained and to a certain extent been reinforced by actions taken after the author left the site. Despite the commitment from the steering committee to aid the team and foster the effort, one of the team members was removed from the team because it was felt that he could be better utilized elsewhere on another project. He was replaced, but the team dynamics then needed to be rebuilt. The effect of this action was not explored. Although the results of this particular endeavor to produce a part and tool by using a team based approach hasn't yielded any hard evidence as to its efficacy, it has highlighted some of the issues regarding this type of undertaking. These will be discussed in the following section.

4.7 Issues in Implementation

Although the jury is still out on the success of this particular experiment, the results have highlighted some areas to target for improvement the next time this approach is used. Despite the efforts to create a champion of the idea through the formation of the steering committee, the desired commitment level for the idea from management was not achieved. This condition by itself is probably enough to doom efforts for team based approaches. If this team approach is to work and become a part of the organization's operating culture, it needs to be nurtured and allowed to take root. From the perspective of the team members, there was no real visible support for what they were trying to do. Nor did they feel like they were in any way accountable for their success as a group, only as individual contributors in their primary function.

A second issue associated with commitment is the commitment of the team members themselves. In the case observed, there were no attempts to create any incentives for the team to remain together for the duration of the project and to achieve its objectives. Yet the issue of incentives has been identified by authorities on product development teams as one means of achieving group alignment.[52] In this particular organization, the author did not observe the use of any type of group incentives in any application of teams over the course of the study. This is potentially an area that should be examined to determine if group incentives should be employed within the existing culture. At a minimum, the approach for identifying team members should be examined. In this particular case, the team members were told that they were going to be on the team. Seeking volunteers may be a better way of gaining members' commitment.[53]

In Section 4.6, it was observed that the team membership had changed after the team had established a working relationship. If at all possible, this should be avoided. The lack of continuity on a team is damaging even if the replacement is technically

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[52] Slade, page 146.
[53] Smith, page 127.

competent.[54] While this sort of arrangement may limit management's ability to redeploy resources as they feel the need, this sort of commitment is required in order to break out of a reactive mode that causes the redeployments in the first place. The level of commitment from management which is signaled by their actions sends a strong message to the participants about the seriousness with which the team effort is viewed.[55]

Team membership and the particular skills of the members involved should be taken into account for future applications of this concept. In the case of this team, five members were involved but there was no specific representation by the actual people who would have to build the tool. This was not an issue with this team because of the skill level and experience of the tool engineer who was a mold maker by trade. However, had it not been for his experience, valuable input would have been forgone during the team meetings. At another company that has attempted to apply this concept, they have gone so far as to include representation from the machine operators in the tool room (CNC programmers) and tool inspection personnel.[56]

The final implementation issue that should be addressed is how to apply this concept such that lessons learned can be captured and diffused through the organization or at a minimum be made available to follow on teams. To accomplish this, it may be beneficial to think of each team as a separate experiment from which data should be gathered. Goals should be set, and performance metrics monitored to understand what approaches work and what don't. Furthermore, more input from the team members should be sought regarding what the problems are in implementation. The steering committee or whoever ultimately becomes the champion of this concept should actively seek this input. A word of caution however, is in order. When input is sought and then not used, future input is likely to be less useful because people will perceive that their contributions are not valued and will spend time on other issues.

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[54] Slade, page 145.
[55] Smith, page 120.
[56] Tull, page 64.

5 CONCLUSIONS

5.1 Review of Major Findings

The purpose of this thesis was to examine the tooling process of a major manufacturer of plastic parts and search for opportunities for the reduction of cost and lead time in the manufacture and acquisition of tools for plastic injection molding. The research focused on two specific opportunities, family tools and mini-teams, both of which seem to have the potential to provide opportunities for reductions in both the cost and the time required to manufacture plastic injection molding tools. The results of this work were encouraging in terms of understanding the benefits and barriers of each opportunity. Furthermore, through this work, progress was made toward identifying some of the important issues regarding problems in exploiting the benefits that the opportunities offer. Unfortunately, because of the time horizon of the work, insufficient experimentation was able to be done to verify the actual improvement potential offered by the opportunities examined. The remainder of this section summarizes the major findings regarding each opportunity.

Family Tools

The conclusion of this thesis regarding family tools is that under certain conditions they offer substantial potential for reducing the up front investment cost for tools. In the case example presented, the initial cost reduction for a set of 10 parts was approximately 55% over the traditional multi-cavity tooling approach. Furthermore, over a low volume range, the total system cost for parts and tools can be less for parts built using family tools than for parts built using traditional tooling approaches. Thus, this option presents an alternative to the traditional tool cost vs. piece price trade off that is often encountered when planning for the manufacture of a new product. At the present time however, the family tool strategy is only applicable in a limited set of circumstances for use with a small set of parts. Understanding when the family tool option is appropriate and having a set of decision criteria for evaluating when they should be used is the first step in making this option available to the tooling organization and the development teams.

Since there is little information generally available regarding family tools, the information presented was gathered primarily by interviewing knowledgeable subjects who have some experience in this area and capturing their knowledge in the form of a set of pro and con arguments for family tools. Because of this, the decision methodology which was derived from this information needs to be tested in practice to verify that the benefits claimed can actually be realized. A low risk approach was suggested by building engineering or prototype tools which are not expected to produce a high volume of product. Information obtained through this experimentation can be used to improve the decision process. However, based on the information available at this time, a prima facie case can be made for the increased use of family tools.

Mini-Teams

The conclusions regarding the mini-team concept, which is still being attempted, are not particularly encouraging. While the benefits clearly exist and have been achieved by some organizations, it is not clear what level of benefits will be achieved in the particular application of the concept that was the subject of this research. From the standpoint of the participants, the experiment was beneficial in terms of accelerating the communication flow between the various parties. However, there is no evidence that this increased flow of communication has translated into new opportunities to overlap functions and move closer to the goal of concurrent engineering. Nor is it clear that the up front involvement of the tooling personnel in the part design process will result in a part that is easier, cheaper, and faster to build a tool for. This will only be able to be ascertained much later in the development cycle.

From the standpoint of implementation, this particular attempt was not successful in overcoming the barriers to cross functional teams. In particular, future implementations should concentrate on achieving support for the concept at a higher level in the organization. This issue of commitment has been identified in both theory and practice as one of the keys to successful implementation. In addition to organizational commitment, achieving individual commitment from the team members and group alignment is also crucial. Future implementations should be more successful if these issues can be overcome.

5.2 The Expert Syndrome

In the course of doing this work, it gradually became obvious that the ideas ultimately articulated in this thesis were not really new to the organization. Furthermore, much of the information required to solve the perceived problem of high tooling costs and long lead times is probably within the organization also. If this is true, why is this information not harnessed to solve the existing problem or at the very least captured in order to create an action plan to solve the problem? The answer to this question may well be the "real learning" that comes out of this work in that it represents a generic issue that has applicability to other similar problems.

The answer may in part be illustrated by an anecdote. Early in the course of this work, a question regarding why a particular tool could not be built was asked of a person who is quite knowledgeable on the subject of injection molding tools and is recognized by their peers as an expert. The expert in this case answered the question with a very convincing argument that was both detailed and lengthy, further supporting the notion that the expert had the answer. In this case, the answer was correct, given the individual's assumptions regarding the state of technology and the use environment. Unfortunately, the expert's assumptions were wrong, and therefore the answer was suspect as well. For lack of a better term, this will be termed the "expert syndrome."

As noted earlier, much of the knowledge for solving the organization's tool related problems probably already resides in fragmented form with various individuals sprinkled throughout the organization. However, much of this information is built on assumptions that are based on the knowledge holder's past experience and limited view of the problem. These experiences and assumptions form the mental models which shape our views of the world. Understanding the assumptions upon which one's knowledge is built on is essential to recognizing when that knowledge is applicable.

The message is that when approaching an issue such as the tooling problem presented in this work, the assumptions of those involved in the problem solving need to be surfaced and tested against reality. If they are not congruent, then the information based on the faulty assumptions needs to be reassessed as to its applicability.

APPENDIX A

The data presented in this Appendix resulted from the case example described in Section 3.6. Table A-1 shows a complete list of the plastic parts in an existing product. These parts were screened according to the criteria laid out in Section 3.5 and the methodology described in Section 3.7. The screening process identified a set of 10 parts suitable for grouping into four family tools. The groupings are shown in the body of the text in Table 3.6-1.

Table A-2 shows the spreadsheet used to perform the economic analysis comparing the proposed family tool groupings with traditional multi-cavity tooling. For all but the Gear Example, two and four cavity tools are considered for both the family tool option and the traditional multi-cavity tool option. The assumptions underlying this analysis are discussed in Section 3.6. Detailed results of the analysis are shown in Table A-3. The tables comprising A-3 show both the total cost of each tooling option over a range of lifetime volumes as well as an amortized cost over the same volume range. Note that the dollar figures shown are not for individual parts but for the set of parts considered for each example.

Sample Part Set for Family Tool Case Example

Part Num.	Part Name	Material Type	4 Cavity Shot Wt. (grams)	Individ. Part Wt. (grams)	Cycle Time (Sec)	Family Tool Candidate?	Reason for Exclusion
1	Fastener A	1	8.00	0.35	14	yes	
2	Box	1	7.10	0.58	15	no	No suitable mates
3	Head	1	26.00	3.80	17	no	Cosmetic
4	Cover A	1	22.00	2.05	17	no	Cosmetic
5	Fastener B	1	4.00	0.26	17	yes	
6	Support A	1	9.50	0.67	18	yes	
7	Support B	1	9.50	0.63	18	yes	
8	Box	1	25.00	3.05	18	no	No suitable mates
9	Support C	1	25.00	4.10	20	no	Part Complexity
10	Cover B	1	60.00	12.50	22	no	Cosmetic
11	Frame	1	NA	NA	26	no	Part Complexity
12	Plate A	2	6.30	0.79	13	no	Cosmetic
13	Retainer	2	6.20	0.21	13	no	Part Complexity
14	Mount A	2	9.00	0.30	16	yes	
15	Mount B	2	11.00	0.83	18	yes	
16	Cover C	2	16.00	2.60	20	no	Cosmetic
17	Cover D	2	20.00	4.00	22	no	Cosmetic
18	Cover E	2	NA	NA	26	no	Cosmetic
19	Gear A	3	14.00	0.10	12	yes	
20	Gear B	3	9.00	0.28	13	yes	
21	Gear C	3	6.30	0.15	13	yes	
22	Gear D	3	9.00	0.24	15	yes	
23	Gear E	3	10.00	0.64	13	no	No suitable mates
24	Gear F	3	8.00	0.20	14	no	4:1 Ratio to other parts
25	Support C	4	5.00	0.08	12	no	No suitable mates
26	Mount C	4	11.50	1.50	16	no	Cosmetic
27	Plate B	4	15.00	2.40	16	no	Cosmetic
28	Support D	4	24.00	2.50	22	no	Part Complexity
29	Window A	5	4.00	0.05	15	no	Cosmetic
30	Window B	5	7.20	0.38	17	no	Cosmetic
31	Window C	5	6.00	0.35	25	no	Cosmetic
32	Support E	6	9.00	0.48	15	no	No suitable mates
33	Plate C	6	13.00	2.35	16	no	Part Complexity
34	Gear G	7	12.50	0.25	12	no	Only part of this material
35	Pin	8	3.40	0.03	16	no	Only part of this material
36	Gear H	9	7.60	0.07	15	no	Only part of this material
37	Gear I	10	10.00	0.15	22	no	Only part of this material
38	Gear J	11	9.50	2.70	16	no	Only part of this material
39	Knob	12	5.00	0.57	17	no	Only part of this material
40	Cover F	13	18.00	3.15	20	no	Only part of this material

Table A-1

Gear Example Family Tools vs. Traditional Multicavity Tools

Mold Type	Part	Num Parts	Num Cav	Tool Cost $000	Shot Wt. (g)	lbs. mat per 1000	Mat Cost $/lb	Cycle Time (sec)	Setup Time (min)	Mach Cost $/hr	Labor Cost $/hr	Workers per Mach	Annual Volume	Setup Quantity	Mat $ per 1000	Mach $ per 1000	Add labor ($/1000)	Setup ($/1000)	Total ($/1000)
Traditional	Gear A	1	2	18	7.0	7.7	2.18	12	120	18	4	0.5	100,000	55,440	17.48	30.00	0.00	0.65	52.94
2 Cavity	Gear B	1	2	18	5.0	5.5	2.18	13	120	18	4	0.5	100,000	51,175	12.48	32.50	0.00	0.70	50.26
	Gear C	1	2	18	4.5	5.0	2.18	13	120	18	4	0.5	100,000	51,175	11.24	32.50	0.00	0.70	48.88
	Gear D	1	2	18	5.0	5.5	2.18	15	120	18	4	0.5	100,000	44,352	12.48	37.50	0.00	0.81	55.88
		Tooling Cost		72													Cost per 1000 part sets		207.96
Traditional	Gear A	1	4	26.5	14.0	7.7	2.18	12	120	18	4	0.5	100,000	110,880	17.48	15.00	0.00	0.32	36.08
4 Cavity	Gear B	1	4	26.5	9.0	5.0	2.18	13	120	18	4	0.5	100,000	102,350	11.24	16.25	0.00	0.35	30.62
	Gear C	1	4	26.5	6.3	3.5	2.18	13	120	18	4	0.5	100,000	102,350	7.87	16.25	0.00	0.35	26.91
	Gear D	1	4	26.5	9.0	5.0	2.18	15	120	18	4	0.5	100,000	88,704	11.24	18.75	0.00	0.41	33.43
		Tooling Cost		106													Cost per 1000 part sets		127.05
Gear 4-1-4 Family Mold		4	4	32	9.6	21.1	2.18	15	120	18	4	1.7	100,000	22,176	47.94	75.00	11.67	1.62	149.85
Gear AB 2-2-4 Family Mold		2	4	30	11.5	12.7	2.18	13	120	18	4	1.8	100,000	51,175	28.71	32.50	5.78	0.70	74.47
Gear CD 2-2-4 Family Mold		2	4	30	7.7	8.5	2.18	15	120	18	4	1.6	100,000	44,352	19.23	37.50	5.00	0.81	68.79
		Tooling Cost		60													Cost per 1000 part sets		143.26

Table A-2a

Mount Example Family Tools vs. Traditional Multicavity Tools

Mold Type	Part	Num Parts	Num Cav	Tool Cost $000	Shot Wt. (g)	lbs. mat per 1000	Mat Cost $/lb	Cycle Time (sec)	Setup Time (min)	Mach Cost $/hr	Labor Cost $/hr	Workers per Mach	Annual Volume	Setup Quantity	Mat $ per 1000	Mach $ per 1000	Add labor ($/1000)	Setup ($/1000)	Total ($/1000)
Traditional	Mount A	1	2	16	5.0	5.5	1.38	16	120	18	4	0.5	100,000	41,580	7.90	40.00	0.00	0.87	53.65
2 Cavity	Mount B	1	2	30	6.0	6.6	1.38	18	120	18	4	0.5	100,000	36,960	9.48	45.00	0.00	0.97	61.00
		Tooling Cost		46													Cost per 1000 part sets		114.65
Traditional	Mount A	1	4	24	9.0	5.0	1.38	16	120	18	4	0.5	100,000	83,160	7.11	20.00	0.00	0.43	30.30
4 Cavity	Mount B	1	4	47	11.0	6.1	1.38	18	120	18	4	0.5	100,000	73,920	8.69	22.50	0.00	0.49	34.85
		Tooling Cost		71													Cost per 1000 part sets		65.15
Mold Mount 2-1-2 Family Mold		2	2	23	6.0	13.2	1.38	18	120	18	4	0.8	100,000	18,480	18.97	90.00	0.00	1.95	122.01
Motor Mount 2-2-4 Family Mold		2	4	35.5	10.0	11.0	1.38	18	120	18	4	1.4	100,000	36,960	15.81	45.00	4.00	0.97	72.36

Table A-2b

Fastener Example Family Tools vs. Traditional Multicavity Tools

Mold Type	Part	Num Parts	Num Cav	Tool Cost $000	Shot Wt. (g)	lbs. mat per 1000	Mat Cost $/lb	Cycle Time (sec)	Setup Time (min)	Mach Cost $/hr	Labor Cost $/hr	Workers per Mach	Annual Volume	Setup Quantity	Mat $ per 1000	Mach $ per 1000	Add labor ($/1000)	Setup ($/1000)	Total ($/1000)
Traditional	Fastener A	1	2	20	4.0	4.4	3.68	14	120	18	4	0.5	100,000	47,520	16.86	35.00	0.00	0.76	57.88
2 Cavity	Fastener B	1	2	18	3.0	3.3	3.68	17	120	18	4	0.5	100,000	39,134	12.64	42.50	0.00	0.92	61.67
		Tooling Cost		38													Cost per 1000 part sets		119.55
Traditional	Fastener A	1	4	31.1	8.0	4.4	3.68	14	120	18	4	0.5	100,000	95,040	16.86	17.50	0.00	0.38	38.21
4 Cavity	Fastener B	1	4	28.5	4.0	2.2	3.68	17	120	18	4	0.5	100,000	78,268	8.43	21.25	0.00	0.46	33.15
		Tooling Cost		59.6													Cost per 1000 part sets		71.37
Fastener 2-1-2 Family Mold		2	2	20	4.0	8.8	3.68	17	120	18	4	0.8	100,000	19,567	33.72	85.00	0.00	1.84	132.62
Fastener 2-2-4 Family Mold		2	4	34	8.0	8.8	3.68	17	120	18	4	1.4	100,000	39,134	33.72	42.50	3.78	0.92	89.01

Table A-2c

Support Example Family Tools vs. Traditional Multicavity Tools

Mold Type	Part	Num Parts	Num Cav	Tool Cost $000	Shot Wt. (g)	lbs. mat per 1000	Mat Cost $/lb	Cycle Time (sec)	Setup Time (min)	Mach Cost $/hr	Labor Cost $/hr	Workers per Mach	Annual Volume	Setup Quantity	Mat $ per 1000	Mach $ per 1000	Add labor ($/1000)	Setup ($/1000)	Total ($/1000)
Traditional	Support A	1	2	32	5.0	5.5	3.68	18	120	18	4	0.5	100,000	36,960	21.07	45.00	0.00	0.97	73.75
2 Cavity	Support B	1	2	23	5.0	5.5	3.68	18	120	18	4	0.5	100,000	36,960	21.07	45.00	0.00	0.97	73.75
		Tooling Cost		55													Cost per 1000 part sets		147.51
Traditional	Support A	1	4	49.4	9.5	5.2	3.68	18	120	18	4	0.5	100,000	73,920	20.02	22.50	0.00	0.49	47.31
4 Cavity	Support B	1	4	36	9.5	5.2	3.68	18	120	18	4	0.5	100,000	73,920	20.02	22.50	0.00	0.49	47.31
		Tooling Cost		85.4													Cost per 1000 part sets		94.62
Support 2-1-2 Family Mold		2	2	27.5	5.0	11.0	3.68	18	120	18	4	0.8	100,000	18,480	42.15	90.00	0.00	1.95	147.51
Support 2-2-4 Family Mold		2	4	43	9.5	10.5	3.68	18	120	18	4	1.4	100,000	36,960	40.04	45.00	4.00	0.97	99.02

Table A-2d

Gear Example Family Tools vs Traditional Multicavity Tools

	Lifetime Cost ($ in 000's)				Amortized Cost ($)			
Volume	Conv 4 Cav	Conv 2 Cav	FM 4-1-4	FM 2-2-4	Conv 4 Cav	Conv 2 Cav	FM 4-1-4	FM 2-2-4
100000	119	93	47	74	1.19	0.93	0.47	0.74
200000	131	114	62	89	0.66	0.57	0.31	0.44
300000	144	134	77	103	0.48	0.45	0.26	0.34
400000	157	155	92	117	0.39	0.39	0.23	0.29
500000	170	176	107	132	0.34	0.35	0.21	0.26
600000	182	197	122	146	0.30	0.33	0.20	0.24
700000	195	218	137	160	0.28	0.31	0.20	0.23
800000	208	238	152	175	0.26	0.30	0.19	0.22
900000	220	259	167	189	0.24	0.29	0.19	0.21
1000000	233	280	182	203	0.23	0.28	0.18	0.20
1100000	246	301	229	218	0.22	0.27	0.21	0.20
1200000	258	322	244	232	0.22	0.27	0.20	0.19
1300000	271	342	259	246	0.21	0.26	0.20	0.19
1400000	284	363	274	261	0.20	0.26	0.20	0.19
1500000	297	384	289	275	0.20	0.26	0.19	0.18
1600000	309	405	304	289	0.19	0.25	0.19	0.18
1700000	322	426	319	304	0.19	0.25	0.19	0.18
1800000	335	446	334	318	0.19	0.25	0.19	0.18
1900000	347	467	349	332	0.18	0.25	0.18	0.17
2000000	360	488	364	347	0.18	0.24	0.18	0.17
2100000	373	581	411	421	0.18	0.28	0.20	0.20
2200000	386	602	426	435	0.18	0.27	0.19	0.20
2300000	398	622	441	449	0.17	0.27	0.19	0.20
2400000	411	643	456	464	0.17	0.27	0.19	0.19
2500000	424	664	471	478	0.17	0.27	0.19	0.19
2600000	436	685	486	492	0.17	0.26	0.19	0.19
2700000	449	705	501	507	0.17	0.26	0.19	0.19
2800000	462	726	516	521	0.16	0.26	0.18	0.19
2900000	474	747	531	535	0.16	0.26	0.18	0.18
3000000	487	768	578	550	0.16	0.26	0.19	0.18
3100000	500	789	593	564	0.16	0.25	0.19	0.18
3200000	513	809	608	578	0.16	0.25	0.19	0.18
3300000	525	830	623	593	0.16	0.25	0.19	0.18
3400000	538	851	638	607	0.16	0.25	0.19	0.18
3500000	551	872	652	621	0.16	0.25	0.19	0.18
3600000	563	893	667	636	0.16	0.25	0.19	0.18
3700000	576	913	682	650	0.16	0.25	0.18	0.18
3800000	589	934	697	664	0.15	0.25	0.18	0.17
3900000	601	955	712	679	0.15	0.24	0.18	0.17
4000000	614	976	727	693	0.15	0.24	0.18	0.17

Table A-3a

Mount Example Family Tools vs Traditional Multicavity Tools

	Lifetime Cost ($ in 000's)				Amortized Cost ($)			
	Conv	Conv			Conv	Conv		
Volume	4 Cav	2 Cav	FM 2-1-2	FM 2-2-4	4 Cav	2 Cav	FM 2-1-2	FM 2-2-4
100000	78	57	35	43	0.78	0.57	0.35	0.43
200000	84	69	47	50	0.42	0.34	0.24	0.25
300000	91	80	60	57	0.30	0.27	0.20	0.19
400000	97	92	72	64	0.24	0.23	0.18	0.16
500000	104	103	84	72	0.21	0.21	0.17	0.14
600000	110	115	96	79	0.18	0.19	0.16	0.13
700000	117	126	108	86	0.17	0.18	0.15	0.12
800000	123	138	121	93	0.15	0.17	0.15	0.12
900000	130	149	133	101	0.14	0.17	0.15	0.11
1000000	136	161	145	108	0.14	0.16	0.15	0.11
1100000	143	172	180	115	0.13	0.16	0.16	0.10
1200000	149	184	192	122	0.12	0.15	0.16	0.10
1300000	156	195	205	130	0.12	0.15	0.16	0.10
1400000	162	207	217	137	0.12	0.15	0.15	0.10
1500000	169	218	229	144	0.11	0.15	0.15	0.10
1600000	175	229	241	151	0.11	0.14	0.15	0.09
1700000	182	241	253	159	0.11	0.14	0.15	0.09
1800000	188	252	266	166	0.10	0.14	0.15	0.09
1900000	195	264	278	173	0.10	0.14	0.15	0.09
2000000	201	275	290	180	0.10	0.14	0.15	0.09
2100000	208	333	325	223	0.10	0.16	0.15	0.11
2200000	214	344	337	230	0.10	0.16	0.15	0.10
2300000	221	356	350	237	0.10	0.15	0.15	0.10
2400000	227	367	362	245	0.09	0.15	0.15	0.10
2500000	234	379	374	252	0.09	0.15	0.15	0.10
2600000	240	390	386	259	0.09	0.15	0.15	0.10
2700000	247	402	398	266	0.09	0.15	0.15	0.10
2800000	253	413	411	274	0.09	0.15	0.15	0.10
2900000	260	424	423	281	0.09	0.15	0.15	0.10
3000000	266	436	435	288	0.09	0.15	0.15	0.10
3100000	273	447	470	295	0.09	0.14	0.15	0.10
3200000	279	459	482	303	0.09	0.14	0.15	0.09
3300000	286	470	495	310	0.09	0.14	0.15	0.09
3400000	293	482	507	317	0.09	0.14	0.15	0.09
3500000	299	493	519	324	0.09	0.14	0.15	0.09
3600000	306	505	531	331	0.08	0.14	0.15	0.09
3700000	312	516	543	339	0.08	0.14	0.15	0.09
3800000	319	528	556	346	0.08	0.14	0.15	0.09
3900000	325	539	568	353	0.08	0.14	0.15	0.09
4000000	332	551	580	360	0.08	0.14	0.15	0.09

Table A-3b

Fastener Example Family Tools vs Traditional Multicavity Tools

	Lifetime Cost ($ in 000's)				Amortized Cost ($)			
	Conv	Conv			Conv	Conv		
Volume	4 Cav	2 Cav	FM 2-1-2	FM 2-2-4	4 Cav	2 Cav	FM 2-1-2	FM 2-2-4
100000	67	50	33	43	0.67	0.50	0.33	0.43
200000	74	62	47	52	0.37	0.31	0.23	0.26
300000	81	74	60	61	0.27	0.25	0.20	0.20
400000	88	86	73	70	0.22	0.21	0.18	0.17
500000	95	98	86	79	0.19	0.20	0.17	0.16
600000	102	110	100	87	0.17	0.18	0.17	0.15
700000	110	122	113	96	0.16	0.17	0.16	0.14
800000	117	134	126	105	0.15	0.17	0.16	0.13
900000	124	146	139	114	0.14	0.16	0.15	0.13
1000000	131	158	153	123	0.13	0.16	0.15	0.12
1100000	138	170	186	132	0.13	0.15	0.17	0.12
1200000	145	181	199	141	0.12	0.15	0.17	0.12
1300000	152	193	212	150	0.12	0.15	0.16	0.12
1400000	160	205	226	159	0.11	0.15	0.16	0.11
1500000	167	217	239	168	0.11	0.14	0.16	0.11
1600000	174	229	252	176	0.11	0.14	0.16	0.11
1700000	181	241	265	185	0.11	0.14	0.16	0.11
1800000	188	253	279	194	0.10	0.14	0.15	0.11
1900000	195	265	292	203	0.10	0.14	0.15	0.11
2000000	202	277	305	212	0.10	0.14	0.15	0.11
2100000	209	327	338	255	0.10	0.16	0.16	0.12
2200000	217	339	352	264	0.10	0.15	0.16	0.12
2300000	224	351	365	273	0.10	0.15	0.16	0.12
2400000	231	363	378	282	0.10	0.15	0.16	0.12
2500000	238	375	392	291	0.10	0.15	0.16	0.12
2600000	245	387	405	299	0.09	0.15	0.16	0.12
2700000	252	399	418	308	0.09	0.15	0.15	0.11
2800000	259	411	431	317	0.09	0.15	0.15	0.11
2900000	267	423	445	326	0.09	0.15	0.15	0.11
3000000	274	435	458	335	0.09	0.14	0.15	0.11
3100000	281	447	491	344	0.09	0.14	0.16	0.11
3200000	288	459	504	353	0.09	0.14	0.16	0.11
3300000	295	471	518	362	0.09	0.14	0.16	0.11
3400000	302	482	531	371	0.09	0.14	0.16	0.11
3500000	309	494	544	380	0.09	0.14	0.16	0.11
3600000	317	506	557	388	0.09	0.14	0.15	0.11
3700000	324	518	571	397	0.09	0.14	0.15	0.11
3800000	331	530	584	406	0.09	0.14	0.15	0.11
3900000	338	542	597	415	0.09	0.14	0.15	0.11
4000000	345	554	610	424	0.09	0.14	0.15	0.11

Table A-3c

Support Example Family Tools vs Traditional Multicavity Tools

	Lifetime Cost ($ in 000's)				Amortized Cost ($)			
Volume	Conv 4 Cav	Conv 2 Cav	FM 2-1-2	FM 2-2-4	Conv 4 Cav	Conv 2 Cav	FM 2-1-2	FM 2-2-4
100000	95	70	42	53	0.95	0.70	0.42	0.53
200000	104	85	57	63	0.52	0.42	0.29	0.31
300000	114	99	72	73	0.38	0.33	0.24	0.24
400000	123	114	87	83	0.31	0.29	0.22	0.21
500000	133	129	101	93	0.27	0.26	0.20	0.19
600000	142	144	116	102	0.24	0.24	0.19	0.17
700000	152	158	131	112	0.22	0.23	0.19	0.16
800000	161	173	146	122	0.20	0.22	0.18	0.15
900000	171	188	160	132	0.19	0.21	0.18	0.15
1000000	180	203	175	142	0.18	0.20	0.18	0.14
1100000	189	217	217	152	0.17	0.20	0.20	0.14
1200000	199	232	232	162	0.17	0.19	0.19	0.13
1300000	208	247	247	172	0.16	0.19	0.19	0.13
1400000	218	262	262	182	0.16	0.19	0.19	0.13
1500000	227	276	276	192	0.15	0.18	0.18	0.13
1600000	237	291	291	201	0.15	0.18	0.18	0.13
1700000	246	306	306	211	0.14	0.18	0.18	0.12
1800000	256	321	321	221	0.14	0.18	0.18	0.12
1900000	265	335	335	231	0.14	0.18	0.18	0.12
2000000	275	350	350	241	0.14	0.18	0.18	0.12
2100000	284	420	392	294	0.14	0.20	0.19	0.14
2200000	294	435	407	304	0.13	0.20	0.19	0.14
2300000	303	449	422	314	0.13	0.20	0.18	0.14
2400000	312	464	437	324	0.13	0.19	0.18	0.13
2500000	322	479	451	334	0.13	0.19	0.18	0.13
2600000	331	494	466	343	0.13	0.19	0.18	0.13
2700000	341	508	481	353	0.13	0.19	0.18	0.13
2800000	350	523	496	363	0.13	0.19	0.18	0.13
2900000	360	538	510	373	0.12	0.19	0.18	0.13
3000000	369	553	525	383	0.12	0.18	0.18	0.13
3100000	379	567	567	393	0.12	0.18	0.18	0.13
3200000	388	582	582	403	0.12	0.18	0.18	0.13
3300000	398	597	597	413	0.12	0.18	0.18	0.13
3400000	407	612	612	423	0.12	0.18	0.18	0.12
3500000	417	626	626	433	0.12	0.18	0.18	0.12
3600000	426	641	641	442	0.12	0.18	0.18	0.12
3700000	435	656	656	452	0.12	0.18	0.18	0.12
3800000	445	671	671	462	0.12	0.18	0.18	0.12
3900000	454	685	685	472	0.12	0.18	0.18	0.12
4000000	464	700	700	482	0.12	0.18	0.18	0.12

Table A-3d

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