MANAGEMENT AND SCHEDULING ASPECTS OF INCREASING FLEXIBILITY IN MANUFACTURING

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Abstract

An increasing number of manufacturing organizations are investing in flexible manufacturing systems (FMS) in an effort to be more responsive to customer demands without having to sacrifice on cost or quality. Often times, however, these companies are failing to achieve the expected benefits. This is especially true when the change in technology is not accompanied by any major changes in manufacturing and organizational practices.

This thesis looks at a change effort to convert from transfer lines to more flexible manufacturing work cells that is taking place within a consumer products company. Along with the change in technology, the company is implementing several lean production practices.

The thesis discusses how performance of the FMS was improved through set-up time reduction. It explains how total quality management (TQM) problem-solving techniques were applied to reduce set-up times. It also shows that system set-ups are sequence-dependent and suggests improved scheduling practices based on this.

To determine how the changes in manufacturing practices affect the use of the new technology, a change-management tool is introduced. This tool helps to determine and account for the various interrelationships between the technological and non-technological changes. To do this, it shows how practices can act to reinforce or oppose one another, and the percentage of opposing and reinforcing interactions provides information on how and when to implement change. The tool is applied to the studied change-effort and is shown to be especially useful in planning the implementation of radical change.

Thesis Supervisors: Stanley Gershwin, MIT Department of Mechanical Engineering
Erik Brynjolfsson, MIT Sloan School of Management
Len DeCandia, Engineering Group Manager, Epsilon Company
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Chapter 1
Introduction

This thesis presents an approach for improving the performance of a flexible manufacturing system (FMS) through both technical and managerial measures. Specifically, technical measures taken to reduce average product set-up time and set-up time variability are explained. In addition, ways to improve scheduling practices are discussed. In discussing relevant scheduling issues, greatest emphasis is placed on the role that set-ups play.

The role that non-technological factors play in the success of an FMS, or other new technology, is also addressed. A change-management tool designed to help organizations determine interactions between various types of practices is introduced. This tool is applied to the change effort taking place at the research site, and its general applicability in other organizations is discussed.

The research for this study was done on-site at a consumer products manufacturing plant within a company that will be referred to here as the Epsilon Company. The study focused on a pilot production group within this manufacturing plant. This group is the testing ground for recently-developed, more flexible manufacturing equipment. New manufacturing and organizational practices -- most of which are characteristic of lean production -- are also being introduced within the pilot group.
1.1 Motivation for Research

In conducting this research, there were two main goals. The first goal was to improve manufacturing performance in some specific and measurable way within the pilot group. The second goal was to gain insights that would benefit all manufacturing organizations in the implementation of flexible manufacturing technology and organizational change.

The first goal was satisfied by the implementation of improvement measures to reduce average set-up time and set-up time variability on the studied manufacturing system. In doing this, total quality management techniques were used to determine root causes and to set improvement-making priorities. The process followed was inspired by Shingo's (1985) efforts to reduce die exchange times at Toyota Motor Company.

The second goal was satisfied in two ways. First, insights into the scheduling of a flexible production system were gained. Currently, most of the scheduling literature on FMS's assumes that set-up times are negligible. This research provides knowledge about some of the relevant scheduling issues when set-up times are significant.

The change-management tool developed in this thesis is the second way in which this work should be of general benefit. This tool is valuable to companies planning any type of significant change, be it the implementation of flexible manufacturing or the introduction of a new human resource policy. By showing how old and new practices affect one another, this tool helps an organization determine which practices may be needed to make a change effort successful and what the general sequence and pace of implementation should be.
1.2 Literature Review

Prior to the late 1980s, mass production, where factories are focused on making a few products as cost effectively as possible, had been the most widely-accepted manufacturing strategy (Skinner, 1974). This strategy was made popular by Henry Ford in the US shortly after World War I and soon spread throughout the world (Womack, Jones and Roos, 1990).

Under this strategy both technology and worker tasks are focused. Equipment is typically designed to make just one product. Similarly, shop-floor workers' tasks are very narrowly defined. Taylorism, where industrial engineers study the manufacturing operation and then break it down into simple rote tasks which can be easily repeated by low-skilled workers, is often the method used to organize production tasks under mass production (Taylor, 1947). Under Taylorism, industrial engineers also conduct time studies to create measures of worker productivity levels. This type of model led to a mentality that the engineers and the managers were the "thinkers" and the shop-floor workers were the "doers" (Simmons and Mares, 1983). A more complete list of mass production characteristics is given in Table 1.1.

The success in the 1980s of "Japanese manufacturing," a strategy for achieving both high quality and wide product variety at low costs, caused many companies to rethink their manufacturing strategies. Until that time it was popularly believed that one had to trade-off low cost and/or high quality to achieve wide product variety. At Toyota Motor Company,
Table 1.1: Key Traits of Mass Production

<table>
<thead>
<tr>
<th>Trait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long production runs</td>
</tr>
<tr>
<td>Low product mix</td>
</tr>
<tr>
<td>Designated equipment</td>
</tr>
<tr>
<td>Standardized parts</td>
</tr>
<tr>
<td>Standardized jobs</td>
</tr>
<tr>
<td>Low cost emphasized over high quality</td>
</tr>
<tr>
<td>Large inventory buffers</td>
</tr>
<tr>
<td>Often vertically integrated</td>
</tr>
<tr>
<td>End-of-line quality control</td>
</tr>
<tr>
<td>Detailed division of labor</td>
</tr>
<tr>
<td>All elements (people, parts, materials, machines) strictly controlled</td>
</tr>
<tr>
<td>Very structured, hierarchical organization</td>
</tr>
<tr>
<td>Centralized decision making</td>
</tr>
<tr>
<td>Limited training to teach specific job-related skills</td>
</tr>
</tbody>
</table>

Sources: Milgrom and Roberts (1993); Womack, Jones, and Roos (1990); Thomas (1993)
however, Eiji Toyoda and Taiich Ohno found that they could have all three if they designed the equipment, processes, and workers' job descriptions to be more flexible. The flexible equipment allowed them to have a wider product line, while costs were kept low through lower inventories and low set-up costs. They also found that they were able to achieve higher productivity and quality by utilizing the mental capabilities of all workers through, for example, their involvement in continuous improvement efforts and decentralized decision making. These type of manufacturing practices have come to be known as "lean production," as they remove many of the perceived excesses (labor, inventory, etc.) of mass production (Womack, Jones and Roos, 1990). A more comprehensive list of lean production traits is given in Table 1.2.

With the success of Toyota and others employing lean production techniques, several companies are now trying to implement similar techniques in their factories. The first steps that many are taking in doing this is to replace designated manufacturing transfer lines with FMS's and to adopt just-in-time (JIT) inventory controls. This has led to a need to better understand how the issues of frequent set-ups and low buffer levels affect scheduling practices.

Gershwin (1987 and 1993), Buzacott (1967 and 1982), Buzacott and Hanifin (1978), Dallery and Gershwin (1991) and several others have written extensively on transfer-lines. Very little has been published, however, on the scheduling of FMS's, and, in what has been published, it is usually assumed that set-up times are negligible. This thesis should provide a better understanding of what some of the critical scheduling issues are for manufacturing systems with significant set-up times. It will also look at how maintaining low buffer levels affects scheduling of an FMS.
Table 1.2: Key Traits of Lean Production

- Machine flexibility
- Broad product lines
- Shared components across different products
- Broadly-defined job functions
- Flexible work rules
- Focus on quality through total quality management (TQM)
- More frequent and speedier product redesigns and improvements
- More frequent product introductions/shorter product development cycles
- Short production runs
- Low inventories
- Make-to-order versus make-to-stock
- More outsourcing
- Tighter supplier and customer relations
- More fluid, flatter organizational structure
- Workers make local decisions
- Open communication between workers and management
- All employees participate in continuous improvement efforts
- Emphasis on continuous learning

Sources: Milgrom and Roberts (1993); Suarez, Cusamano, and Fine (1992); J. Womack, D. Jones and D Roos (1990); and Thomas (1993)
There is strong evidence that even with proper scheduling and buffer controls, many FMS's will still fail to achieve the expected gains in productivity over traditional, more specialized equipment. In a study of 95 US and Japanese companies with flexible manufacturing technology, Jaikumar (1986) found that the majority of the US companies failed to achieve increased productivity -- and that in some cases productivity even declined -- with the more flexible technology.

He attributes this to the fact that the less successful companies continued to run their factories by mass production rules and that such practices act in opposition to the benefits of using flexible technology. For example, these companies tended to do few product set-ups and to have high inventory and high-volume production runs. MacDuffie and Krafcik's (1989) study of automotive assembly companies supports this idea of needed complementary practices. In their study of 62 plants they found that the plants with the highest productivity and quality levels had in place both flexible manufacturing equipment and lean production organizational practices.

Several researchers have argued intuitively that complementary practices and strategies are needed in order to reap the full benefits of FMS's or other advanced technologies. For example, Bryjolfsson (1990) models how changes in technology and the costs of information will lead to a cluster of organizational changes consistent with the "new managerial work." Suarez, Cusamano, and Fine (1992) and Milgrom and Roberts (1990, 1991, and 1993) apply mathematical models to try to quantify the complementarities. Suarez et al. use an established multivariate statistical technique called principal components analysis (PCA) to determine the correlation coefficients, while Milgrom and Roberts apply lattice theory and supermodularity.

A second goal of this thesis research was to find a more intuitive way to help organizations understand the complex web of interrelations. To do this a change-management tool,
referred to as the Matrix of Change (MOC), was developed. Inspired by the House of Quality (Hauser and Clausing, 1988), the MOC allows one to visually see the interactions between various activities. In filling in the matrices, one can simply use positive and negative signs to indicate whether two practices act to reinforce or oppose one another, or one can apply a mathematical model or an empirical measure to estimate the magnitude of the interaction. Although less rigorous, the use of positive and negative signs is easier to visually interpret, and that is the method used in this thesis.

1.3 Layout of Document

Chapter 2 provides historical background on Epsilon's motivation for change. In sections 2.1 and 2.2 the market conditions and Epsilon's manufacturing strategy prior to the decision to invest in flexible manufacturing technology are discussed. Then in section 2.3 the technology investment as well as the decision to adopt new organizational and social practices is addressed.

Chapters 3 through 6 look at the technical improvement efforts. Chapter 3 orients the reader by giving a detailed description of the layout of the flexible work cell and by discussing the relevant scheduling and performance factors for the manufacturing system. Chapter 4 addresses the causes and types of machine downtime for the flexible work cell. Chapter 5 then examines an effort conducted to reduce average set-up time, one of the major causes of machine downtime on the maker. Chapter 6 proposes a method for grouping set-ups by complexity level and discusses the implications that this grouping methodology has for scheduling of the work cell.

In Chapters 7 through 10, the view of what affects manufacturing performance is broadened. Chapter 7 addresses the role that complementary practices play in
implementation of new technology and discusses how this has affected the change effort within the pilot group.

Chapter 8 introduces a change-management tool aimed at helping organizations better understand the interactions between complementary practices, and Chapter 9 examines the tool's implications for change management.

In Chapter 10 the tool is applied to the change effort within the pilot group. The results of this application and the general usefulness of the tool are discussed.

Chapter 11 draws conclusions on the technical and managerial efforts to improve the performance of the flexible work cell and discusses areas of future work.
Chapter 2

Motivation for Change

The need for change arose from the fact that Epsilon began to lose market share in the product category produced at the research site. In examining why this had happened, management determined that the manufacturing strategy the company had been following was no longer competitive.

2.1 Industry Dynamics

The motivation for the change effort within this company arose in the late 1980s and early 1990s when the company's market share began to drop significantly. Between 1989 and 1991 the company's market share in one of its main product lines dropped a total of 9.0 percentage points, which represented a 16 percent decrease in its total market share (see Figure 2.1). In addition, its dollar share dropped by 8.8 percentage points, or a 13 percent decrease in the company's total dollar share (see Figure 2.2).

There were many reasons for this market share loss. Competition had increased due to
Source: Nielsen

Figure 2.1: Industry Market Share Graph for the Period 1989-1991
Source: Nielsen

Figure 2.2: Industry Dollar Share Graph for the Period 1989-1991
new entrants, in the form of private labels and a new Japanese brand-name competitor,\(^1\) and the competition was more cost-competitive and responsive to certain customer needs than was Epsilon.

Even with the new competition, most customers perceived the overall quality of the Epsilon product to be highest and were willing to pay more for the Epsilon brand name. However, there were limits to how much more they were willing to pay. For the 3-year period over which the market data was collected, Epsilon raised its average product price by 18 percent in order to offset the effect of rising production costs and falling sales.

It is likely that this created a negative feedback loop, with sales continuing to drop more as prices increased. Over the three-year period, Epsilon's market share in this product category dropped by 16 percent, while the average price of its products increased by 18 percent (see Figure 2.3). Also, as more consumers tried the other brands, they discovered that these brands offered some desirable features that were not available in Epsilon's products. Thus, in order to regain competitiveness, Epsilon needed to lower costs and increase customer responsiveness. Purchasing new equipment was one way to accomplish these objectives.

Epsilon had not invested in new manufacturing equipment since the early 1980s, and the majority of its equipment had been bought in the early 1970s. With such old equipment, Epsilon had a high percentage of machine downtime, and this percentage continued to

---

\(^1\) It is not obvious why new entrants emerged at this time. One reason may be that the availability of new, more flexible technology lowered the barriers of entry (i.e. new entrants could start off with flexible equipment that could easily be changed over to make a variety of products that met a wide variety of customer needs, while older producers had more specialized equipment.) Also, since the majority of new competition came from private label products, it might be that with the maturing of this product type, consumers were becoming less sensitive to brand name.
Figure 2.3: Average Product Price and Market Share for the Period 1989-1991

Source: Nielsen
increase with time. In addition, its main competitors had newer equipment that had both higher throughput rates and greater flexibility. This added flexibility allowed its competitors to hold less work-in-process (WIP) and finished goods (FG) inventories. All of these factors led to Epsilon's cost of goods being higher than its competition's.

In addition to being lower cost, the competition was gaining market share because they were more responsive to certain customer needs. Even though Epsilon had more products in its product line, the different products in the competition's lines were more differentiated and seemed to respond better to actual customer needs. This was especially true for packaging. The customer, in general, found that the competition's products were packaged in a way that made them easier to use.

Another factor in Epsilon's loss of market share was the fact that the competition had come out with a new product feature that proved to be extremely popular with consumers. Epsilon had not ambitiously pursued developing this new feature, and, as a result, was now trying to play catch-up in this category.

The main reason behind Epsilon's not being more responsive to these customer needs was that its equipment was too inflexible to easily accommodate the needed modifications. Some flexibility could be achieved through hand packaging, but this was very costly.

2.2 Historical Manufacturing Strategy

The older equipment in place in the factory was largely purchased in the 1970s when mass production's "focused factory" was in vogue (Skinner, 1974). In keeping with the tenets of mass production, all of this equipment is dedicated to either assembling or packaging one given product type. Products in this industry vary in both size and types of materials used. Accordingly, each of the older assembly machines is only capable of making one
product of a given size and material type. Similarly, the packaging equipment is only capable of packaging one size of product in one set quantity.

To further focus manufacturing, the older equipment was originally arranged by type. Packaging was placed in one area and assembly in another, and within these areas the equipment was arranged by the type and size of the product being made or assembled. The workers running this equipment, similarly, have narrowly-defined jobs in order to allow each worker to focus on his or her specific tasks. For example, machine operators are trained on just one type of equipment. Their job is only to run that particular piece of equipment. They do not have to worry about getting raw materials because that is the responsibility of the line tenders. Nor do they have to worry about doing any kind of machine maintenance, as that is the sole responsibility of the mechanics. Thirteen key practices that were in place in the company's historical manufacturing strategy are listed in Table 2.1. Many of the listed practices are the same as those listed in Table 1.1 for mass production. (For those practices which are the same but are worded differently, a reference to the mass production practice is made in parentheses after the listed trait.)

This focused strategy makes sense as long as you have a small product mix. It worked amazingly well for Henry Ford during the time that automobile customers were satisfied with a variety limited to black Model Ts. Up until the 1980s the situation was similar for the product category produced at the research site, with only a small product mix being offered by any of the competition. Also, since the product category was very mature, there was no strong reason to think that the industry dynamics would change at that time. Taking this into account as well as the fact that in the 1970s Epsilon had almost 100% of
Table 2.1: Key Traits of Historical Manufacturing/Business Strategy

- Designated equipment
- Production areas separated by machine type, rather than product line
- Narrow job functions (standardized jobs)
- Salaried employees make all decisions ("thinkers")
- Hourly employees follow instructions ("doers")
- Functional groups work independently of one another (detailed division of labor)
- Keep line running no matter what (cost emphasized over quality)
- Thorough final inspection by QA (end-of-line quality control)
- Raw materials made in-house (vertically integrated)
- Large WIP and FG inventory buffers
- Production workers' pay tied to amount produced
- Vertical communication flow (very structured, hierarchical organization)
- Six management layers (centralized decision making)
the market share, continuing on with a mass production manufacturing strategy appeared to be a good idea.

According to the prevailing investment strategy, it also made sense for the company not to invest in new capital equipment. When market share is relatively high and market growth is relatively low, Boston Consulting Group's growth share matrix indicates that the business should be treated like a cash cow. Few investments should be made, and the profits should be milked (Hax and Majluf, 1984). The dropping market share in the late 1980s, however, caused Epsilon to rethink their manufacturing and investment strategies.

2.3 New Manufacturing Strategy

In order to turn things around, the company decided it needed to do three main things -- invest in new capital equipment, restructure its product lines, and focus on its core competencies.

2.3.1 Flexible Technology

Epsilon determined that it needed to invest in new capital equipment in order to maintain a strong presence in the studied market category. The perceived disadvantages of the older technology are listed in Table 2.2. Some of these disadvantages include a high percentage of mechanical downtime (14%), high percentage of waste (8.5%), and low throughput rates (less than two times the rates of more advanced systems). The fact that the older technology is virtually impossible to modify to either make improvements to existing products or to produce new products is another strong disadvantage.
Table 2.2: Disadvantages of Older Technology

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Low maximum operating speed (0.4 [product unit/minute])^2</td>
</tr>
<tr>
<td>• Heavy maintenance required due to age and complexity of machinery</td>
</tr>
<tr>
<td>14% mechanical downtime</td>
</tr>
<tr>
<td>• High waste levels (8.5%)</td>
</tr>
<tr>
<td>• High labor content</td>
</tr>
<tr>
<td>• Each machine only capable of making one product type</td>
</tr>
<tr>
<td>• High inventory levels associated with specialized equipment</td>
</tr>
<tr>
<td>• Difficult to retrofit equipment to meet customers' packaging requirements</td>
</tr>
<tr>
<td>• Difficult to retrofit equipment to make most of the desired new products</td>
</tr>
</tbody>
</table>

^2 "Product unit" is a generic measure, which is an undisclosed multiple of a standard unit of measurement for quantity. This convention is used in order to disguise proprietary production information.
In order to overcome these disadvantages, the company decided that the new equipment would have to be more flexible. Commercially-available equipment, however, did not offer the degree of packaging flexibility that was desired. The company turned this around, and decided to make flexible technology a source of competitive advantage for them by designing the equipment in-house. To keep competitors from learning the details of the new technology and thus maintain their competitive advantage, it was decided that no outside tours would be given through the new production area and that the new equipment would be placed in an area of the factory that was not visible from any outside windows.

Reduced costs and improved customer responsiveness were the key factors used to justify the investment in the new technology. The specific cost and quality factors cited are given in Tables 2.3 and 2.4. After the proposal was approved, the company began work on designing and implementing the first flexible work cell, which is now in production in the pilot group. Initially, only one FMS was built and put into production. The reasoning behind this was that improvement ideas gained from using the first system could be incorporated into the next generation equipment. Near the end of the research period, the designs for the next systems were completed and a graduated plan for installing the additional systems and converting the majority of production over from the old technology was being formulated.

2.3.2 Non-Technological Changes

In addition to the new technology, several non-technological changes were made. Some of these changes were seen as being directly related to the new technology, but most were not. All of the changes, however, were considered to be in-line with the recently-formulated
### Table 2.3: Cost Benefits of New Technology

- Higher throughput rates (2 to 5 times greater)
- Lower maintenance costs
- Higher yields/lower waste levels
- Less downtime to replenish raw material (materials automatically added while machine is running)
- Lower FG and WIP inventory levels
- Lower labor content
- Less factory space needed (number of production systems cut by a factor of at least 3 and majority of manual packaging eliminated)
- Shorter product development cycles

### Table 2.4: Increased Customer Responsiveness Due to New Technology

- More differentiated product mix
- Higher line-item fill rates
- Better able to meet customer packaging requirements
- More frequent product introductions/shorter product development cycles
- More frequent and speedier product redesigns and improvements
operations vision statement, a four-point objective statement championed by the Operations Vice President (see Figure 2.4). Furthermore, some of the changes were made plant-wide, while others were initially made just within the pilot group.

**Line Rationalization**

The first major change, which was plant-wide, was to restructure existing product lines. At that time Epsilon had several different line-items on the market; however, there were only slight differences among many of them. It was expensive to produce such a wide assortment, and market research indicated that often the customer did not see a clear difference among several of the line items. In addition, with so many items, it was difficult for Epsilon to maintain high overall line-item fill rates, where fill rate is the average percentage of the total retail customer's demand that is met for each line item.

Thus, an effort called "line rationalization" was conceived. Under this effort, product variations that were not seen as adding any additional value to the customer over other line items were eliminated, and the total number of line items within the product line were reduced. This led to decreased production costs, as well as increased line-item fill rates. In fact, projections indicate that line rationalization should allow the average line-item fill rate to increase from 86 to 98 percent.

It seems ironic that the total number of products was decreased in order to be more responsive to customer needs. At that point in time, however, there was great overlap in the existing product-line assortment. The goal of line rationalization was to eliminate variety for variety sake (which led to increased costs for the consumer) and to promote an attitude that the development of any new line items should result out of a true market need.
Operations Vision Statement

We are a bold, reliable, forward-looking organization committed to the customer. We meet all customer orders on time by focusing on this vision:

- An energized organization of trained, developed and empowered people
- Zero non-conformance to requirements
- Conversion of raw materials to finished goods in 24 hours
- Elimination of all non-value added costs

Figure 2.4: Operations Vision Statement
Core Competencies

Another set of changes were made in an effort to focus the organization on its core competencies. The firm determined that its existing, value-adding core competencies were in marketing and final assembly and packaging operations. Mechanical and electrical design were also determined to be valuable competencies as long as in-house equipment design was used as a source of competitive advantage.

The investment in the new technology supports all three of these areas. The flexibility of the new equipment makes it easier for Marketing to implement new product ideas and special promotions. The new technology assists Operations in its daily activities, and designing the new technology serves to strengthen internal Engineering design skills.

Two other non-technological changes that were made in the effort to focus on core competencies were 1) the implementation of concurrent engineering practices and 2) the conversion to outsourcing of raw materials. Through concurrent engineering practices, communication between the Marketing, Engineering, and Operations groups should improve, and this, in turn, should lead to better utilization of the various competencies within each of these groups. The decision to outsource raw materials was made because these operations were not considered to be core competencies; high quality materials and more responsive service could be achieved through outsourcing.

Quality Focus

Several other changes were made to place greater focus on quality issues. For example, all workers received total quality management (TQM) training and are now encouraged to use systematic problem solving techniques. Another effort to focus on quality was the rearrangement of production areas (both the old and new technology) into work cell formats, where assembly and corresponding packaging operations are clustered together.
The hope in doing this is that downstream quality issues will be highlighted. Another intent is to make WIP inventories more visible, so that workers will be less likely to build up excess buffer levels.

**Flatter, More Open Organizational Structure**

Another plant-wide effort is the reduction of management levels, which is leading to a "flatter" organization. Simultaneously, there are efforts to decrease reliance on vertical communication and to increase horizontal, cross-functional communication. Concurrent engineering and continuous improvement efforts are two examples of how this is being promoted.

Also, there is a general feeling that the company has to move away from its traditional "us versus them" union-management relationship. This adversarial union-management relationship evolved over several decades under the plant's mass production strategy. With such a built-up history, it has been difficult to make changes aimed at restructuring this relationship. The existence of narrowly-defined work rules in current employment contracts further limits what changes can be easily made.

**Pilot Group Changes**

The way in which the pilot group was formed has allowed Epsilon more latitude to make change within this group than in the rest of the plant. No workers were involuntarily moved to the pilot group; nor were any employees laid off as a result of the new technology. Instead, the company allowed workers to join the group voluntarily. Because of this, the union has allowed the company greater flexibility in determining job classifications and pay structure within the pilot group. Workers were fully informed of the type of changes that would be in place within the group prior to joining in order to screen out people who would be resistant to the type of changes that were to be made.
Scope of Responsibilities

The company knew from the start that job responsibilities had to be broadened in order to efficiently utilize the new technology. In addition to their current skills, operators would need basic computer skills and the ability to do frequent product set-ups in order to run the FMS. In addition, the company decided to stipulate that workers would have to operate all three machines within the flexible work cell. This was done to increase quality. The reasoning was that if the workers are their own customers and suppliers (working on both upstream and downstream operations) that they will have a better feeling for relevant quality issues.

Removal of Incentive Pay

Another change was that the pilot group workers are all paid the same flat hourly rate instead of having their pay based on the quantity they produce. Again, part of the reason for this is to increase the focus on quality. The company does not want the employees to sacrifice quality for quantity. Another reason for going to flat pay is to discourage workers from building up large inventory levels. JIT raw material deliveries and kanban inventory controls were other measures put in place within the pilot group to help maintain low inventory levels.

Team Focus

Finally, new practices specifically aimed at eliminating the "us versus them" attitude were proposed for the pilot group. The union workers within the group are involved in setting work rules. For example, initially management wanted to broaden job responsibilities so that operators were required to do mechanical changeovers and some preventive maintenance. The union workers within the group, however, were against this -- partially because the mechanics wanted to maintain their separate status, but also because certain operators would not have been able to meet the additional (both physical and skill) requirements. Management listened to their arguments and agreed to continue to have
mechanics perform these functions. Union workers also serve on the design review committee, and, in that capacity, give feedback to the engineers designing the next generation equipment. In addition, the engineers and operations management within the pilot group frequently solicit input informally from the union workers.

The ultimate plan is to organize the pilot group production workers into "empowered work teams." Within such teams, the supervisor will have the title of group leader and will work more closely with the line workers. For example, if the group were short-handed for some reason, the group leader would be able to fill in on the line. Also, workers will be given more authority to make certain local decisions. Already, pilot group workers are able to shut down the line if they feel there is a problem, and they often have the final word on whether product is rejected or accepted. In this way it is hoped that the effort will be seen as a team effort and the team leader/supervisor more as a teammate than someone who tells the workers what to do and then monitors their performance. A list of 14 practices that are in place or in the process of being put in place within the pilot group (and in some cases throughout the entire plant) is given in Table 2.5. Many of these practices are the same as those listed in Table 1.2 for lean production. (For those which are the same but are worded differently, a reference to the corresponding lean production practice is made in parentheses after the listed trait.)

Issues surrounding the discussed technological and organizational changes taking place within the pilot group are addressed in the following chapters.
Table 2.5: Key Traits of New Manufacturing/Business Strategy

<table>
<thead>
<tr>
<th>Trait</th>
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<tbody>
<tr>
<td>Flexible equipment and jobs (machine flexibility, broadly-defined job functions)</td>
</tr>
<tr>
<td>Supervisors can fill in on line (flexible work rules)</td>
</tr>
<tr>
<td>Systematic problem solving (TQM)</td>
</tr>
<tr>
<td>All employees contribute ideas (all employees participate in continuous improvement efforts)</td>
</tr>
<tr>
<td>Concurrent engineering</td>
</tr>
<tr>
<td>Vision given from top management</td>
</tr>
<tr>
<td>Operators responsible for quality</td>
</tr>
<tr>
<td>Stop line if not running at speed (focus on quality)</td>
</tr>
<tr>
<td>All operators paid same flat rate</td>
</tr>
<tr>
<td>Areas organized in work cells</td>
</tr>
<tr>
<td>All materials outsourced (more outsourcing)</td>
</tr>
<tr>
<td>Use kanban inventory control (low inventories)</td>
</tr>
<tr>
<td>Three to four management layers (more fluid, flatter organizational structure)</td>
</tr>
<tr>
<td>Line rationalization</td>
</tr>
</tbody>
</table>
Chapter 3

Description of Pilot Work Cell

This chapter provides a description of the work flow through the flexible manufacturing cell that was studied. In this case, flexible refers to both product and process. The assembly portion of the cell is capable of assembling a variety of products, while both of the packaging systems are capable of packaging a variety of different products. In addition, the first packaging system has process flexibility, as it is able to vary the assortment and quantity of product codes packaged at any one time. The layout of the work cell, product demand, and some scheduling and performance issues are described below.

3.1 Work Cell Configuration

The work cell consists of three main components -- one main station which assembles the products (which will be referred to as the "maker") and two packaging stations (which will be referred to as "packer 1" and "packer 2"). The maker assembles various products which are then packaged at either packer 1 or packer 2. There are three main inventory storage areas in the system. The first is for raw material (RM) inventories and is located in front of
Figure 3.1: Production Flow through Work Cell

- B_{11}-B_{15} = Raw Material Buffers
- M_1 = Maker
- B_{21}-B_{25} = WIP Buffers
- P_1 = Packer 1
- P_2 = Packer 2
- B_3 = Finished Goods Buffer
the maker. The second is for WIP inventories and is located between the assembling and packaging stations. The final buffer area is for FG inventories and is located after the two packaging stations. A schematic of the production cell is given in Figure 3.1.

Five different raw materials are needed to make any one product. Although the size and type of raw materials used for the different products vary, a total of five are needed at any one time. The manufacturing process is continuous, but assembling operations must be shut down whenever a given raw material needs to be replenished. The maker is currently being modified so that the replenishment of three of the five raw materials is done automatically while the maker is still running.

During the first half of the assembly operations, the individual parts are physically connected to one another. Midway through the maker, the parts are separated from one another. As the product comes off of the maker, it is stored on an inventory cart. At this point the different product types are referred to by WIP codes. A production run is typically as long as it takes to fill a cart; although, if demand is less than a cart load or if the packaging system downstream is starved for material, sometimes shorter runs are made. Furthermore, the size of a full inventory cart varies slightly for the different products. During the course of this research, five different WIP codes were assembled on the maker. The approximate amount of product that can be stored in a cart for each of those five WIP codes is represented by $X_i$, where $i$ is the WIP code number. These values are given below:

- $X_1$: 100 product units
- $X_2$: 90 product units
- $X_3$: 80 product units
- $X_4$: 80 product units (due to demand, the typical size is 40)
- $X_5$: 80 product units (due to demand, the typical size is 40)
The use of inventory carts provides a discontinuity in the otherwise continuous production process. The accumulation of WIP onto the carts serves to decouple the assembly portion of the manufacturing operation from that of the packaging, so these operations are somewhat buffered from machine failures and other causes of downtime in the other half of the cell. The size of the WIP buffer level between assembly and packaging operations is equal to the sum of the amount of product in each filled cart. Thus, the buffer level is equal to the total amount of product in inventory carts and is bounded by the sum of the products of \( X_i \) and \( N_i \), where \( N_i \) is the number of carts filled with WIP code \( i \). Or,

\[
B_2 = p_1 + p_2 + \ldots + p_j + \ldots + p_n \leq \sum_{i=1}^{s} X_i N_i \text{ [product units]},
\]

where \( B_2 \) is the amount of material stored in all of buffer 2, \( p_j \) is the amount of product on cart \( j \), \( n \) is the total number of filled carts, and \( N_i \) is the total number of carts filled with WIP code \( i \). If all \( n \) carts are filled, the maker is blocked and unable to assemble any additional products.

From buffer 2, products go on to either packer 1 or packer 2 in inventory cart lot sizes. Both packer 1 and packer 2 need to be shut down when a new inventory cart of WIP is added to the system. Packer 1 is highly flexible and capable of running all five codes. During, my stay, however, only codes 1, 2, and 3 were run on this system. Thus, for simplicity's sake, it is assumed that only these three codes are run on packer 1. Similarly, it is assumed that only codes 4 and 5 are run on packer 2.

Packer 1 is capable of packaging varying assortments of up to four different WIP codes at any one time. During the entire research period, however, packer 1 packaged just one final product that was an assortment of product codes 1, 2, and 3. Again, for reasons of simplicity, it is assumed that these three codes are always run simultaneously on packer 1. Thus, the buffer levels for WIP codes 1, 2, and 3 (\( B_{21} \), \( B_{22} \), and \( B_{23} \)) must be greater than...
zero at all times in order to keep packer 1 from being starved. (This is indicated on the schematic by combining the $B_{21}$, $B_{22}$, and $B_{23}$ buffers into a larger buffer area.)

Packer 2 is less flexible, and is only capable of packaging one product code at a time. Thus, either the buffer level for WIP code 4 ($B_{24}$) or for WIP code 5 ($B_{25}$) must be greater than zero to keep packer 2 from being starved. After the packaged end products come out of either packer 1 or packer 2 they are then stored in a FG warehouse or shipped directly to a retail outlet.

### 3.2 Demand for Parts

#### Demand at Packer 1

Demands for product codes 1, 2, and 3 were constant during the time of the study. These codes were being made for a new final product that was to be released to stores later in the year. Thus, demand for these codes was set at a constant value in order to build up FG inventory levels to the forecasted quantities needed at the time of the product release. Codes 1, 2, and 3 were packaged in a ratio of 4:3:1, respectively. Using a conservative waste level estimate of 6 percent for the FMS$^4$ and assuming 15 shifts per week, results in the following product demands$^5$ at packer 1:

- **code 1:** 85 [product units/shift] or 1272 [product units/week]
- **code 2:** 64 [product units/shift] or 954 [product units/week]
- **code 3:** 21 [product units/shift] or 318 [product units/week]
- **Total Demand:** 170 [product units/shift] or 2544 [product units/week]

---

$^3$ Meaning higher than expected.

$^4$ Six percent is the waste level for the entire system. Since the majority of waste products are removed at the packaging stations, the entire 6 percent is added on to the demand at those stations.

$^5$ Demands are typically given by Planning in weekly amounts. The shift demands are also given for packer 1 to help illustrate that all three codes are always being consumed whenever packer 1 is running. By contrast, packer 2 rarely packages more than one code during a shift's time.

40
In the future, total demand at packer 1 is expected to remain roughly the same, although the product mix may vary.

**Demand at Packer 2**

During the research period, packer 2 was used to package two existing products. One of these used WIP code 4 and the other used WIP code 5. Unlike the demand for the WIP codes being used for the new product ramp-up, demand for these codes fluctuated due to effects in the marketplace. Again, assuming a 6 percent waste level, the ranges over which demand varied for packer 2 are given below:

- **code 4:** 0 - 460 [product units/week]
- **code 5:** 0 - 460 [product units/week]
- Total Demand: 0 - 920 [product units/week]

As some of the older technology in the plant is phased out, total demand at packer 2 is expected to increase to about 2544 product units per week, or nearly triple the current demand.

**Demand at Maker**

Since all of the WIP codes for the work cell are made on the maker, the maker needs to produce all the product consumed by both packer 1 and packer 2, or

\[ d_M = d_{P1} + d_{P2}, \]

where \( d_M \) is the demand that must be met by the maker, \( d_{P1} \) is the demand for product at packer 1, and \( d_{P2} \) is demand for product at packer 2, with waste levels factored in. As the old technology is phased out and the work cell gears up to full production, the anticipated weekly demand at the maker is 5088 production units. If the maker is able to meet this demand, four to five of the new flexible assembly stations should be able to replace 21 of the older, specialized assembly stations.
For the maker to meet its demand, it must have corresponding levels of the needed raw materials. These levels vary not only with total demand, but also with changes in product mix. The scheduling of raw material deliveries, in itself, is not trivial. The scheduling issues in this paper, however, will focus on those related to the scheduling of the maker to meet the demand of the two packers. Although the scheduling of raw material arrivals at the maker is not dealt with directly, it is not assumed that the maker is never down due to starvation. All downtime, including that due to starvation, is incorporated into the maker throughput rates, which is discussed in more detail in Chapter 4.

**Push-Pull System**

Both push and pull systems are currently used to move inventory through the flexible work cell. Currently raw materials are pushed into the system. They are delivered from storage to the work cell area in average daily amounts. The goal, however, is to move more towards a pull system for raw materials. To do this, there is a plan to decrease time between supplier deliveries (down to every 1 to 5 days), so that material is ordered as it is needed. Smaller and more frequent RM deliveries will lead to reductions in: 1) needed RM inventory storage space, 2) inventory holding costs, and 3) losses due to obsolescence and storage damage (such as due to extreme temperature or humidity levels).

Although raw material is "pushed" to the maker, the plan is for it to be "pulled" to packer 1 and packer 2. This will be accomplished through a kanban system, where an inventory cart of product is produced for every cart consumed at either packer 1 or packer 2. This process was followed during the initial proving of the new technology. When the flexible cell went into production, the pilot group slipped back into a "push mentality" -- running the maker until all of the inventory carts were filled, no matter what was happening at the

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6 Some of the raw materials that are currently still made in-house are sometimes delivered straight to the maker, rather than going into storage first.
packaging lines. Now the production group is moving back towards a pull system using kanban inventory control.\textsuperscript{7}

Furthermore, in the future it is planned that current demand, rather than historical sales data, will be what "pulls" finished goods through the final production stations. Under this scenario, finished goods warehouses could often be bypassed with goods being shipped directly to retail outlets. Two company goals -- to use information technology to connect directly to both suppliers and customers and to reduce total cycle time to 24 hours -- will assist this effort.

\textbf{3.3 Machine Flexibility}

The flexibility of the maker is achieved through both mechanical and electrical means. Mechanical die stations and other physical components are designed so that they can be easily replaced or adjusted during certain product set-ups. In addition, computer programs are downloaded in order to reset certain parameters when a different product is run. Currently, the maker is operated through voice controls. There are plans to add mechanical override controls, which could be used in the case of a problem with the voice-recognition system.

Two measures of flexibility are average set-up time and number of set-ups. Machine flexibility is related to the time it takes to do set-ups; the shorter the time, usually the more flexible the system. In addition, the number of set-ups performed is an indication of the degree to which the flexibility of the system is being utilized; the more set-ups, the higher the utilization of flexibility. Inventory levels can also be an indication of how effectively the system flexibility is being used. Suarez, Cusamano and Fine (1992) have found that

\footnote{Actually, a push system, where material is pushed from the maker into buffer 2 until a target level of WIP for each of the 5 codes is achieved would not be drastically different from this.}
increased flexibility allows a manufacturing system to be more responsive to changes in current demand and, thus, lowers needed buffer levels.

3.3.1 Product Set-Ups

The term "flexible manufacturing system" is used in several different contexts. In the literature at least four are mentioned (Gershwin, 1993; Fine, 1993; Suarez et al., 1992). They are:

1) Product flexibility: ability to produce more than one part-type
2) New-product flexibility: ability to create new part-types quickly
3) Process flexibility: ability to process the same part in more than one way
4) Volume flexibility: ability to increase output with no detrimental effect on efficiency and quality

The maker has product flexibility, and requires product set-ups in order to exercise this flexibility. The fact that the maker is changed over to produce different product WIP codes is the key feature that sets it apart from the designated transfer lines on the other side of the factory. The less time that is spent on set-ups, the more time the maker is available for production and, thus, the more flexible it is.\footnote{The other issue that makes "manufacturing flexibility" a vague term is that there are no hard measures for the different types of flexibility. For example, product set-up time is a measure of the flexibility for types 1 and 2, yet a system that has one minute set-up times and one that has 8-hour set-up times may both be considered flexible.} An effort to reduce average set-up times on the maker and the results of that effort are discussed in Chapter 5.

For the maker there are currently 10 different set-ups that are regularly performed on the system. These 10 set-ups can be broken into six set-up categories of similar complexity. The average time and variability involved in each of these set-ups affects when and how often each of these set-ups is performed. This issue is examined in depth in Chapter 6.
Chapter 4
Production Downtime

Any operation of a manufacturing system that leads to the production of part types is considered a production event. This is the only type of event that directly affects the company's bottom line goal of making money by producing products that are wanted by customers. System time that is spent on production events is referred to as uptime. Events that take time away from production events are referred to as downtime. Some downtime events are controllable, while others are not. Some of the controllable downtimes, such as preventive maintenance and product set-ups, may actually result in the system being more productive when it is up then if the time was never taken for these activities.

Nonetheless, a goal of most manufacturing organizations is to minimize the time spent on any non-production events. This can be done both by reducing the actual time needed to accomplish a certain activity and by reducing the number of times that the activity is done. This chapter examines the different types of downtime on the maker, and discusses both the degree of controllability and predictability associated with the various types.
4.1 Types of Downtime

Downtime can be a result of either controllable or uncontrollable events, where control is defined as the operations supervisor’s (or other planner’s) ability to schedule when downtime occurs. Whether or not the event of the machine going down is controllable, once it is down, the predictability of when it will be up again can vary. The controllability and predictability of the various types of downtime for the maker are discussed in the following sections.

4.1.1 Controllability of Downtime

Controllable downtime events on the maker include shutting the system down for: 1) product set-ups, 2) conducting experimental runs of potential new products, 3) preventive maintenance, 4) machine calibration, 5) on-line engineering redesign (such as for setting up the automatic raw material handlers) 6) on-line programming, and 7) entering in of new voice codes.

Even downtime due to training sessions, meetings, lunches, and breaks -- which is typically out of the control of the supervisor (Gershwin, 1993) -- is controlled to a large degree within the pilot group. This is done by either staggering these events (such as for lunch and breaks) or planning them for the end of the shift and bringing the next shift’s crew in early (such as for meetings and training sessions). Thus, these types of events are usually scheduled so that they do not become a reason for downtime, and, if they do, it is usually a controlled decision to do so.

The events of going down for the changing of inventory carts and refilling of raw materials are controllable downtime events up to a point. This control is lost, however, at the point when the inventory cart becomes completely full or that the raw material becomes completely empty. When either of these events occurs, the operator is forced to shut the
system down. Since the operators typically do wait almost until this point to shut down for inventory cart changes and raw material refills, these activities are more out of the control of the planner than in his or her control.

Unfortunately, most of the downtime events on the maker are out of the control of the scheduler. Downtime events which are clearly uncontrollable on the maker include the system going down due to: 1) machine failures (both electrical and mechanical), 2) repair of an unexpected failure, 3) worker absence due to sickness or emergency, 4) starvation due to a late raw material delivery or poor quality of raw materials, 5) blockage due to the upstream system being down for one of the already listed reasons, 6) failure of system to recognize operator's voice pattern, 7) lunches and breaks on third shift (when an extra person is not available to cover), and 8) holidays, vacations, and plant-wide shutdowns. (Table 4.1 breaks types of downtime into controllable and uncontrollable activities, depending upon which they most often are.)

4.1.2 Predictability of Downtime

Most of the downtime that occurs in the cell is unpredictable. There is even some degree of unpredictability in the length of downtime for controllable events. For example, this is true for set-ups. For the maker there is uncertainty in how long any given set-up will take, and the more difficult the type of product set-up, the more variable is the downtime. Similarly, engineering redesign work may end up taking more or less time than planned. The amount of downtime due to more routine activities -- such as preventive maintenance, simple programming changes, and even regularly-planned meetings -- is much more predictable.
Table 4.1: Controllability of Downtime

<table>
<thead>
<tr>
<th>Controllable Downtime</th>
<th>Uncontrollable Downtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>• product set-ups</td>
<td>• changing of inventory carts</td>
</tr>
<tr>
<td>• experimental runs of new products</td>
<td>• refilling of raw materials</td>
</tr>
<tr>
<td>• preventive maintenance</td>
<td>• machine failures</td>
</tr>
<tr>
<td>• machine calibration</td>
<td>• repair of an unexpected failure</td>
</tr>
<tr>
<td>• on-line engineering redesign time</td>
<td>• worker absence due to sickness or emergency</td>
</tr>
<tr>
<td>• on-line programming</td>
<td>• starvation</td>
</tr>
<tr>
<td>• entering in of new voice codes</td>
<td>• blockage</td>
</tr>
<tr>
<td>• training sessions</td>
<td>• failure of system to recognize operator's voice pattern</td>
</tr>
<tr>
<td>• meetings</td>
<td>• 3rd shift lunches and breaks</td>
</tr>
<tr>
<td>• 1st and 2nd shift lunches and breaks</td>
<td>• holidays</td>
</tr>
<tr>
<td></td>
<td>• vacations</td>
</tr>
<tr>
<td></td>
<td>• plant-wide shutdowns</td>
</tr>
</tbody>
</table>
Although the timing of when inventory carts are changed and raw materials refilled is somewhat uncontrollable, the amount of downtime due to these activities is highly predictable. For the majority of uncontrollable downtime events, however, this is not the case. These events include downtime due to 1) machine failures, 2) repair of unexpected failures, 3) unplanned worker absences, 4) late raw material deliveries, 5) changes in workers' voice patterns, and 6) blockages due to unplanned downtimes on upstream operations. Even for these events, there is varying amount of warning. The longer the warning period, the more time the organization has to act to either avoid the impending downtime or to make provisions for what to do when the system does go down.

For instance, the amount of preventive maintenance that has been done and how long the system has been run since the last failure or preventive maintenance may be indications of how likely it is that a failure will occur in the near future. Also, machine performance may start to degrade prior to complete failure, which makes the events of failure and machine repair more predictable. In addition, by being prepared for uncontrollable downtime, an organization may be better able to predict the length of downtime. For example, if an organization has on hand the needed resources for machine repair -- spare parts, technical expertise, mechanical drawings, etc. -- the variability in machine repair time is likely to be less than if this were not the case. Missed vendor deliveries and unplanned worker absences are also out of the control of the production planner and largely unpredictable. However, the more warning the planner receives from the outside party in such instances, the more time s/he has to react (go to another vendor, ask someone to work overtime, etc.) in order to reduce or eliminate any potential downtime.
4.2 Effect of Downtime on Throughput Rates

Throughput rates on the maker vary for the different WIP codes. Throughput rates may also vary as a result of changes in production conditions. These issues and how throughput rates can be calculated to factor in for downtime is discussed below.

4.2.1 Gray Area between Uptime and Downtime

Sometimes a gray area between uptime and downtime exists on the maker. This is when the line is not running at the standard rate for the given product type.\(^9\) Sometimes product quality is poor when the machine is run at the standard rate, but good product can be produced if the machine rate is lowered. The typical reasons for poor quality at high speeds are 1) variability in raw materials, 2) worn mechanical parts, or 3) slight misalignment within the system. When run at lower speeds, the maker is more robust to these type of variations.

There is some debate over whether or not it is more productive under these circumstances to run the system at reduced rates or to stop the machine all together and try to correct the root problem. Burman (1993) claims that spending time to address such issues in the short-term often results in higher productivity rates over the long-term. Needed technical assistance is not always readily available on the maker to assist in solving such problems,\(^{10}\) so there is, at times, some argument for running at reduced machine rates. The current thinking at Epsilon, however, is that the problem should be addressed immediately because such action will lead to higher overall productivity and quality levels.

The event of only being able to operate at reduced machine rates is unpredictable. It is, however, much more likely to occur when something in the system has recently changed.

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\(^9\) The size of the products being run affects throughput rates, with the smaller sizes having higher rates.

\(^{10}\) Machine operators are currently not authorized to make any mechanical adjustments to the equipment. This must be done by either a mechanic, an engineer, or possibly a supervisor.
Thus, it most often occurs after product set-ups that involve mechanical changes. It also is likely to occur when a new lot of raw materials is introduced to the system.

4.2.2 Downtime Factored into Throughput Rate

This paper focuses on the role that downtime due to set-ups plays in the scheduling of an FMS. In order to account in some way for the other types of downtime (even the gray areas), throughput rates are calculated by dividing the amount of product produced on the maker by total production time minus any time spent on set-ups. Because the rates are inherently different for different sized products, a separate rate is determined for each WIP code. This can be represented by

$$\mu_i = \frac{P_i}{(T_i - S_i)}$$

where $\mu_i$ is the throughput rate for WIP code $i$, $P_i$ is the amount of WIP code $i$ produced during the production run, $T_i$ is the time that elapsed since the last production run ended and the production run for code $i$ ended, and $S_i$ is the amount of time during the time period $T_i$ which was spent to set up to run code $i$. 
Chapter 5

Reduction of Set-Up Downtime

During the two months previous to the research period, downtime on the maker due to set-ups had ranged from 30 minutes to 4 hours. Although, the production scheduler had reasonable control over when the system went down for a set-up, doing so was highly risky; one was never very certain of when the system would be able to run again after setting up for a new product. If frequent set-ups were to be done on the system, both the average set-up time and the variability in set-up time had to be reduced.

5.1 Study of Set-Up Procedure

For this reduction effort, Epsilon's target average set-up time was 20 minutes. This was chosen because it had been the number used for capacity planning purposes.11 The first step taken in the process to reduce set-up times was to conduct interviews with the engineers who were involved in the design, maintenance, and monitoring of the equipment. Nearly all these engineers felt that a design flaw was at the heart of the problem.

11 This assumed an average set-up frequency of two per shift.
During the first half of the assembly operations, the individual parts are physically connected to one another. After being separated, the parts are fed through the section of the machine referred to as the "handler." The general feeling among the engineers was that the handler was not robust enough to the different sized products run on the maker. They felt that this was leading to high set-up times because whenever a set-up was done to change over to a different sized WIP code, a significant amount of time was needed to tweak the system in order to get the products to feed properly into the handler. Therefore, the engineers believed that either this section of the machine had to be redesigned to better accommodate all product dimensions or that a separate handler, to be replaced during each set-up, should be designed for every product type.

After this information was collected, a series of time studies of set-ups on the maker was begun. To do these, set-ups were broken down into all the different operations taking place. These operations and the corresponding amount of time spent on each of them were recorded for each set-up. The timing for the set-up began as soon as the machine went down prior to a product change and ended as soon as quality product was being run on the line.

5.1.1 Root Cause Analysis

After observing several set-ups, a team composed of workers who actually performed the set-ups (two operators and one mechanic) and the researcher was formed to determine the root causes for what added time to product set-ups on the maker. The purpose of working with this team was twofold. First, their knowledge was needed to determine the root causes behind some of the set-up activities. Second, the group could be used as a vehicle to generate interest and support for improving set-up performance among the union workers.
The Ishikawa diagram produced from the group effort is shown in Figure 5.1. The reasons for added time were divided between those related to materials, manpower, methods, and machine issues. Added time was considered to be any time spent tweaking something after the general procedure had been completed or time that was not used efficiently (such as failing to do procedures in parallel whenever possible).

Unlike the engineers' predictions that a technical fix was all that was needed, most of the downtime turned out to be due to poor methods. Often times no preparation for the set-up was done prior to the maker being shut down, even though several items can be done while the machine is still running. Similarly, once the set-up began operations were sometimes done in sequence when they could be done in parallel. For example, some operators liked to completely finish their portion of the set-up before calling a mechanic to do the mechanical changes. This was done in spite of the fact that most of the mechanical and operational procedures can be done simultaneously.

Furthermore, procedures were not always done in the most efficient way. The problem with the handler turned out not to be one of its needing to be redesigned, but that the proper methods and gauging were needed for it to be adjusted correctly. There were no predetermined handler settings for the different WIP codes, which resulted in a lot of time spent during each set-up trying to readjust the settings by trial and error. Part of the reason this was the case was because there was no gauge mounted on the handler for easy reading.

Finally, one significant technical problem was identified. A large amount of time was being spent to align the crimp roll, the part of the machine that distinguishes each individual product. It was felt that simply changing methods would not improve this situation and that a technical redesign of at least part of the crimp roll station would be needed.
Based on the root cause analysis and the time study numbers, four top reasons for added set-up time were determined. There are:

- Inefficient Methods
- Alignment of the Crimp Roll
- Adjustment of the Handler Settings
- Alignment of Raw Materials

"Inefficient methods" included several of the current practices, most of which involved either failing to do internal operations while the maker was operating or doing operations in sequence when they could be done in parallel. All totalled, these types of actions led to approximately 64 percent of excess downtime at the time of the study. The second biggest contributor was having to align (and realign) the crimp roll; this contributed another 17 percent. The next cause was adjustment of the handler settings, which added 7 percent. Aligning raw materials was the fourth cause signalled out, with it contributing approximately 5 percent. All other causes accounted for the remaining 7 percent. A Pareto chart of these top causes for added set-up time is shown in Figure 5.2.

5.2 Improvement Efforts

The top three of these four causes were selected for improvement efforts. The improvement steps that were taken for each are given below.

5.2.1 Improved Methods

The first step taken to reduce set-up time was to prepare set-up process sheets for both the operational component of the set-up, which is done by the machine operators, and the mechanical component of the set-up, which is done by the mechanics. These sheets
Figure 5.2: Pareto Diagram of Top Causes for Additional Set-Up Time
outlined the specific tasks involved in doing a set-up and helped to make clearer the
distinction between operational and mechanical set-up procedures. The basic form for
these two process sheets are shown in Appendices A and B. (Process steps have been
disguised or omitted to conceal proprietary information.)

The process sheets were organized in a way to separate external work, which has to be
done while the machine is shut down, from internal work, which can be completed while
the maker is still running. For the operators, this means two separate sections -- steps that
are done before the maker stops and steps that are done while it is stopped. Work that can
be done before the maker is stopped includes some paper work as well as preparation of the
new raw materials and inventory cart. For the mechanics there are three sections -- steps
that are done before the machine is shut down, steps that are done while it is shut down,
and steps that are done after it is back up again. The "before" work includes setting up
tools and parts to be replaced, while the "after" work includes the cleaning, greasing, and
repair of removed parts.

In addition, steps were placed on the sheets to help in other improvement efforts. For
example, there is one space on the mechanic's process sheet to record any adjustments
done to the handler and another to record whether the crimp roll needed to be aligned (in
order to track the occurrence of this).

Prior to putting in place the process sheets, many operators had different methods for
carrying out the various steps for a product set-up. To determine the "best methods,"
operators were observed and interviewed about why they did a step in a certain way. For
some of the steps, it was determined that there clearly was a better way of doing it and that
some of the operators' methods were inefficient. For those steps, the "better way" was
what was listed on the process sheet. For some steps, however, it seemed that different
ways worked better or worse for different operators, and two or three possible methods were proposed for performing these steps.

The process sheets were introduced in a group meeting format. In introducing the process sheets, the researcher facilitated a discussion of the various merits of different methods. This was done to get buy-in to the set-up methods and to help the operators make decisions on what method would work best for them on the steps which could be done in more than one way. Some minor changes were made to the process sheets based on feedback received in this meeting, and they went into use soon after that.

In practice, the mechanics had to actually fill out a separate process sheet for each set-up because of the need to record adjustments to the handler and crimp rolls. The operators just used the sheet as a guide and did not have to fill it out. At the same time that the new procedures were put in place, a chart for recording set-up times was placed near the maker. This allowed the workers to see any progress they were making.

5.2.2 Determination of Handler Operating Window

As mentioned above, in an effort to define the operating window for the different product codes, the mechanics were asked to record any adjustments made during a set-up. In that way, the settings used for both the product type run before and after the set-up were known. To facilitate this, a gauge was placed on the handler. Within three weeks of recording the settings, one set of settings that worked for WIP codes 1, 2, 3, and 5 was determined, while another set for WIP code 4 was determined.

5.2.3 Redesign of Mechanical Shaft

To eliminate the need for realignment of the crimp roll each time a different sized roll was placed in the machine, a redesign of the crimp roll shaft was proposed by one of the
company machinists. This redesign provided a stationary position for the shaft within the
crimp roll station through the use of timken thrust bearings. The bearings minimized any
movement of the crimp roll which could lead to misalignment. If for some reason the roll
did have to be aligned after being mounted in the crimp roll station, lock collars were placed
on either side of the shaft with threads of the same pitch as that of the crimp pattern. This
allowed for any needed realignment to be done with the crimp roll still loaded in the station.
In the past, the entire roll had to be removed from the machine to properly make these
adjustments. Initially, the new design was tested on the crimp roll used for WIP code 1, as
that is the code with both the highest demand and, at that time, the highest number of
product set-ups.

5.3 Results of Improvement Efforts

In the month prior to beginning any improvement efforts, 17 set-ups were recorded.
Average set-up time during that first month was 87.9 minutes, with a standard deviation of
37.6 minutes. During the next two months there was increased monitoring of set-ups, and
work with the set-up reduction team began. In addition, set-up methods were put in place
towards the end of this time period. During the two-month period, 73 set-ups were
recorded. Average set-up time was 58.2 minutes, with a standard deviation of 41.1
minutes. In the following month all of the improvement measures were in place. In
addition to the new process sheets, the pre-determined handler settings were being used,
and a redesigned shaft was in place for WIP code 1, the code with the highest demand.
Twenty-nine set-ups were recorded after all three of the improvements were in place. The
average set-up time during this period was 28.6 minutes, with a standard deviation of 19.1
minutes. These values are listed in Table 5.1, and a chart of the individually-recorded set-
up times is shown in Figure 5.3. (All 118 recorded set-up times are shown in Appendix C.
The times are divided by set-up type, which will be explained in the Chapter 6).
The drop in average set-up time during months two and three was due to a variety of reasons. One reason was that the mix of set-ups being done changed during this time. There was a large increase in the percentage of simpler set-ups being done due to the fact that during that time production of WIP code 5 began on the maker. A more detailed explanation of this is given in Chapter 6. A second reason for the decline is attributed to a Hawthorne effect. The fact that all set-ups were being closely monitored may have caused some workers to focus more on doing them in a timely manner. The introduction of the new procedures towards the end of this time period is a reason for the drop in average set-up time towards the end of the period. There is no clear reason, however, for why the standard deviation rose slightly during this period.
Figure 5.1: Set-Up Times over 4-Month Period

M1 = Month 1
M2-3 = Month 2 and 3
M4 = Month 4
In month four, after all the improvement measures were in place, a significant decrease in both average set-up time and standard deviation was seen. With the redesigned shaft in place, time spent on crimp roll realignment for WIP code 1 was reduced to zero. Similarly, excess time spent making adjustments to the handler was eliminated through the determination of settings for the different codes. In addition, excess time spent due to improper operational procedures was greatly reduced.

There is still more room to reduce set-up times. Additional measures, such as improving the raw material alignment system, could further decrease time spent on set-ups; however, more dramatic time reductions are likely to be seen through improved scheduling procedures. As was seen in months 2 and 3, scheduling a higher percentage of simpler set-ups (which take less time on the average), results in a lower average set-up time.

In addition, if the total number of set-ups can be reduced, this decreases total downtime due to set-ups and frees up more time for production events. When the goal for an average set-up time of 20 minutes was set, it was assumed that there would be two set-ups per shift, or that 40 minutes per shift would be spent on set-ups. During the fourth month of the study, however, only 0.74 set-ups were performed on average per shift, which means only 21.2 minutes per shift were spent on set-ups. Thus, set-up time during this period was, on average, 18.8 minutes per shift less than what was planned for in the capacity studies, even though the average set-up time was slightly higher than the figure used in the study. It is important, however, to not carry the reduction of set-ups so far that the original benefits of the flexible technology are lost. For example, the number of set-ups should not be reduced by so much that high costs due to lower customer responsiveness and/or higher inventory levels are incurred.

\[\text{set-up time per shift} = (0.74)(28.6) \text{ minutes/set-up} = 21.2 \text{ minutes/shift} \]

12 Set-up time per shift is equal to the number of set-ups per shift times the average set-up time; in this case, set-up time per shift = (0.74)(28.6) [set-ups/shift][minutes/set-up] = 21.2 [minutes/shift].
Chapter 6

Scheduling Issues

"When people do the scheduling, they sometimes do it in ways that they cannot explain. They sometimes make up methods as they go along. This can be acceptable if the resulting performance is satisfactory." (Gershwin, 1993)

The ability of an FMS to produce a variety of parts can lead to reduced inventories and faster responses to changes in demand requirements when compared to traditional production methods. However, production scheduling is more complex because, at each point in time, there are more choices to be made. For every moment that an FMS\(^{13}\) is available, a system manager (human or computer) must determine either which part type to run or if the machine is allowed to stand idle. In order to reap the potential benefits of the flexible technology, it is critical that the system be scheduled in a way that system resources are used efficiently. This chapter focuses on scheduling issues for the assembly portion of the FMS. Particular emphasis is placed on scheduling issues related to product set-ups.

Currently the production supervisor is responsible for scheduling of the maker. This chapter begins by looking at how scheduling is currently done by this person -- what are the goals, how are they met, and what are the potential impediments (what makes

\(^{13}\) Product flexibility is assumed.
scheduling non-trivial). Section 6.2 then shows how set-ups can be divided by type based on the components that make up the set-up. It is then hypothesized that set-up type should affect the frequency, length, and sequence of production runs. Compiled data from over 198 shifts is examined to test the proposed hypotheses. The chapter closes with considerations and suggestions for how to efficiently schedule the maker.

6.1 Current Scheduling Procedures

Currently, none of the scheduling is computerized. It is all done manually by the shop-floor supervisor. On each Friday, the supervisor is given weekly demands for the final products which are made on the two packaging lines. Factoring in waste levels, the supervisor determines from the final code demands how much of each WIP code will have to be made to meet the next week's demand. Any surplus from the week before is subtracted from this figure, while any backlog is added. Based on this, a rough schedule is made on either Friday evening or Saturday morning (if there is overtime scheduled), and needed revisions are made to the schedule throughout the following week.

Prior to the beginning of each shift, the supervisor goes out to the work cell and writes the scheduling instructions for the next shift on a board near the maker. He\(^{14}\) typically puts up the production planned for the next shift plus the beginning half of what is planned for the following shift, in case plan is exceeded. After each shift, the supervisor reevaluates the situation -- how much of the plan was made on the maker for the last shift, what is the current rate that products are being consumed on the two packaging lines, and what are the current WIP inventory levels. If need be, he makes revisions to the next shift's plan and then writes the plan for the next shift out on the board by the maker.

\(^{14}\) The pronoun he is used because the two current supervisors are men, and these are the scheduling rules that they have worked out -- not general rules that Epsilon gives to all supervisors.
The main goal of scheduling is to ensure that demand is met. For the maker this means that not only must all the needed WIP codes be made, but that they must be made before either of the packaging lines is forced to go down due to starvation. Since currently packer 1 is scheduled at 100 percent of capacity and packer 2 is typically only scheduled at 15 - 30 percent of capacity, there is more slack in the system for the WIP codes run on packer 2. WIP codes 1, 2, and 3, which are run on packer 1, however, must always be available in order for demand at packer 1 to be met.

Because of this, the primary scheduling goal for the maker is that packer 1 is never starved. The second goal is to meet the demand for WIP codes 4 and 5 (and any other WIP codes) needed at packer 2. The third goal is to have excess time left over for: 1) experimental runs by the R&D group, 2) preventive maintenance, 3) training, 4) machine calibration, and 5) any engineering redesign or on-line programming work.

To track how much of demand has been met, each day the supervisor calculates the difference between planned and actual production levels. If all of a given code is not made by Friday, the supervisor tries to schedule overtime on the weekend in order to meet demand. If that is not possible, the unmet demand is rolled over to the next week. Packer 1 is never left idle. If all of the demand at packer 1 is met before the week is up and there is no need to schedule any kind of downtime on the system, the line continues to package final products. In this case, the maker must continue to supply packer 1 with the needed WIP codes. Since packer 1 is building up product for a new product release, there is no downside of going over plan; the sooner the needed inventory is built up, the sooner the product can be released to retail stores. It is also not unusual for packer 2 to produce up to 30 percent more than actual demand. When this happens, the surplus is simply subtracted from the next week's demand. The scheduler is not dissuaded from going over plan, as his numbers are not affected by going over plan and holding extra inventory.
6.1.1 Meeting Demand at Packer 1

Charting the production schedule so that it focuses on demand at packer 1 and keeping a day's worth of inventory are the two main practices done to ensure that packer 1 never goes down due to starvation.

The production schedule is made so that it explicitly focuses on the consumption of product at packer 1. Each week the supervisor puts a chart up on the whiteboard in his office. There are 17 columns on the chart to represent the 17 shifts (15 shifts during the week and two shifts on Saturday) typically scheduled on packer 1. A tick mark is placed in each column to represent the amount of WIP for codes 1, 2, and 3 that are expected to be on hand for that shift. This is based on current WIP inventory levels, planned production rates, and expected consumption rates. At the end of each day, the chart is updated based on actual consumption and production rates.

For ease of calculation, consumption rates of 1, 1, and 1/4 inventory carts per shift are used for WIP codes 1, 2, and 3, respectively, when determining what the inventory levels for these codes will be throughout the week. This corresponds to rates of 100, 90 and 20 product units per shift for WIP codes 1, 2, and 3, respectively. In order to meet demand, the average consumption rates must be 85, 64 and 21 product units per shift. Using higher than expected consumption rates for codes 1 and 2 is done as an added measure to help ensure that packer 2 is never starved. The consumption rate for code 3 is not inflated because it is consumed at a much lower rate, and any fluctuations in this rate should be detected in time through inventory counts at the end of each shift.

Producing the schedule in this manner highlights what is taking place at packer 1. If inventory levels for any of the three codes consumed at packer 1 falls below scheduled levels, this shows up, and the supervisor will typically re-schedule production on the maker to bring levels back up to where they should be.
A second measure to ensure that packer 1 is never starved is to keep an adequate supply of WIP inventory for each product code on hand at all times. The target inventory levels are three shifts supply of each code, or roughly three inventory carts of code 1, two carts of code 2, and one cart of code 3. Thus, set-ups are typically planned at least one day prior to when existing inventory levels are expected to run out. In reality, the supervisors estimate that this often slips to one-half to two shifts prior to when existing WIP levels will run out.

6.1.2 Meeting Demand at Packer 2

WIP codes that feed into packer 2 are only produced on the maker when there is an adequate supply of inventory of the three codes run on packer 1. Since packer 2 is currently underutilized, no explicit calculations are done to determine when it will be starved for material. Typically, it can be starved for material 70 - 85 percent of the time and still meet demand as long as the remainder of the time on the packaging line is uptime.

As a rule of thumb, the WIP codes for packer 2 are produced as early in the week as possible. This is done to help ensure that demand is met on packer 2 by creating a time buffer. If, for some reason, production of the codes for packer 2 are interrupted, there is still time left to re-schedule this work later in the week.

Another rule of thumb is to try to schedule set-ups so that codes 4 and 5 (which are consumed on packer 2) are always produced either after each other or after WIP code 2. This is because all three of these products have roughly the same dimensions, and the set-up times for going between them is both shorter and less variable than for most of the other set-ups. Also, once the maker is set up for either WIP codes 4 or 5, the entire week's demand is often run for the given WIP code. This is done both to minimize the number of set-ups and also to get the demand for packer 2 taken care of so that the maker's efforts can be focused on packer 1 for the remainder of the week.
6.1.3 Scheduling Impediments

Unplanned Downtime

The task of the supervisor is complicated by random failures of the three production stations as well as other sources of unplanned downtime. It is important that the production policy is set to anticipate these unplanned downtimes and be able to react so that demand is met. With the new technology, there are fewer stations to produce the same amount of product. Thus, the failure of any one station within the newer flexible work cells has the potential of disrupting production by a much greater degree than the failure of any one work station in the past. Therefore, it is even more important that policies anticipate and react to downtime.

Both the maker and packer 2 have excess capacity, so it is easy to adapt to unplanned downtime on these two stations. However, packer 1 is scheduled to run 100 percent of the time, with only planned downtimes (such as for changing inventory carts and changing work crews) taken into consideration. Any significant amount of unplanned downtime on packer 1 causes it to fall behind. Thus, as mentioned earlier, it is extremely important that the maker is scheduled so that packer 1 is never starved.

Downtime Due to Set-Ups

Although controllable, set-ups are another potential impediment to meeting demand. That is because currently there is uncertainty in how long any given set-up will take. Normally, as noted above, the time to perform product set-ups between codes 2, 4, and 5 is fairly short and predictable. The time to change between other codes, however, is typically longer and much more unpredictable. This is especially true for any changes to or from code 1.
When asked about this point, the supervisors said that they observed a variability in code 1 set-up times. During periods in which these set-ups could be done without complications arising, they increase the number of code 1 set-ups and decrease the length of code 1 production runs. However, once some complication arises with a code 1 set-ups, there are problems with all of these type set-ups for a while following this. When this occurs, they tend to schedule fewer and longer code 1 runs.

In general, the supervisors try to schedule so as to minimize the total number of set-ups performed, as this minimizes downtime due to set-ups. Two factors, however, may cause the maker to be changed over more than the schedulers might otherwise prefer. First, of all, the amount of WIP inventory that can be built up is limited by the number of inventory carts. Currently this number is 18. If the maker were to produce at its predicted full-capacity rates, it should produce about 12 inventory carts per day. Thus, running one product code for an entire day would result in two-thirds of the buffer inventory being filled by one of five product types.

The other reason for doing several set-ups is the need to have a certain amount of inventory built up in all three of the WIP codes that feed into packer 1 at all times. Since codes 1 and 2 are consumed at rates four and three times that of code 3, respectively, set-ups to codes 1 and 2 are required most frequently.

**Production Run Length**

The length of an individual production run can be no longer than the time it takes to fill up an inventory cart with product, although total run length for a given product type may be several times this in length. Product run lengths are typically determined by scheduling the maker to run until a given number of inventory carts have been filled. Occasionally a quantity less than a full inventory cart is produced. This may be done for a product code on packer 2 if demand is less than a full cart's worth. It also may be done for codes going
to packer 1 if the machine must be changed over quickly in order to ensure that inventories of all three of the packer 1 codes are maintained between the maker and packer 1.

Occasionally, run lengths are determined by time. For example, set-ups are scheduled, when possible, so that they do not overlap across shifts. Set-ups also must be performed at a set time if a mechanic is needed for the set-up and he or she is going to be unavailable due to a meeting or another job responsibility. In order to ensure that a set-up is started by a certain time under such conditions, the schedule may read something like "Produce up to 3 carts of code 2. As soon as 3 carts of code 2 are produced, set-up maker for code 4. If you have not set up for code 4 by 1:00 pm, change over from code 2 at that time even if less than 3 carts have been produced. Run product 4 until the second shift crew comes in at 2:00 pm." 

**Buffer Sizes**

As mentioned earlier, total WIP buffer size is limited by the amount of inventory carts in the system, which is currently 18. To minimize holding costs, it is best to maintain low buffer levels. Since packer 2 is currently underutilized, less WIP is needed between the maker and packer 2 then between the maker and packer 1, which is 100 percent utilized.

**6.2 Effect of Set-Ups and Throughput Rates on Scheduling**

Even though the primary goal of the current scheduling practices is to keep packer 1 from being starved, on the average packer 1 is starved 13.8 minutes per shift, or 2.9 percent of the time. Although this number is small, it is not insignificant. Furthermore, during the times packer 1 is starved for one material, there are often substantial amounts of WIP for

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15 This is done because the workers prefer to not take over a set-up midstream; each has certain methods he or she likes to follow in doing a set-up, and the previous worker may not do things exactly the same way.

16 This is not a schedule, so this is not a scheduling rule. Instead, it is a rule for what will happen in real time.
the other codes. Through improved scheduling techniques, this number can, therefore, be reduced to the point where it is insignificant. In addition, improved scheduling techniques could remove other inefficiencies and perhaps reduce the number of production shifts that are needed to meet demand by the maker.

This section shows how set-ups can be broken down into individual components and how these components can be combined to create six different set-up types. Hypotheses are drawn about the effect that set-up type should have on frequency, length, and sequence of production runs. In addition, a hypothesis about the correlation between product volume and throughput rates is made which, if true, could lead to more accurate scheduling.

6.2.1 Analysis of Product Set-Ups

There are 20 possible set-ups for the five product codes. Since the set-up to go from code A to code B contains the same components as the set-up to go from code B to code A, there are only 10 distinct set-ups for the five product codes. Table 6.1 lists these set-ups, and Figure 6.1 shows the set-up states for these 10 transitions. By breaking the various set-ups down into components, one finds that there are only six unique combinations of the various components. The four basic components that make up all possible set-ups for the five WIP codes are listed in Table 6.2.17 These components can be further broken down into levels of complexity. Components 1 and 2 are composed of operations that are performed by the machine operator only and are less complex. Components 3 and 4 are composed of both operational and mechanical changes, and are, as a result, more complex (see Figure 6.2). The six different combinations of these components that represent actual set-ups are shown in Figure 6.3.

17 Set-up work that can be done while the machine is still running has not been included, as it should not add to the amount of time the system is down. Such work includes items such as exchanging raw material pallets, recording raw material lot numbers, setting up tools and mechanical components for a mechanical set-up, and cleaning and greasing mechanical components.

18 Both a mechanic and an operator are needed to perform set-ups with level 2 components.
### Table 6.1: Ten Set-Ups Performed on the Maker

<table>
<thead>
<tr>
<th>Set-Up Number</th>
<th>Description of Set-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>code 1 &lt;=&gt; code 2</td>
</tr>
<tr>
<td>2</td>
<td>code 1 &lt;=&gt; code 3</td>
</tr>
<tr>
<td>3</td>
<td>code 1 &lt;=&gt; code 4</td>
</tr>
<tr>
<td>4</td>
<td>code 1 &lt;=&gt; code 5</td>
</tr>
<tr>
<td>5</td>
<td>code 2 &lt;=&gt; code 3</td>
</tr>
<tr>
<td>6</td>
<td>code 2 &lt;=&gt; code 4</td>
</tr>
<tr>
<td>7</td>
<td>code 2 &lt;=&gt; code 5</td>
</tr>
<tr>
<td>8</td>
<td>code 3 &lt;=&gt; code 4</td>
</tr>
<tr>
<td>9</td>
<td>code 3 &lt;=&gt; code 5</td>
</tr>
<tr>
<td>10</td>
<td>code 4 &lt;=&gt; code 5</td>
</tr>
</tbody>
</table>
Figure 6.1: Set-Up States for WIP Codes 1 through 5
Table 6.2: Four Basic Set-Up Components

<table>
<thead>
<tr>
<th>Component 1 -- End-of Run Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• reset counters</td>
</tr>
<tr>
<td>• fill in final counts on production sheets</td>
</tr>
<tr>
<td>• replace inventory cart</td>
</tr>
<tr>
<td>• change primary raw material</td>
</tr>
</tbody>
</table>

Component 2 -- Handler Adjustment

Component 3 -- Mechanical changes (change in x dimension)

• Change cutting tool
• Change and align crimp pattern dies
• Change encoder
• Download appropriate computer recipe

Component 4 -- Mechanical changes (change in y dimension)

• Change tooling hardware
• Change waste removal drive
• Replace transfer mechanism
• Adjust spacing for end finishing station
• Replace remaining raw materials
• Align raw material guides
Figure 6.2: Set-Up Components Separated by Level of Complexity
Figure 6.3: Set-Up Types and Corresponding Components
From Figure 6.3, one can see that as the set-up type number increases, so does the complexity of the set-up. Thus, it is predicted that both average set-up time and the standard deviation of the set-up time should increase with increasing set-up type number.

If it is true that the average set-up time and standard deviation increase with increasing set-up type, average set-up time could be decreased either by reducing (or eliminating) some of the more difficult set-up types and/or increasing the number of easier set-up types that are performed. In addition, if the total number of set-ups performed did not increase, changing the ratio of set-ups in the way just described would also lead to lower overall downtime due to product set-ups.

To better understand which set-up types should be performed more or less often than others and in which order, Figure 6.4 shows the type of set-up that needs to be performed to get from one product type to another. From Figure 6.4 one can deduce that total set-up time is sequence-dependent, as it varies depending on the order in which the product codes are run. Burman (1993) analyzed a production system with somewhat similar characteristics. In his FMS, he found a "clustering" effect among machine states, where the complexity of the set-up required to move between states (represented by nodes) within a given cluster is much less than the complexity of the set-up required to move from a machine state within one cluster to another state in another cluster. This is similar to how, in this situation, the lower the set-up type number, the easier it is to move between two codes.
Figure 6.4: Product Transitions Separated by Set-Up Type
To illustrate how total set-up time is dependent on production sequence for the maker, four different round-robin sequences, where all parts are the same and only order differs, for the five codes are examined. The sequences are:

1) code 2 -- code 5 -- code 4 -- code 3 -- code 1 -- code 2  
2) code 2 -- code 4 -- code 5 -- code 3 -- code 1 -- code 2  
3) code 2 -- code 3 -- code 4 -- code 5 -- code 1 -- code 2  
4) code 2 -- code 3 -- code 5 -- code 4 -- code 1 -- code 2  

The set-up types that are performed for each of the four sequences are shown below in order of increasing complexity:

Sequence 1: I, II, IV, V, and V  
Sequence 2: II, II, III, V, and V  
Sequence 3: II, III, IV, V, and V  
Sequence 4: II, III, III, V, and VI

What this first shows is that either two set-up type Vs or one set-up type V and one set-up type VI must be performed for every cycle. Since set-up type VI is more complex than type V, total set-up time should be decreased by avoiding a sequence such as sequence 4 which involves a set-up type VI. One can also easily see that sequence 3 should require more downtime for set-ups than sequence 1 or sequence 2. This is because sequence 3 only differs from either sequence 1 or 2 by just one set-up type, and in both cases the type is of a higher number (III > I when compared to sequence 1, and IV > II when compared to sequence 2).

---

19 This assumes that total time for the other three set-ups in the sequences with two type V set-ups is less than or equal to the remaining three set-ups in the sequence with a type VI set-up. This can be demonstrated to be the case here, where the total time for sequence 4 is greater than for sequence 2.
What is not obvious from this is whether total time for sequence 1, on average, will be greater or less than total time for sequence 2. This is because the sequences vary by two set-up types, with one from each sequence being higher and one being lower than the corresponding set-up types in the other sequence. One would need to collect empirical data to see how the average times differ between set-up type I and set-up type IV.

6.2.2 Production Throughput Rates

A final hypothesis is that product throughput rates should vary as a function of the total volume of the product, with lower volume products having higher throughput rates. This is because, as long as the machine is run at the same speed for different volume products, it should take less time for the lower-volume products to pass through the maker. This would mean that the throughput rate of code 1 would be the highest; those of codes 2 and 5 should be approximately the same and should be the next highest; that of code 4 should be the third highest; and code 3 should have the lowest throughput rate. Currently one throughput rate is assumed for all codes produced on the maker. If throughput rates vary significantly for the different codes, having this information could increase scheduling accuracy. To test this hypothesis and the others mentioned in this section, production data was collected. The results are given in the following section.

6.3 Observed Performance

A study of 198 production shifts was conducted. Data from this study was used to test for four things. The first was to see if the predicted correlation between set-up type and average set-up time and standard deviation existed. The second was to see if the difference in set-up times was having an effect on current scheduling practices. The third item was to see if the predicted correlation between product volume and throughput rate existed. The
final item was to see how actual production run lengths, WIP inventory levels, and product sequencing corresponded with target goals.

6.3.1 Data Collection Methodology

Production data was recorded by shop-floor workers over a period of 198 shifts. For each shift, the workers recorded the product codes that were produced on the maker, the time that each code was run on the system, and any downtime due to set-ups. In addition, the researcher was present for approximately 45 of the recorded set-ups, and, thus, is able to confirm the times for these set-ups.

During the course of the study, eight different product codes were made on the maker. Only data for WIP codes 1 through 5 is presented. Of the other three additional codes produced, one was produced in a small amount, while the other two were experimental product codes. During the course of the study, production runs for codes 1 through 5 accounted for 96.2 percent of all production runs and 97.6 percent of total production time.

6.3.2 Average Set-up Times

Table 6.3 presents the average set-up times for the six different set-up types. (The set-up time data for the 118 individual set-ups is presented in Appendix C.) As predicted, there is a correlation between set-up time and set-up type. With the exception of set-up type IV, the average set-up time increases with increasing set-up type number. If set-up type III is ignored, the average set-up time for set-up type IV follows the trend. The fact that the average time for set-up type IV did not prove to be greater than the average time for set-up type III is most likely due to the small sampling of type IV set-ups. Only five of these set-ups were recorded, which is not a large enough sample to be statistically significant.
Table 6.3: Average Set-Up Times for the Six Set-Up Types

<table>
<thead>
<tr>
<th>Set-up Type</th>
<th>Number of Set-ups</th>
<th>Average Set-up Time (min.)</th>
<th>Standard Deviation (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>10</td>
<td>6.1</td>
<td>3.1</td>
</tr>
<tr>
<td>II</td>
<td>28</td>
<td>23.5</td>
<td>25.7</td>
</tr>
<tr>
<td>III</td>
<td>15</td>
<td>37.1</td>
<td>15.6</td>
</tr>
<tr>
<td>IV</td>
<td>5</td>
<td>33.0</td>
<td>11.5</td>
</tr>
<tr>
<td>V</td>
<td>56</td>
<td>77.3</td>
<td>37.8</td>
</tr>
<tr>
<td>VI</td>
<td>9</td>
<td>83.7</td>
<td>73.1</td>
</tr>
</tbody>
</table>

In general, the standard deviation of set-up time also increases with increasing set-up type number, as predicted. Set-up types III and IV are the exceptions. The standard deviation for set-up type IV is less than that for type III, and the standard deviations for both types II and III are less than that for set-up type II. Again, the reason that the standard deviation for set-up type IV does not follow the predicted pattern is likely due to the small sampling size.

The difference in standard deviation that is shown between types II and III is likely a real difference. Each of these two set-up types is composed of component 1 plus an additional component. For type II the second component is an operational procedure, and for type III the other component is a mechanical procedure. It is entirely possible that the average time to perform mechanical component 3 is greater than that for operational component 2, yet, that the variance for 3 is lower.
In fact, this was almost surely the case for the first three months of the study, and 11 of the 15 data points come from this time period. This is because component 2 involves making needed adjustments to the handler and this procedure was highly variable prior to month 4 (when the improvement efforts discussed in Chapter 5 went in place).

6.3.3 Set-up Type Frequency

Section 6.2 proposes that set-up times are sequence dependent, and that one can use the average times for the various set-up types to determine the sequence with the lowest total downtime due to set-ups for a given set of product codes.

It was hypothesized that overall set-up time can always be lowered by rearranging the sequence so that a type V set-up is performed in place of a type VI set-up. Thus, a direct set-up between codes 1 and 4 should never be performed. The set-up frequency data shown in Table 6.4, however, shows that this type of set-up accounted for 13.9 percent of all code 1 set-ups.\(^{20}\) Thus, even though less than the average number of set-ups involving code 1 were type VI set-ups, several type VI set-ups were performed. This implies that overall set-up time should be able to be lowered by decreasing this percentage further.

Section 6.2 also points out that if round-robin sequencing, where each code is run the same number of times as the others, is employed, code 1 (type V + type VI) set-ups should account for 40 percent of total set-ups. In the study these set-ups account for 48.9 percent of all set-ups, so code 1 was actually run more frequently than the other codes. These types of set-ups have the longest average set-up time. If the number of these set-up types performed was reduced in relation to the other types and the average length of code 1 runs increased, the average set-up time should be reduced. Furthermore, if the ratio was

\(^{20}\) This number is found by dividing the number of type VI set-ups by the sum of type V and type VI set-ups (total number of set-ups involving code 1), or \(13.9 = \frac{6.8}{42.1 + 6.8}\).
Table 6.4: Set-Up Type Frequency

<table>
<thead>
<tr>
<th>Set-up Type</th>
<th>Number of Set-ups Performed</th>
<th>Percentage of Total Set-ups (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>II</td>
<td>28</td>
<td>21.1</td>
</tr>
<tr>
<td>III</td>
<td>15</td>
<td>11.3</td>
</tr>
<tr>
<td>IV</td>
<td>5</td>
<td>3.8</td>
</tr>
<tr>
<td>V</td>
<td>56</td>
<td>42.1</td>
</tr>
<tr>
<td>VI</td>
<td>9</td>
<td>6.8</td>
</tr>
</tbody>
</table>

lowered and the total number of set-ups not allowed to increase, total set-up time should also decrease. Code 1 is the code that is consumed at the highest rate at packer 2, so it may be difficult to do this. Additional WIP will most likely have to be held, and there may not be sufficient inventory carts to allow for this.

6.3.4 Production Throughput Rates

The third hypothesis to test was whether there exists a correlation between throughput rate and product volume. If this were true the following relationship

\[ \mu_1 > \mu_2 = \mu_5 > \mu_4 > \mu_3, \]

where \( \mu_i \) is the throughput rate of code \( i \), should hold. Actual throughput data for the five
codes is shown in Table 6.5. This data gives the following relationship:

$$\mu_1 > \mu_2 > \mu_4 > \mu_5 > \mu_3,$$

Thus, other than the prediction that the throughput rate of code 5 should equal that of code 2, this prediction is accurate. The difference in the throughput rates of codes 5 and 2 is likely explained by the difference in the raw materials used to produce the two products. Although total product volume is the same for the two codes, a different raw material is used in producing code 5, and the use of this material leads to the need for more frequent cleaning of the production system.

Table 6.5 Average Throughput Rates and Standard Deviations

<table>
<thead>
<tr>
<th>Product Code</th>
<th>Average Throughput Rate (product units/min.)(^{21})</th>
<th>Standard Deviation (product units/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.53</td>
<td>0.16</td>
</tr>
<tr>
<td>2</td>
<td>0.46</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.37</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>0.41</td>
<td>0.13</td>
</tr>
<tr>
<td>5</td>
<td>0.40</td>
<td>0.19</td>
</tr>
</tbody>
</table>

\(^{21}\) All downtime, other than that due to product set-ups is factored into the throughput rate as explained in Chapter 4.
Initially, it was surprising that the throughput rate of code 4 was as great or slightly greater than that of code 5, since the volume of product 4 is slightly more than that of 5. However, unlike all of the other codes, code 4 does not produce a particular raw material by-product which needs to be removed from the system periodically for the other codes. The gain in uptime due to this may more than compensate for the fact that the product 4 volume is slightly greater than that of code 5.

6.3.5 Length of Production Runs and Level of WIP Inventories

The final point of interest for the production study was to see how average length of production runs and inventory levels compared with the scheduling practices the supervisors try to follow.

Average production data on the length of production runs is given in Table 6.6. These values seem to be in good agreement with existing practices. One stated practice is that production runs for codes 4 and 5 are typically long in order to get the production of packer 2 codes completed early in the week. This seems to be true, as the average length of these production runs is roughly the same as that for code 1, which has a much higher average demand.

The fact that the average production run length for code 3 is one-half of that of code 1 even though code 3 is consumed at a rate one-fourth of that for code 1 is also consistent with standard scheduling practices. The supervisor typically does not schedule production runs for any time increment shorter than what it takes to fill some multiple of full carts. Code 3 is consumed at only an average rate of 0.25 inventory carts/shift, however. Thus, it takes 4 shifts on packer 1 to consume every inventory cart of code 3 that was produced on the maker in an average 0.45 shifts. By comparison, it takes, on average, 1.3 shifts to
consume every inventory cart of code 2 produced and just 1.1 shifts, for every inventory
cart of code 1. Thus, following a practice of scheduling full inventory cart production
runs, leads to fewer production runs of code 3 and, therefore, greater fluctuations in code 3
WIP levels.

Average WIP levels are given in Table 6.7. The production scheduler stated that inventory
levels were kept very low for codes 4 and 5, as these codes were packaged on a line with
excess capacity. This is definitely true for code 5 which had an average WIP level of 0
inventory carts. The average level for code 4 was also relatively low compared to that held
for codes 1 and 2. The target WIP levels used by the supervisor in scheduling codes 1, 2,

<table>
<thead>
<tr>
<th>Product Code</th>
<th>Average Run Time (shifts)</th>
<th>Standard Deviation (shifts)</th>
<th>Number of Runs</th>
<th>Percentage of Total Time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8</td>
<td>1.0</td>
<td>33</td>
<td>29.8</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>0.9</td>
<td>38</td>
<td>26.2</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>0.4</td>
<td>20</td>
<td>9.0</td>
</tr>
<tr>
<td>4</td>
<td>1.9</td>
<td>1.2</td>
<td>22</td>
<td>19.7</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
<td>1.2</td>
<td>15</td>
<td>12.7</td>
</tr>
</tbody>
</table>
Table 6.7: Average Production and Work-In-Process Levels

<table>
<thead>
<tr>
<th>Product Code</th>
<th>Total Units Made (product units)</th>
<th>Total Good Units (product units)</th>
<th>Total Units Packed (product units)</th>
<th>Average WIP (product units)</th>
<th>Average WIP (inventory carts)</th>
<th>Average WIP (number of shifts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12,689</td>
<td>11,928</td>
<td>11,456</td>
<td>472</td>
<td>4.7</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>9,517</td>
<td>9,056</td>
<td>8,592</td>
<td>464</td>
<td>5.2</td>
<td>7.3</td>
</tr>
<tr>
<td>3</td>
<td>3,172</td>
<td>2,982</td>
<td>2,864</td>
<td>118</td>
<td>1.5</td>
<td>5.7</td>
</tr>
<tr>
<td>4</td>
<td>7,679</td>
<td>7,218</td>
<td>7,068</td>
<td>150</td>
<td>1.9</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>4,160</td>
<td>3,911</td>
<td>3,989</td>
<td>-79(^2)</td>
<td>0.0</td>
<td>N/A</td>
</tr>
</tbody>
</table>

and 3 are 3, 2, and 1 inventory carts, respectively. The supervisor felt, however, that average values fell below these targets. The study showed the opposite. Average WIP levels exceeded target levels by at least 50 percent for all three of these codes, with each averaging more than five shifts of inventory.

Finally, a stated policy was to sequence runs so that code 4 typically ran both after and before either code 2 or code 5 and that code 5 typically ran both after and before either code 2 or code 4. The percentage of times these codes actually preceded or followed one another is given in Table 6.8. There are four possible codes that can precede or follow any other code. Thus, if all codes were run equally as often and sequencing was completely random, 50 percent of the time these codes should be either preceded or followed by the other two

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22 Waste levels for this product must have been 4.1% or less to explain how more product was packed than was assumed to be good using a 6.0% waste level.
codes. In fact, code 4 was preceded 66.6 percent and followed 65.0 percent of the time by either code 2 or code 5. Code 5 was preceded 57.3 percent and followed 46.7 percent of the time by either code 2 or code 4. Thus, there was a definite effort to sequence code 4 as described, but no noticeable effort to sequence code 5 as described.

6.4 Suggested Scheduling Policies

The data demonstrated that average set-up times do increase with increasing set-up type number, where set-up types are defined in Section 6.2. This results in overall set-up time being sequence dependent. Ideally, one would have a real-time scheduling algorithm that would take into account the differences in average set-up times in general (which would be constantly updated electronically after each production run) as well as recent trends and current values in making scheduling decisions. This program would also be updated with the latest throughput rate information and would be able to factor in the potential costs and benefits related to any scheduling decision.
Unfortunately, such a program, if it captured all the nuances of the FMS, would be extremely complicated to develop. Instead, some scheduling recommendations, based on the empirical data, are made in the following paragraphs.

Based on the argument that both average set-up time and variability increase with increasing set-up type, type VI set-ups should be eliminated (code 1 and 4 should never follow directly after one another). In addition, the percentage of type V set-ups should be reduced, while the length of those runs should be increased. This will lead to higher needed WIP levels for code 1 as well as possibly for codes 2 and 3, although they are not likely to have to increase above the levels observed in the study. During the study, more than five shifts worth of WIP was held, on average, for each of the three codes consumed at packer 1. Additional inventory carts are being produced, so if extra buffer levels are needed, this should not be a problem.

Furthermore, run lengths of less than full inventory cart levels should be considered for code 3 because of the low consumption rate of this code at packer 1. In the past, this practice was partly avoided due to the fact that there were only 18 available inventory carts (and there was a fear of "wasting" any of the available space). The additional carts should enable greater flexibility in production runs lengths.

In addition to the suggestions already made, the effect of increasing the percentage of type I, II, and III set-ups, which have lower average time and variability than the three other type of set-ups, should be examined. The current goal of sequencing codes 4, 5, and 2 next to one another is an indication that this relationship is already understood at some level within the current scheduling practices. In addition to lowering average set-up time, doing more frequent (and, as a result, shorter) runs for code 4 and 5 should increase the flexibility of the FMS by allowing it to switch back from a packer 2 WIP code to a packer 1 WIP code faster than in the past. This should tend to reduce needed WIP levels for packer
1, while WIP levels need not increase for the packer 2 codes because of the fact that packer 2 is currently underutilized.

In fact, another recommendation is to eliminate the holding of WIP inventory for both codes 4 and 5 as long as packer 2 is highly underutilized. With only 15 to 30 percent of its capacity being used, there should be no need to hold any long-term buffer before this station, where long-term buffer is defined as any net positive amount of WIP remaining after all of the demand has been met for the week.

These recommendations should result in more efficient use of production time on the maker and reduce the total number of shifts that the maker must be scheduled to run. In fact, there is reason to believe that reducing the number of scheduled shifts on the maker will lead to increased inefficiencies in itself. Currently, only about 55 percent of the maker's estimated capacity is needed to produce the demand at packers 1 and 2, yet the maker appears to have little excess capacity. The maker is typically scheduled for full-production for all 15 regular shifts, with overtime being scheduled at least two times a month in addition to this.

It is possible that because the time is scheduled, the production rate conforms to the scheduled time. In other words, there is little sense of urgency. If, for example, a worker knows that he or she has an entire shift to produce 2 inventory carts of code 2, it will take the worker one shift to produce those two carts -- even though four carts of code 2 could have been produced in the same amount of time.
In the effort to reduce set-up times on the maker, it was the change in methods -- not the technical redesign -- that had the biggest impact. Similarly, wide-spread cultural and organizational changes may be needed for the FMS to achieve its full potential in increased flexibility and productivity (Brynjolfsson, 1991; Malone and Rockart, 1991). Jaikumar (1988) explains this relationship by using the analogy of a family that replaces its car with a helicopter yet makes no changes in its daily routine. As a result, the family's quality of life is no greater with the helicopter than it was with its station wagon. If, instead of a helicopter, the family had purchased a mini-van, only moderate lifestyle changes would have been needed for it to gain the benefits of the new technology.

Epsilon's change in technology -- going from dedicated transfer lines purchased in the 1970s to flexible work cells custom-designed in the 1990s -- is comparable to going from a station wagon to a helicopter. Yet, if Epsilon fails to make needed cultural and organizational changes that will complement the potential strengths of the FMS, the new equipment could end up being treated like a mini-van -- its full potential being wasted. Determining what complementary practices are needed, however, is not easy to do when
the technology is so revolutionary. Having to determine how to implement the needed changes further complicates the matter. The role of complementarities and other change implementation issues surrounding the pilot group effort are addressed in this chapter.

7.1 Role of Complementarities

Often times companies put in place new technology expecting that the technology alone will be some kind of a cure-all (Clark, 1989). Research has shown, however, that just putting in place new technology rarely results in significant increases in productivity (Brynjolfsson, 1993). In Jaikumar’s (1986) study of 95 US and Japanese companies that had put in place flexible manufacturing technology, he found that the majority of the US companies failed to achieve productivity increases because the manufacturing practices in place reinforced the old technology. These companies had in place practices such as long production runs, few (if any) machine changeovers, and high WIP and FG inventories -- all of which complemented the use of inflexible manufacturing equipment. When they converted to flexible equipment, they kept in place these other practices, and Jaikumar proposes that these practices kept the new technology from fulfilling its potential.

When Epsilon introduced the new technology, it realized that there was also a need for non-technological changes. For the most part, however, it saw these other changes as being independent from the technology. While expanding operator job responsibilities was seen as a needed complementary to the flexible equipment, practices such as lower inventory levels and increased employee involvement were put in place as separate "good

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23 The reason that more of the non-technological changes have been made in the pilot group than in the rest of the plant has more to do with union rules than the fact that the changes are seen as being complementary to the new technology. Within the pilot group certain union rules have been relaxed (refer to section 2.3.2), which has enabled the company to make changes in work practices and compensation schemes for this group which would require a change in the union contract to be implemented in the rest of the plant.
ideas," even though these are two practices often cited as reinforcing the benefits of flexible manufacturing (Jaikumar, 1986; Milgrom and Roberts, 1993; and Suarez et al, 1992).

Another reason that the implementation of the various changes has been uncoordinated is because different changes fall under the authority of different functional groups within the company. For example, Engineering has responsibility for designing and implementing the new technology; Operations and Planning has authority over changing inventory holding practices; Human Resources has responsibility for coordinating TQM training; and top management takes responsibility for promoting special programs, such as line rationalization.

Other than the new technology, only four of the 14 new paradigm practices listed in Table 2.5 have been introduced exclusively to the pilot group. The other nine new practices have been introduced throughout the entire plant. The four new practices which so far have just been introduced to the pilot group include 1) expanded job responsibilities for the shop-floor workers, 2) reduction in status distinctions between workers and supervisors (supervisors can fill in on line), 3) removal of incentive pay (all operators paid same flat rate), and 4) use of kanban to maintain low inventory levels.

As all of these new practices are co-evolving in the pilot group, it seems that many of the new practices do reinforce one another, but the interactions are still not well understood. In addition, it is becoming evident that additional changes may be needed to reap the full benefits of the new technology. For example, the workers who most effectively operate and maintain the flexible technology have a very different approach than the workers who successfully run the older lines. The pilot group's top mechanic is a prime example of this. When he worked in the main area of the plant, he was known as a troublemaker because he worked around the system (not worrying about whose job was whose) in order to get a job done. This disregard for rules and authority clashed with the standardized mass production
work environment. Within the pilot group, however, this willingness to be flexible in order to get the job done is viewed as an asset, and this person now stands out as a star employee.

7.2 Implementation of Change

When the implementation of joint change efforts is uncoordinated, companies often fail to realize the full benefit of the combined new practices. Furthermore, it is likely that, when implemented in isolation, some new practices may be put in place which oppose one another (Senge, 1990). This section discusses issues that need to be addressed when implementing change and some of the implementation decisions that were made by Epsilon.

7.2.1 Where to Implement Change

The location of the change effort can greatly affect its success. Where to implement change depends to a large degree on how much the change disrupts current practices. If many of the proposed changes act in opposition to the existing corporate culture, it may be best to introduce the new practices in an isolated site.

Greenfield Site

Going to a greenfield site offers a means of isolating the change process from the effects of the company's existing culture. This option is especially useful in the case of radical cultural change. For example, by building its Saturn plant in Tennessee, far from the rest of its plants, GM created a greenfield site for its implementation of radically different manufacturing and human resource policies.

Although going to a greenfield site isolates a change effort from resistance within the organization, this isolation also makes it more difficult to later disseminate the new practices to the rest of the organization. The fact that GM as a whole has not learned more
from Saturn is one of the few criticisms made of that change effort (Woodruff, 1992). The other main problem with going to a new site is that it is very expensive. The company has to believe that the changes will generate enough business to justify opening a new site.

**Existing Site**

Often times companies that are implementing radical change cannot justify the cost of going to a greenfield site. In those cases, the company may try to create a mini-greenfield site within the organization. This can be done through a "skunkworks" effort. To do this, a core group that is responsible for initiating the change effort is formed. This group is often located in an isolated area of the plant and organized in a way to shield it from existing practices and corporate culture which might serve to counteract the change process.

This is the approach that Epsilon has taken with the formation of the pilot group. Because the new technology is considered to be a radical break from the older technology, it was felt that its development and introduction needed to be isolated from the rest of the plant in order for it to be successful. The isolation of the group and the fact that union work rules are relaxed within the pilot group have also made it easier to introduce non-technological changes in work practices and worker compensation. One of the main reasons that Epsilon opted not to go to a greenfield site is that it wants to disseminate the technological and non-technological changes made in the pilot group throughout the rest of the existing plant.

**7.2.2 How and When to Make Change**

How and when changes are implemented will also affect the success of a change effort. In planning change, an organization needs to determine whether it is best to try to design all changes ahead of time or allow some things to evolve over time. In addition, organizations need to determine in what order and at what rate they want to put in place change.
Design Versus Evolution

In deciding when to implement change, an organization needs to decide how proactively to design the change effort -- whether it has to plan out all aspects of the "new paradigm" ahead of time or whether it can allow some aspects to evolve over time. An example of the latter is when organizations put in place "islands of automation" with the plan that they will be linked later (Hayes and Jaikumar, 1988).

This is similar to the approach that Epsilon has taken in introducing flexible technology. As changes in organizational structure, manufacturing practices, and compensation schemes are put in place, relationships between the new practices are evolving. No detailed plan for how these changes might act to complement the new technology has been made.

This evolutionary approach is often viewed as lower risk than designing all changes up front. Such an approach is not likely to work, however, if all the changes are highly dependent on one another. For example, when Federal Express converted to a hub-and-spoke mail system, it could not make the change gradually. The changing of its materials handling, routing, and delivery systems all had to be well-coordinated with respect to each other for the overall change effort to be a success (Hayes and Jaikumar, 1988).

Parallel Versus Sequential

The order in which individual changes are introduced can also affect the success of a change effort. In the case of Federal Express, they felt that they had to put all of the changes in place at once to be successful. If the change effort is less radical, it is easier to introduce individual changes gradually. Internal and external pressures can affect the rate of implementation, as well, with the rate typically increasing in the face of mounting pressures.

Since the change-process at Epsilon has been evolutionary in nature, the changes have occurred sequentially. The first changes that were made in Epsilon's conversion to its new
manufacturing strategy were changes in the way the company approached problem solving and quality issues. In 1988 all of the employees went through a formal TQM training program. This training laid the groundwork for putting in place the new paradigm practices (see Table 2.5) of 1) systematic problem solving, 2) increased employee contribution, 3) concurrent engineering, and 4) operators being responsible for quality.

The next major changes were the formation of the pilot group and the introduction of the new technology into that group in the early 1990s. Other changes made at this time within the pilot group were: 1) the expansion of job responsibilities for shop-floor workers, 2) the organization of the new technology in a work cell layout, 3) conversion from piece rate to flat pay (with each worker's hourly pay being based on their average rate under the incentive plan), and 4) reduction of inventory through the use of a kanban system. During the same time period there were company-wide, top-down initiatives to reduce total line items (through the line rationalization effort) and to reduce management layers. In 1992 the three components of the FMS were in place, and the pilot group went into full production with the new equipment. In addition, worker compensation was changed so that all operators receive the same hourly rate.

Once the work cell went into production, there was an added external pressure that had not been there during the period the technology was being proven. Under this pressure, the group reverted back to some traditional work practices. For example, during the testing of the system, the workers were told how much of each product had to be made and then they determined the order in which to run the different product codes. After the group went into production, however, the supervisor took back full responsibility for scheduling (see Chapter 6). In addition, WIP inventory levels rose once the FMS was in production. During the testing period, inventory levels were kept to two inventory carts or less per WIP code. After the group went into production, the average WIP levels were around five inventory carts for the two main WIP codes (refer to Table 6.8).
The group is now in the process of reevaluating what the optimal inventory levels and scheduling practices should be for the work cell. In addition, the "next generation" FMS work cells are now coming on-line. With this added capacity, the Operations group needs to determine if they will continue to produce several codes on each system or dedicate each system to making primarily one product type.

7.3 Planning Approach Needed

In making implementation decisions, it is important to look systematically at the organization -- look at how the changes that fall under the various functional domains of Engineering, Operations, Human Resources, Marketing, Accounting, etc. affect one another and the overall organizational structure and business strategy. This is especially true when the organization is making a radical change -- such as the change in technology that is being made at Epsilon -- because dramatic changes in technology typically require accompanying organizational and cultural changes. To take into account the systematic effect of changes that fall under various functional domains, an organization needs a methodology for examining the interactions between the different types of changes.

The next chapter introduces a change-management tool which allows an organization to examine interconnections between practices. In doing so, the tool sheds light on some of the implementation issues discussed in this chapter. Finally, the tool could prove to be an effective vehicle for bringing groups together to discuss and plan change.
Chapter 8

Matrix of Change:  
A Change-Management Tool

The Matrix of Change (MOC) is a change-management tool inspired by the House of Quality (Hauser and Clausing, 1988). Like the House of Quality, it is a tool which should help improve communication and bring together employees from different functional groups. Unlike the House of Quality, which is most often used for planning incremental improvements -- the MOC is likely to be of greatest benefit when an organization is planning radical, non-evolutionary change.

The MOC provides a method for determining interrelations among both existing practices and new practices, as well as interrelations between old and new practices. In so doing, it seeks to show which practices reinforce one another and which potentially oppose each other. The density as well as the sign of the complementarities guide the user in making decisions about what changes to make, as well as how, where, and when to implement the selected changes. The tool can be used to help plan a change effort, as well as to assess the progress that has been made midway through a change implementation.
The MOC can appear somewhat intimidating at first. After its various conventions and components are understood, however, users are able to grasp information from the chart in a single glance. In explaining the three individual matrices that help make up the MOC, sub-sections of an MOC filled out for the change effort at Epsilon are referred to. The interactions that are assigned in these matrices come from empirical studies and/or theoretical models found in the literature (Jaikumar, 1986; Krafcik and MacDuffie, 1989; Milgrom and Roberts, 1992, 1993; Suarez et. al., 1992). These interactions are referred to as the “accepted” interactions in this and later chapters.

8.1 Chart Conventions

The definition of complementarity that is used when filling out the matrix is the following: two activities are defined as reinforcing, or complementing, each other if doing more of one of them increases the returns to doing more of the other. Conversely, two activities are defined as opposing, or counteracting, each other if doing more of one of them decreases the returns of doing more of the other. Defined in this way, complements are symmetric. That is, if doing more of activity A raises the value of increases in activity B, then doing more of activity B raises the value of increasing activity A (Milgrom and Roberts, 1993).²⁴

Both the magnitude and sign of the complementarity can be used when filling in the MOC; here, however, only distinctions between sign, reinforcing (+) and opposing (−), are made. If two practices are not known to either reinforce or oppose one another, the space is left blank. To distinguish between complementarities and rankings, numbers are used in the ranking sections. The system used for each of the two ranking is explained later in this chapter.

²⁴ This definition is closely related to the concept of supermodularity as described by Milgrom and Roberts (1990), where a function is supermodular if the sum of the whole is greater than the sum of the individual components. Or \( f(x) + f(x') \leq f((\min(x, x') + f(\max(x, x')) \), where \( x \geq x' \) if \( x_i \geq x_i' \) for all \( i \), \( \max(x, x') \) is the point whose \( i \)th component is \( \max(x_i, x_i') \), and \( \min(x, x') \) is the point whose \( i \)th component is \( \min(x_i, x_i') \).
8.2 Old and New Practices

The MOC is composed of three separate matrices and two ranking sections. Two lists, one of practices making up the old paradigm and one with the proposed practices for the new paradigm, are placed on the chart so that the old and new practices correspond with the columns and rows of the three matrices. The practices used for constructing the MOC in this chapter come from the lists of Epsilon's old and new strategy traits listed in Tables 2.1 and 2.5.

In order to get a broad view of the different interactions at play in the change effort, various types of practices -- technological, manufacturing policy, compensation schemes, and organizational structure -- were selected. The old practices are listed so that they define the rows of the main matrix and the new practices, so that they define the columns.

The various practices can then be grouped into sub-categories. Two possible grouping criteria are functional types (such as manufacturing practice, human resource policy, etc.) and strategic goals. In setting up the matrix to be used in this thesis, practices were grouped by strategic goals. This was done because it was considered to be a good way to tie the practices in place on the shop floor to the company's vision statement. The old practices were grouped under three goals which are often associated with mass production (Milgrom and Robert, 1993; Thomas, 1993), and the new practices were grouped under the four points of the operations vision statement (see Figures 8.1 and 8.2).
Run an efficient, low-cost operation

- Designated equipment
- Areas separated by machine type
- Narrow job functions
- Salaried employees make all decisions
- Hourly workers carry them out
- Functional groups work independently
- Keep line running no matter what

Meet Product Requirements (quality and quantity)

- Thorough final inspection by QA
- Raw materials made in-house
- Large WIP and FG inventories
- Pay tied to amount produced

Hierarchical structure to clearly define roles & responsibilities

- Vertical communication flow
- Several management layers (6)

Figure 8.1: Old Practices Grouped by Strategic Objective
Energized, Empowered Organization

- Flexible equipment, jobs
- Supervisors can fill in on line
- Systematic problem solving
- All employees contribute ideas
- Concurrent engineering

Zero Non-Conformance to Requirements

- Vision given from top
- Operators responsible for quality
- Stop line if not running at speed
- All operators paid same flat rate

24-Hour Conversion of Raw Materials to Finished Goods

- Areas organized in work cells
- All materials outsourced

Elimination of All Non Value-Added Costs

- Low inventories using kanban
- Few management layers (3-4)
- Line rationalization

Figure 8.2: New Practices Grouped by Vision Statement Objectives
8.3 First Triangular Matrix

The first matrix of the MOC is a triangular matrix to the left of the column of "old practices." This matrix allows one to examine the interrelations among practices that make up the old paradigm. An example of this matrix, filled in for five of the old practices, is given in Figure 8.3. In this example, six of the 10 possible interactions are reinforcing (positive), and there are no opposing practices. The existence of positive symbols in this matrix does not imply that the strategy is a "good" strategy, it only indicates that the practices that make up the old strategy act to reinforce one another.

For example, in Figure 8.3 the use of equipment dedicated to making just one part type complements the practices of narrow job functions, large WIP and FG inventories, and pay for quantity. The practice of pay for quantity also complements that of narrow job functions, since this type of incentive pay focuses the workers on one primary task. The use of several management layers reinforces the practice of narrow job functions because the more layers to divide tasks across, the more specific the task description can be. Finally, the practice of pay for quantity encourages workers to build up large WIP and FG inventories, so these two activities are complements.

8.4 Second Triangular Matrix

The second triangular matrix allows the user to examine the interrelations among new practices. An example of this matrix filled in for six of new practices is given in Figure 8.4. In this example, three of the 15 possible interactions reinforce one another, while one pair of practices oppose one another.

Both expanded job responsibilities and lower inventory levels complement flexible equipment. This is because, the more the machine flexibility is being utilized, the broader the responsibilities that the workers must fulfill (e.g. multiple set-ups) and the lower the
Figure 8.3: First Triangular Matrix
Figure 8.4: Second Triangular Matrix
needed inventory levels. On the other hand, the line rationalization effort, in which product mix is reduced, acts in opposition to increases in flexible equipment. Finally, decreases in management layers are shown to complement increases in job responsibilities. These two practices are complementary because, as management layers decrease, there is an increase in the amount of responsibilities pushed down in the organization.

8.5 Transition Matrix

The transition matrix is the main square matrix that is used in determining the relationships between old and new practices. As noted at the beginning of this chapter, the rows in the transition matrix are defined by the old practices and the columns by the new practices. Figure 8.5 shows the transition matrix portion of the MOC filled in for the five old practices and six new practices already mentioned. Eleven of the possible 30 interactions are negative (in opposition to one another), and two are positive (reinforcing of one another).

Many of the relationships are self-evident. For example the use of designated equipment is in opposition to the use of flexible equipment, and the practice of narrow job functions opposes the practice of expanded job responsibilities. The practice of pay tied to amount produced acts in opposition to the practice of flat pay. Holding large inventory levels counteracts maintaining low inventory levels. Having several management layers opposes having few management layers. Brief explanations for the less evident interactions are given in the next paragraphs.

The use of designated equipment complements the practice of line rationalization. Line rationalization represents a lowering of the product mix, and the use of designated equipment is complemented by a low product mix. Similarly, the practice of narrow job
### Grid Rankings

- Reinforcing practices
- Weak to no interaction
- Opposing Practices

### Old Practices

<table>
<thead>
<tr>
<th>Hierarchical Structure</th>
<th>New Practices</th>
<th>Energized Organization</th>
<th>Zero Non-conformance</th>
<th>Elimination of non-value-adding costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run an efficient, low-cost operation</td>
<td>Designated equipment</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Narrow job functions</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Meet Product Requirements</td>
<td>Large WIP and FG inventories</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pay tied to amount produced</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Several management layers (6)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.5: Transition Matrix
functions complements the practice of line rationalization, as job responsibilities are easier to define, the lower the mix of products made.

The practice of designated equipment counteracts that of expanded job responsibilities, since job responsibilities generally decrease with decreasing machine flexibility. Conversely, the existence of narrow job functions acts in opposition to the use of flexible equipment. The practice of having narrow job functions also opposes the practice of few management layers because, as organizations "flatten" their structure, the scope of responsibilities at each of the remaining levels broadens. For the same reasons, the practice of having expanded job responsibilities acts in opposition to the existence of several management layers.

Large inventory levels counteract the use of machine flexibility. This was a conclusion of the work of Suarez et al (1992), and is discussed in Chapter 3. Finally, the practice of pay for quantity opposes the practice of expanded job responsibilities. This is because under such an incentive plan the workers are not motivated to take on any added responsibilities that might take time away from when they can be producing more product (Holmstrom and Milgrom, 1991).

8.6 Value Ranking of Existing Traits

The value ranking portion of the MOC is used to determine how strongly employees still value the old/existing practices. This portion of the MOC is a column to the right of the listed old practices. In it, employees assign a ranking to each of the old practices. A ranking of "+1" is assigned to practices which the employee feels should still be in place and one of "+2," to those which the employee strongly feels should still be in place. A
A sample value ranking section is shown in Figure 8.6. The respondent in this example feels strongly that the practice of narrow job functions be eliminated (-2), that inventory levels should not be maintained at their former high levels (-1), and that pay for quantity is still a good incentive (+1). The blanks beside the practices of designated equipment and several management layers indicate that the respondent does not feel strongly about either maintaining or eliminating these practices.
8.7 Factors Influencing Acceptance of Change

The influence ranking portion of the MOC is designed to evaluate employees' motivations for accepting or rejecting the various new practices. In this ranking section, there is a row for each factor that may have an effect on the employee's decision to accept or reject a new practice. The employee fills out this section by indicating whether the factor would influence them to accept (+1), strongly accept (+2), reject (-), or strongly reject (-2) the corresponding new practice.

Figure 8.7 shows an influence ranking section that has four factors: 1) self satisfaction, which means the desire for personal growth and rewarding challenges, 2) peer influence, 3) job security, and 4) union influence. In this sample ranking, the respondent has indicated that maintaining his or her job is a positive influence for accepting all six of the listed new measures. For four of the new practices this is the only factor the respondent felt would influence his or her behavior. In choosing whether or not to be receptive to the new technology, the respondent indicated that co-workers and the local union would influence him or her to not want to accept the new technology. In deciding whether or not to take on increased responsibilities, the respondent's desire for self-satisfaction would influence them to strongly accept.
<table>
<thead>
<tr>
<th>Influence Ranking</th>
<th>Self Satisfaction</th>
<th>Peer Influence</th>
<th>Job Security</th>
<th>Union Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value/Ranking</td>
<td>+2</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.7: A Sample Influence Ranking for New Practices
This chapter discusses how to interpret the MOC and what the implications from this are for change implementation. In doing this, the three matrices are viewed as different states within Epsilon's manufacturing system. The first triangular matrix represents the "old state," the second triangular matrix represents the "new state," and the transition matrix represents the transitory state that must be passed through to get from the old to the new. Figure 9.1 shows a completed MOC (minus ranking columns) that can be referred to during this chapter.

9.1 The Three States: Sign and Density of Interactions

The stability of any of the three states (represented by the three matrices) increases with increasing percentage of complementary practices. A state with numerous opposing practices is unstable. A state with few interactions (either reinforcing or opposing) is not inherently unstable, yet, at the same time, there is nothing binding the combination of
Figure 9.1: Matrix of Change for Selected Practices
practices together. Finally, a state with numerous complementary practices is stable because the practices act to reinforce one another.

9.1.1 The Old Paradigm

The sign (where reinforcing is positive and opposing is negative) and density of the interactions in the first triangular matrix supply information about the stability of the old paradigm and the order in which old practices might best be changed.

The majority of the existing interactions in the first triangular matrix are expected to be complementary because the existing state is usually one that has been in place for a while, which would imply it is fairly stable. It is likely that the density of complements in the old state has even increased over time as practices have had the opportunity to co-evolve. For example, the practice of holding large inventory levels was not specifically planned, but evolved largely due to the type of equipment and incentive scheme in place.

The greater the percentage of reinforcing practices in this state, the more stable it is, and, thus, the more difficult the various practices will be to change. The practices which will be eliminated most easily are those that act in opposition to the other practices. After that, it will be easiest to change the practices that are unaffected by the others or only reinforce a few of the other practices.

Practices which complement several of the other practices are referred to as "underlying practices." These underlying practices will likely be hardest to change, but these should be removed fairly early on in the change process (typically after the easier changes just described have been made). This is because as long as these practices remain in place, they will continue to reinforce several of the other old practices. Even if these other practices are
changed, the tendency will be to revert back to those ways as long as the underlying practices are still in place. An example of this can be seen in Figure 9.1. In the first matrix, the use of designated equipment complements three of the other four practices listed. From this matrix, one can see that as long as the old technology is in place, it will be difficult to expand job responsibilities, lower inventory levels, or remove pay based on quantity.

If there are several underlying practices and those practices oppose the new practices, the majority of changes should be made in parallel, rather than sequentially. This is because, in such a case, the old paradigm is so positively bound that nearly any remaining practice is likely to pull the entire system back towards the old state.

9.1.2 New Paradigm

The sign and density of the interactions in the second triangular matrix give information about the expected stability of the new paradigm and whether or not the new practices need to be added in parallel or if they can be added sequentially.

If the proposed changes have been planned so that they reinforce one another, the second triangular matrix should have a high number of positive symbols and little or no negative symbols. If this is not the case, the new state is not highly stable and the proposed changes need to be reevaluated. Any new practices that act in opposition to other new practices should definitely be reevaluated, as such practices could undermine the success of the proposed change effort.

The amount of inter-connectivity in the new matrix affects how well coordinated the implementation of change has to be. If several of the practices reinforce one another, all of the practices may have to be implemented at the same time in order to gain the expected benefits (such as the case with Federal Express). If the degree of inter-connectivity is
lower, new practices can be put in place at different points in time, and there is more room to allow the system to evolve on its own (with new practices being added or changed over time). In either case, if possible, it is good to put in place underlying new practices early on, so that they will reinforce the other changes as they are made.

9.1.3 Transition Matrix

The information gained from the transition matrix is the most useful (of the three matrices) for planning the implementation of change. The percentage of positive and negative symbols in the transition matrix indicates how disruptive the change process will be, and, thus, assists in making decisions about where and when to implement change.

Incremental Change

If there are a fair amount of complementary practices and few opposing practices, the change will be relatively incremental and non-disruptive. Such a change might be the addition of a new line item or a packaging change made to an existing product. When the transition matrix is fairly stable, there are more options for how to proceed with implementation. The pace and order of implementation is not as likely to affect the success of the implementation.

Radical Change

On the other hand, if there is a high percentage of negative symbols in the transition matrix, this symbolizes that the change is extremely disruptive and that the change-process will be inherently unstable. In these instances, choosing where and when to implement change is more critical. In general, the higher the density of opposing practices, the greater the need for isolation and/or speed. Since the system will tend to pull towards the old state as long as the old practices (which act in opposition to the new ones) remain in place, it is
important to either shield the change process from the old state or remove the old practices quickly.

In most cases it is difficult to remove the old before the new has been proven. Therefore, an organization needs to look for ways to shield the change process. As discussed in Chapter 7, going to a greenfield site is an option when change is very disruptive. Another option would be to isolate the change effort somehow from daily operations at an existing site.

Besides changing the location, it may be necessary to change the people in the case of highly disruptive change. For the implementation of radical change, the assistance of an outside change-agent is nearly always recommended. This person's role is to help the company challenge its basic assumptions and be more receptive to change. For particularly radical, or frame-breaking, change, it is often recommended that the top management team be replaced, as it may be so closely identified with the old way of doing business that radical change cannot succeed with it still in place (Tushman and Newman, 1988).

In addition, if a particular group of people are left significantly worse off by the change effort (such as middle managers when management layers are being reduced), it is usually best to remove them early on in the change process. Much like the old practice that acts in opposition to the new practices -- as long as these people are left in place, they will act to pull the system towards the old state (Rousseau, 1989, and Milgrom and Roberts 1992).

**Order of Implementation**

Regardless of how disruptive the change effort will be, the transition matrix provides some general guidelines for how to order changes. In general, the easiest new practices to put in place are those that complement old practices. It may be advantageous to change these practices early on and use them as a "bridge" between old and new. If, however, the new practice reinforces a high percentage of old practices, it may be dangerous to put this
practice in early on, as it will tend to push the system towards the old state equilibrium point.

The new practices which are the next easiest to put in place are those which are unaffected by the old practices. Since these practices are relatively easy to put in place and will serve to reinforce the other practices as they are added, these changes should be made early in the process. This is especially true if the practice is an underlying practice in the new matrix.

The new practices which will be most difficult to put in place are those that oppose several old practices. If the change is not taking place in an isolated area, it may, in fact, be impossible to put in place these new practices until the opposing old practices are removed. Either way, it is best to have a foundation of other new practices in place prior to implementing a new practice which acts in opposition to a high percentage of the old practices. Having the foundation in place will help to keep the added new practice from reverting back due to its being in opposition to the old practices.

9.2 Rankings: Indications of Receptiveness to Change

The value ranking and the influence ranking are both indications of how receptive the affected parties will be to the change effort. The value rankings show which old practices are most valued and by which groups of employees, while the influence rankings indicate why employees may or may not be motivated to change to the new practices.

9.2.1 Value Rankings

The value rankings assigned to the old practices are indications of how receptive the employees will be to changing these practices. If a practice is assigned a negative ranking, the employees feel that it should be removed. Therefore, they should be receptive to the proposed change. If a practice receives a positive value ranking, however, the employees
still feel that it is a practice that should be followed. In this case, it will be harder to get buy-in to eliminate the practice.

This gives added information for making implementation decisions. An old practice may be complementary with several of the other old practices, but it may be relatively easy to eliminate if the workers believe there is a need for change. Training and other efforts aimed to educate people on the need for change will lower the value rankings for old practices and make it easier for them to be removed.

9.2.2 Influence Ranking

The influence ranking helps to show how aligned the new practices are with the interests of the various affected parties. Ideally, the employees will feel self-motivated to go along with all of the new changes. If the workers' only motivation to go along with the changes is to remain employed, the company should see if it can "reframe" the new practices in ways that will be more in-line with the workers' personal and career goals. Otherwise, the workers may go along with the change effort only to keep their jobs and then leave as soon as they can find other employment. Furthermore, if this is the workers' only motivation, they are likely to give a minimal level of support.

The influence that co-workers, the union (if one exists), and other affected groups exert can affect how and where change is implemented. If the influence ranking indicates that certain groups widely oppose the new practices, the company needs to act. The company should first try to convince these groups of the validity of the changes. If this does not change things, the company needs to act to minimize the influence of any opposing groups. For example, if a company feels that the union strongly opposes the new practices, they may choose to move to a non-union site for the implementation.
9.3 Systematic View

Completing the MOC helps employees from different areas of the company to see the system-wide effect of various changes and to better understand the company's vision. It also helps the employees to better understand the motivations of their co-workers.

Viewed as a whole the MOC allows one to quickly grasp a fairly complete picture of the change effort. Users are able to see where the company is starting (first triangular matrix), where it is going (second triangular matrix), and how disruptive the process to get from one state to the other will be (transition matrix). If the old and new practices have been chosen so that they reflect key practices from a variety of functional areas, the MOC should capture non-obvious interactions and provide a system-wide view of the change-effort.

The grouping of the new practices by strategic goals shows the user what specific practices are being implemented to meet the company objectives, while the complementarities in this matrix can be used to explain the reasoning behind implementing the various new practices. Finally, the influence and value rankings allow the different functional groups to better understand the motivations and priorities of the employees in other groups.
Chapter 10

An Application of the Matrix of Change

To see what insights the MOC might supply on the change process at Epsilon as well as to test its use in a corporate setting, three different groups within Epsilon were asked to fill out the MOC. The groups that were surveyed include 1) salaried engineers and managers working with the pilot group (group SPG), 2) union workers in the pilot group (group UPG), and 3) salaried managers working in the main plant area (group SMP). This chapter looks at the results from this application of the MOC and discusses the possible implications. In addition, the success of this application as well as the general applicability of the tool is discussed.

10.1 Data Gathering and Processing Methodology

To fill in the MOC, detailed questionnaires were given to all of the workers involved in the pilot group effort as well as some of the workers in the main plant. The following two

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25 A fourth group, union workers in the main plant (UMP), were also asked to fill out questionnaires for the value and influence ranking sections.

26 The majority of the employees are accustomed to filling out questionnaires because every two years each Epsilon employee fills out a detailed questionnaire in order to evaluate the company’s performance on various dimensions.
sections explain how the information was gathered and processed in order to fill in the MOC.

10.1.1 Data Gathering Methodology

Value and Influence Ranking
Two questionnaires were distributed to workers to determine the value and influence rankings. These questionnaires and the tabulated group responses are shown in Appendices D and E. The questionnaires were distributed to the 17 union workers in the pilot group, 14 of the salaried workers involved with the pilot group (these people included the plant manager, an engineering group manager, an operations manager, an operations supervisor, and 10 engineers), two supervisors from the main plant, and eight union workers from the main plant.

MOC Forms
In addition, three of these groups were asked to individually fill out the three matrices in the MOC. (The union workers from the main plant were not asked to fill the matrices, as they could not be given time while at work to do this.) The MOC form that was distributed is shown in Appendix F. Instructions, for filling out the matrices are printed on the form. In addition, oral instructions were given when the forms were distributed.

Six members of the SPG group and one member of the UPG group sought out additional instruction as they were filling out the questionnaire. A problem some encountered was that all relationships did not appear to be symmetric. For instance, one respondent felt that the more worker pay is based on quantity produced, the greater the returns of having high inventory levels; yet the same person did not feel that the more inventory that is held, the

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27 Six of these engineers are involved with the design of the new equipment, three of them are involved in the support of the new FMS, and one is responsible for evaluating the performance of the new system.
greater the returns of linking pay to quantity produced. People who asked about this, were instructed to indicate a relationship if they felt there was one in at least one direction.

Another problem some had was getting beyond whether or not they considered a practice to be a good one. This was especially true for many of the managers who had bought into the change effort so much that they now viewed the old practices as "bad." As a result, initially, they had difficulty assigning any positive symbols in the first triangular matrix.

10.1.2 Filling in the MOC

All 14 members of the SPG group, both members of the SMP group, and 14 of the 17 members of the UPG group returned the two questionnaires used to fill in the ranking sections of the MOC. The 14 SPG members, two SMP members, and six of the 17 UPG members returned completed MOC forms. How this data was processed and used to fill in an MOC chart for each of the three groups is explained.

Value and Influence Rankings

Value rankings for each group were determined from the compiled questionnaire scores in the following way, where x equals the average group score:

<table>
<thead>
<tr>
<th>Average Group Score from Questionnaire (x)</th>
<th>Value Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 \leq x \leq 5.0</td>
<td>+2</td>
</tr>
<tr>
<td>4.0 \leq x &lt; 4.5</td>
<td>+1</td>
</tr>
<tr>
<td>2.0 &lt; x &lt; 4.0</td>
<td></td>
</tr>
<tr>
<td>1.5 \leq x \leq 2.0</td>
<td>-1</td>
</tr>
<tr>
<td>1.0 \leq x \leq 1.5</td>
<td>-2</td>
</tr>
</tbody>
</table>

One form from the SPG group was eliminated from scoring. The respondent had filled in a positive or negative symbol in every single square, which was interpreted as a misunderstanding of the directions.
For influence rankings, the respondents were asked to place pluses and minuses to indicate whether a certain factor would influence them to accept (+) or reject (-) each of the listed new practices. To indicate a strong influence, they were instructed to place either a double positive or a double negative sign (refer to Appendix E).

To tally the responses, the total number of plusses and minuses for each practice was calculated. If there were both plusses and minuses, each plus-minus pair canceled each other out to yield a net positive or net negative value. Considering that up to two plusses or two minuses could be given for each response, rankings were scored in the following way:

<table>
<thead>
<tr>
<th>Sign</th>
<th>Percentage of Possible Responses (x)</th>
<th>Influence Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>33 ≤ x ≤ 100</td>
<td>++</td>
</tr>
<tr>
<td>+</td>
<td>17 ≤ x &lt; 33</td>
<td>+</td>
</tr>
<tr>
<td>+/-</td>
<td>0 ≤ x &lt; 17</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>17 ≤ x &lt; 33</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>33 ≤ x ≤ 100</td>
<td>-</td>
</tr>
</tbody>
</table>

**MOC Interactions**

Basically, the same scoring procedure used to determine influence rankings was used to determine interactions for the three matrices. Net totals of either positive or negative symbols were tallied, and the relationship between practices were then determined as follows:

<table>
<thead>
<tr>
<th>Sign</th>
<th>Percentage of Possible Responses (x)</th>
<th>Relationship between Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>33 ≤ x ≤ 100</td>
<td>+</td>
</tr>
<tr>
<td>+</td>
<td>17 ≤ x &lt; 33</td>
<td>+</td>
</tr>
<tr>
<td>+/-</td>
<td>0 ≤ x &lt; 17</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>17 ≤ x &lt; 33</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>33 ≤ x ≤ 100</td>
<td></td>
</tr>
</tbody>
</table>
10.2 Results: Comparison to Expectations

A full MOC filled in using the interactions identified in the literature (Jaikumar, 1986; Krafcik and MacDuffie, 1989; Milgrom and Roberts, 1992, 1993; Suarez et. al., 1992) is shown in Appendix G. The compiled MOCs for the SPG, UPG, and SMP groups are shown in Appendices H, I and J, respectively. In this section both the general results of these three groups and selected specific results from the SPG group are compared to the expected results (based on the accepted relationships found in the literature). The SPG group was selected over the other two groups for two main reasons: 1) the sample size was the largest for this group and 2) the respondents in this group had received the most detailed instructions.

10.2.1 Matrix Densities and Ranking Results

This section examines the general responses from the surveyed work groups and compares them to the expected responses. In doing this, it looks primarily at the sign and density of interactions and not at specific individual interactions. The positive and negative matrix densities for the different groups are listed in Table 10.1 and will be referred to in the following paragraphs.

For all three matrices there is very good agreement between the SPG group's percentages and the expected percentages. Only for the old matrix, does one of the SPG group's densities vary much from the expected percentage. The percentage of positive, or reinforcing, interactions is only 25.6 for the SPG group, while the expected percentage is 35.9.

The SMP group has very good agreement with expected results for the old matrix. Its percentage of reinforcing interactions is 32.1 compared to an expected percentage of 35.9,
Table 10.1: Percentage of Positive and Negative Interactions

<table>
<thead>
<tr>
<th>Group</th>
<th>&quot;Old&quot; Matrix</th>
<th>&quot;New&quot; Matrix</th>
<th>Transition Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>positive (%)</td>
<td>negative (%)</td>
<td>positive (%)</td>
</tr>
<tr>
<td>Expected Percentage</td>
<td>35.9</td>
<td>0.0</td>
<td>26.4</td>
</tr>
<tr>
<td>Salaried Pilot Group (SPG)</td>
<td>25.6</td>
<td>0.0</td>
<td>26.4</td>
</tr>
<tr>
<td>Union Pilot Group (UPG)</td>
<td>23.1</td>
<td>0.0</td>
<td>9.9</td>
</tr>
<tr>
<td>Salaried Main Plant (SMP)</td>
<td>32.1</td>
<td>0.0</td>
<td>15.4</td>
</tr>
</tbody>
</table>

and its percentage of negative, or opposing, interactions is 0.0, which is in agreement with the expected percentage. The UPG group' results also compare relatively favorably for the old matrix, with a positive and negative percentage of 23.1 and 0.0, respectively.

For the SMP and UPG groups, however, the agreement is much less for both the new and transition matrices. For the new matrix, both the UPG and the SMP groups have a lower than expected percentage of reinforcing interactions (positive) and a higher than expected percentage of opposing interactions (negative). For positive interactions, the UPG group indicates 9.9 percent and the SMP group indicates 15.4 percent, while the expected percentage is 26.4. For negative interactions, the UPG group has a density of 5.5 percent and the SMP one of 6.6 percent compared to the expected value of 2.2 percent.

29 The "expected percentages" are taken from the MOC in Appendix G, which was filled in based on reinforcing and opposing interactions discussed in the literature.
For the transition matrix, both of these group's negative densities fall far below expected values. The density for the UPG group is 7.1 percent and that of the SMP group is 3.8 percent compared to the expected percentage of 21.4. In addition, the positive density of 1.1 percent for the SMP group falls well below the expected 3.8 percentage, although the 4.4 percentage for the UPG group is in fairly good agreement.

The value rankings from the four groups surveyed indicate that the union workers value the old practices more than either of the salaried groups (see Figure 10.1). Six out of 13 of the traits are given negative rankings by the salaried pilot group workers, and 8 out of the 13 old practices are given negative rankings by the salaried workers from the main plant. Conversely, only two out of 13 practices are given negative rankings by the pilot group workers, and none of the old practices are ranked negatively by the union workers in the main plant. Furthermore, none of the practices are indicated as being valued by the salaried pilot group workers and only one is valued by the salaried workers from the main plant. On the other hand, two practices are valued by union pilot group workers and six are valued by the union workers from the main plant.

For the influence rankings, one thing that stands out is that both of the groups from the main plant are more motivated by job security than those in the two pilot groups (see Figure 10.2). Negative motivational factors only show up for four of the 14 new practices. The SPG group indicates that self satisfaction will influence them to not accept the reduction in management layers. Both the union groups feel that the union will influence them to not go along with outsourcing. The UPG group also feels that the union and peers will be a negative influence for accepting that the supervisor be able to fill in on the line. The union group from the main plant feels that these same two groups will be a negative influence for accepting the new equipment and expanded job responsibilities.
Old Practices

- Designated equipment: -1 (SPG), -1 (UPG), +1 (SMP), +1 (UMP)
- Areas separated by machine type: -1 (SPG), -1 (UPG), +2 (SMP), +2 (UMP)
- Narrow job functions: -2 (SPG), -2 (UPG), -1 (SMP), -1 (UMP)
- Salaried employees make all decisions: -1 (SPG), -2 (UPG), -1 (SMP), -1 (UMP)
- Hourly workers carry them out: -2 (SPG), -1 (UPG), -2 (SMP), +1 (UMP)
- Functional groups work independently: -2 (SPG), -2 (UPG), -1 (SMP), +1 (UMP)
- Keep line running no matter what: -1 (SPG), -1 (UPG), +1 (SMP), +1 (UMP)
- Thorough final inspection by QA: +2 (SPG), +1 (UPG), +2 (SMP), +2 (UMP)
- Raw materials made in-house: +1 (SPG), +1 (UPG), +2 (SMP), +2 (UMP)
- Large WIP and FG inventories: -1 (SPG), -2 (UPG), +1 (SMP), +1 (UMP)
- Pay tied to amount produced: -1 (SPG), -1 (UPG), -1 (SMP), -1 (UMP)
- Vertical communication flow: -1 (SPG), -1 (UPG), +1 (SMP), +1 (UMP)
- Several management layers (6): -1 (SPG), -2 (UPG), +1 (SMP), +1 (UMP)

Figure 10.1: Value Rankings for the Four Test Groups
<table>
<thead>
<tr>
<th>Value/Influence Rankings</th>
<th>+2 Strong positive</th>
<th>+1 Positive</th>
<th>-1 Negative</th>
<th>-2 Strong negative</th>
</tr>
</thead>
</table>

**Figure 10.2: Influence Rankings for the Four Test Groups**
10.2.2 Comparison of Specific Responses

This section examines some of specific responses from the SPG group and compares them to the expected responses.

Old Matrix

In this matrix, all of the reinforcing interactions listed by the salaried workers are in agreement with the expected interactions (see Figure 10.3). Two reinforcing interactions are missed by the SPG group; however, they are two of the more debatable pairs of complementary practices from the literature. They are the reinforcing interactions between designated equipment and pay for quantity and between narrow job functions and several management layers.

New Matrix

There is more discrepancy in the results for the second triangular matrix than for the first (see Figure 10.4). The SPG group responses match with the accepted responses for two of the reinforcing interactions. Two interactions are missed, and one additional relationship is indicated by the group. First, the opposing interaction between line rationalization and flexible equipment is missed. The group also fails to see any relationship between low inventory levels and flexible equipment. In addition, flat pay and expanded job responsibilities are indicated to be reinforcing, when this is not a well-accepted relationship.

Old Versus New

For the selected practices in the transition matrix, the Epsilon group indicates 10 opposing interactions -- eight of which are in agreement with the accepted responses (see Figure 10.5). For one relationship, the study group indicates the wrong sign. It indicates that
Figure 10.3: Old Matrix: Results Compared to Expected Responses
### Results from SPG Group

<table>
<thead>
<tr>
<th>New Practices</th>
<th>Expected Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energized Organization</strong></td>
<td><strong>Zero non-conformance</strong></td>
</tr>
<tr>
<td>Flexible equipment</td>
<td>Expanded job responsibilities</td>
</tr>
<tr>
<td>Expanding job responsibilities</td>
<td>All operators paid same flat rate</td>
</tr>
<tr>
<td>Low inventories using kanban</td>
<td>Few management layers (3-4)</td>
</tr>
<tr>
<td>Line rationalization</td>
<td></td>
</tr>
</tbody>
</table>

#### Grid Rankings
- Reinforcing practices
- Weak to no interaction
- Opposing Practices
<table>
<thead>
<tr>
<th>Grid Rankings</th>
<th>New Practices</th>
<th>Energized Organization</th>
<th>Zero non-conformance</th>
<th>Elimination of non-value-adding costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Reinforcing practices Weak to no interaction - Opposing Practices</td>
<td>Flexible equipment</td>
<td>Expanded job responsibilities</td>
<td>All operators paid same flat rate</td>
<td>Low inventories using kanban Few management layers (3-4) Line rationalization</td>
</tr>
</tbody>
</table>

### Old Practices

<table>
<thead>
<tr>
<th>Rank of efficient, low-cost operation</th>
<th>New Practices</th>
<th>Energized Organization</th>
<th>Zero non-conformance</th>
<th>Elimination of non-value-adding costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designated equipment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Narrow job functions</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Large WIP and FG inventories</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pay tied to amount produced</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Several management layers (6)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Results from SPG Group

### Old Practices

<table>
<thead>
<tr>
<th>Rank of efficient, low-cost operation</th>
<th>New Practices</th>
<th>Energized Organization</th>
<th>Zero non-conformance</th>
<th>Elimination of non-value-adding costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designated equipment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Narrow job functions</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Large WIP and FG inventories</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pay tied to amount produced</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Several management layers (6)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Expected Responses

Figure 10.5: Transition Matrix: Results Compared to Expected Responses
designated equipment acts in opposition to line rationalization, when, in fact, it reinforces it. The other differing response is consistent with the interpretation of flat pay used in the second matrix -- the group feels that flat pay opposes the practice of narrow job functions.

In addition, the group misses three interactions. It does not see a reinforcing interaction between narrow job functions and line rationalization. It also does not feel that the existence of several management layers opposes expanded job responsibilities or that high inventory levels acts in opposition to the use of flexible equipment. Both of these last two omissions are consistent with the two missed interactions in the second matrix.

10.3 Implications for Change Effort

This sections examines the conclusions that can be drawn from the group responses and discusses Epsilon's implementation decisions in light of the results from the MOC.

10.3.1 Interpretation of Employee Results

Old Matrix
The results indicate that all three groups understand well the interactions in the old matrix. This makes sense because all three have had some direct experience with the traditional manufacturing paradigm at Epsilon. The fact that the positive densities for both pilot groups fall significantly below the expected values is likely due to the fact that these groups are now removed from many of the old practices.

New Matrix
The results from the new matrix indicate that the SPG group is the best informed of the three groups on what the potential reinforcing practices are for the new state. The fact that this group fails to see any opposing interactions, however, may indicate that they are too close to the change effort to be truly objective.
Furthermore, some of the complementarities assigned by the SPG group indicate that the group may be overly optimistic on some of the points in the new paradigm. For example, the group indicates that flat pay reinforces workers taking on expanded job responsibilities. While it may be true that flat pay leads to an increase in job responsibilities over a pay-for-quantity incentive scheme, it is not widely accepted that the more people are paid the same, the more they contribute. In fact, the opposite is more widely accepted. Typically, the existence of some pay differential provides incentive for workers to work harder so that they might rise to the higher level (Lazear, 1988). The fact that the shop-floor workers assign no complementary symbol between flat pay and expanded responsibilities (or any of the other new practices) further indicates that the SPG group may be optimistic in its expectations about the behavior that flat pay will promote.

The high percentage of opposing interactions that the UPG and SMP groups indicate for the new matrix appears to be a result of their feelings about worker motivation. Both of these groups indicate that the practices of outsourcing and letting supervisors fill in on the line oppose the practices of workers contributing ideas and/or expanding workers' responsibilities. This is because many of the workers are against outsourcing and having supervisors be able to fill on the line. They see these things as potentially taking jobs away from them. Thus, the implementation of these changes could lead to lower worker cooperation with other measures. Rather than showing up as a true opposing interaction, this information should probably show up in the influence ranking to show that all of the incentives may not be aligned with some of the new practices.

**Transition Matrix**

Again, the responses in the transition matrix indicate that the SPG group is the most informed about the planned changes, although some of the SPG group's responses in this matrix indicate possible misinterpretations of interactions. For example, the group indicates that line rationalization acts in opposition to the use of the old, designated
equipment. In fact, it is well accepted that decreasing product mix reinforces the use of less flexible equipment. The SPG group's interpretation is likely due to the fact that line rationalization is not viewed as decreasing product mix, but rather as increasing customer responsiveness (see page 29).

Besides a lack of information about the new practices, a reason for the low density of interactions assigned by the UPG and SMP groups for the transition matrix may be that these respondents started to lose energy by the time they reached this last matrix. Since they would have already been through 169 squares before reaching this last matrix, this is actually quite likely.

**Value and Influence Rankings**

The higher value rankings given by the union workers indicate that these workers will resist the proposed changes more than the salaried workers. The higher rankings may also indicate that these workers have received less information on the benefits of changing some of the old practices.

The fact that the workers from the main plant indicate job security as an influence in accepting change more often than the pilot group members seems to imply that these workers are not sure of what their roles will be in the new paradigm. The influence ranking also indicates that the reduction of management layers is misaligned with the salaried workers' interests and that changes in work practices and use of outsourcing are misaligned with the union's interests.

**10.3.2 Implementation Decisions**

The order in which Epsilon has implemented change is consistent with what is recommended by the MOC. They first put in place practices which did not highly oppose
the old practices -- such as systematic problem solving and concurrent engineering -- before putting in place the most disruptive changes, the new technology and work practices.

The results from the MOC indicate that the change effort is fairly disruptive as the relative percentage of negative symbols is much higher than that of positive symbols (21.4 compared to 3.8). The fact that Epsilon has tried to isolate the pilot group indicates that they recognize the disruptive behavior of the change.

The MOC also points out some discrepancies in Epsilon's plan. One of these is that line rationalization acts to oppose flexible equipment, the key practice in the new paradigm. If line rationalization ends up being more than a one-shot effort to eliminate unneeded product variations, the line rationalization concept will act to reinforce the idea that the new equipment be treated like the old equipment -- with each work cell being dedicated to making one type of product.

The MOC also indicates that the new matrix has not been planned to be highly reinforcing. The percentage of positive symbols is 21.4 compared to 35.9 percent for the old matrix. One of the key reasons for this is that the use of incentive pay in the old matrix reinforces many of the other old practices, while flat pay is uncorrelated with all of the new practices. When asked about this, a top manager said that the company was intentionally putting in a "neutral" compensation scheme until the system had evolved to the point where they better understood the behavior that they wanted to promote and how to measure it. At that point, Epsilon will put in place a compensation scheme that reinforces desired practices. If the change to flexible technology is one that can evolve, this is a logical plan.

Indications seem to be, however, that the evolutionary approach is causing the flexibility of the system to be underutilized. When the pilot group went into production, the external pressure pushed the group back towards mass production practices, and this trend may be continuing. As the new equipment is being brought on line, there is a debate going on over
whether or not to dedicate each of the cells to making primarily one product code. If Epsilon follows this path, its productivity levels may be higher than what they would be with each cell producing multiple products. If regular changeovers are not done on the new equipment, however, Epsilon will lose some flexibility in developing new products and in making modifications to their existing line of products -- two of the advantages it wanted to gain by investing in the flexible technology.

The results from the ranking sections also offer some relevant information for making implementation decisions. The results from the UPG group indicate that the change effort could benefit from this group gaining more information about the reasoning behind changing to the new practices. Also, if Epsilon wants to be preparing the employees in the main plant for some of the changes to come, this group is in need of more information on the new practices. In addition, the influence rankings indicate that there are some misaligned incentives. For instance, the practice of the supervisor filling in on the line is perceived by the workers as a threat to their job security. This and other instances of misaligned incentives could be addressed by reframing the new practice so that the workers see that it should not pose a threat to them.

10.4 General Applicability of the MOC

The application of the MOC change-management tool to the effort at Epsilon substantiates both that the tool can be successfully applied and that the information to be gained from it is of use to the organization. This section discusses those issues as well as how the tool might be applied in other settings.
10.4.1 Successfulness of Application

The SPG group's responses were fairly consistent with the accepted responses, indicating that the tool can be properly applied in a corporate setting. The overall percentage of reinforcing (+) and opposing (-) interactions assigned by the group for the three matrices was in very good agreement with the expected results. This means that the group correctly identified the relative stability of the three matrices. In the specific comparison that was conducted, the group correctly identified 14 out of 23 interactions (60.9 percent), missed eight, and incorrectly identified three interactions. In general, the omissions and incorrect responses were a result of the workers limiting their view of possibilities to what they had seen at Epsilon (such as assuming worker compensation has to be either flat pay or pay-for-quantity).\textsuperscript{30}

10.4.2 Potential Benefits of the Tool

The application of the tool demonstrates its many potential benefits. By showing the systematic effect of the proposed changes, it allows a company to make better decisions about what changes to implement and where and when to implement the changes. The existence of opposing interactions in the new matrix points out practices which could undermine the change effort and which, therefore, should be reevaluated. The percentage of opposing interactions in the transition matrix indicates how disruptive the change process will be and helps an organization in making decisions about how isolated and how rapid the change process should be.

The rankings help point out where education and training may be needed. In addition, the influence ranking helps point out where incentives may be misaligned. Negative rankings in this section highlight a need to either "reframe" the change so that incentives are better

\textsuperscript{30} This indicates that an outside consultant might be valuable in helping to administer the MOC.
aligned or to remove or isolate factions whose interests are misaligned with those of the 
change effort.

10.4.3 Application in Other Settings

Although individual questionnaires and forms were used to fill out the MOCs for the 
purposes of this research, in general, it will make more sense for the tool to be applied in a 
group setting. The reasons for this are many fold. First, one of the potential benefits of 
the tool is to bring together employees from different groups so that they can better 
understand both the system-wide effects of the proposed changes and the concerns of their 
co-workers. If questionnaires are filled out in isolation, this will not occur.

Second, there is less chance for misinterpretations if the form is filled out in a group 
setting. If one person starts to get confused, for instance, about whether two "bad" 
practices can complement one another, the rest of the group is there to help get him or her 
back on track.

A third reason for filling the MOC out in a group setting is because it is a lot of work for 
any one person due to the sheer volume of squares to fill in. For example, to account for 
the interactions among and between 12 old and 12 new practices, one needs to process 
through 276 squares. In addition to this, there are 12 value rankings for each group to fill 
out and 12 influence rankings for each motivational factor considered.

The MOC may also be applied in a more rigorous way. Even more detailed of 
questionnaires can be filled out in order to try to quantify not only the sign, but also the 
magnitude, of the various interactions. Such an application could help to further research 
efforts on the role of complementarities. If such an application is to be used, however, it 
may be wise to limit the number of practices which are studied. Even with just 13 old and
14 new practices to consider, the respondents quickly grew weary when filling out the questionnaires.

Besides the large volume of squares to fill in, a short-coming with the MOC is that there is no exact definition of what constitutes a high, medium, or low density of interactions. Furthermore, there is no way of knowing for sure that the "right" old and new practices have been selected. For example, as discussed earlier, self-motivated workers appear to be a needed complementary with the new technology, yet this was not even directly considered in the MOC. If this is a critical element in the change effort, the conclusions that are drawn from the MOC may be misleading. To help ensure that practices are selected carefully, the first step in using the MOC should be a brainstorming session by management to determine which old and new practices will be used.

Another shortcoming of the tool is that it does not take into account the basic assumptions behind the changes. For example, the management's reasoning behind going to flat pay is not captured in the MOC. Hopefully, however, a discussion of basic assumptions will accompany the filling out of the form when it is done in a group setting. This may be especially important when two or more organizations are cooperating in a change effort (e.g. in a "value-adding partnership").

31 This was indirectly taken into account through the self-satisfaction influence ranking.
Chapter 11
Conclusion

11.1 Summary of Work

This thesis has presented technical and managerial methods for improving the productivity of an FMS.

11.1.1 FMS Improvement through Local Efforts

Improvements in the performance of the FMS were made at a local level through set-up time reduction and improved scheduling. The greatest improvements in set-up performance were gained through changes made in set-up procedures, rather than through technical redesigns of the equipment.

Results from a study carried out over 198 production shifts showed that set-ups are sequence-dependent on the maker. As a result, the ordering of set-ups is important, and some set-up types should be completely eliminated. Furthermore, it is suggested that the ratio of difficult to easy set-ups be decreased, with slightly higher buffer levels then being held for the codes that require more-difficult set-ups.
11.1.2 FMS Improvement through Global Efforts

The need for complementary practices to reinforce the benefits of the flexible technology is discussed in the thesis. The Matrix of Change is a change-management tool that is presented to assist companies in determining interactions between practices and in planning the implementation of change. It attempts to show the current state of the system, the vision of where the company is going, and the path that must be traveled to get from one to the other.

This tool is most useful when the proposed change is radical and the implementation of change needs to be well-designed. It can, however, be applied for any type of change, and it can even be used to help an organization determine whether an evolutionary or designed approach is more appropriate for the effort. In addition, the tool is valuable when involvement of several functional areas is critical for the success of the change effort.

11.2 Suggestions for Future Work

To further improve scheduling on the maker, a detailed scheduling algorithm should be developed. Relevant production data should be automatically downloaded to this program, so it can factor in any system performance improvements.

The MOC needs to be applied in more settings to test for its usefulness and to determine what modifications may be needed by potential users. Furthermore, the tool could assist in research efforts aimed at better defining the role of complementarities.
Appendix A: Check List for Operator Set-Up on the Maker

NAME: ___________ from: CODE_________ to: CODE_________
DATE ___________

In the 15-30 min. prior to a set-up:

_____ Fill out all paperwork that can be completed before machine stops.
_____ Make sure an empty inventory cart is ready to go.
_____ Exchange raw materials in the area as soon as it is clear that supply on the maker will be enough to complete the current run.
_____ Load new raw materials.

As soon as the maker is stopped for a set-up:

_____ If more than one operator is present, one assists machinist.
_____ Complete paperwork.
_____ Do any needed cleaning.
_____ Load appropriate software.
_____ Finish loading raw materials.
_____ Do rough adjustments of guides to align raw materials.
_____ Run maker to check alignment.
_____ Check alignment with handler engaged.
_____ Move guides as needed to improve alignment.
_____ Do pre-start checks.
_____ Once making good product, stop and empty waste from inventory cart.
_____ Start production run.
Appendix B: Check List for Mechanical Set-Up on the Maker

NAME: _____________ from: CODE__________ to: CODE__________
DATE _____________

In the 15-30 min. prior to a set-up:

_____ Line up mechanical parts that will be needed for the set-up.
_____ Bring tool cart (with all necessary tools) into area.
_____ Bring ladder over near the maker.

As soon as the maker is stopped for a set-up:

_____ Change tooling.
_____ Reset counters.
_____ Change crimp rolls.
_____ Check crimp pattern alignment.
_____ If necessary, align crimp pattern. Check (x) if alignment needed. _____
_____ Change encoder.
_____ If needed, adjust handler. Record any adjustments below:

Record settings: A:__________ B:__________ C:__________

After machine set-up is complete:

_____ Clean and grease removed parts as needed.
_____ Replace tooling pads as needed.
_____ Arrange for repair or replacement of any removed parts that are damaged.
Appendix C: Set-Up Data Recorded over 4-Month Period

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Appendix D: Value Rankings of "Old Practices"
(Questionnaire and Responses)

Example Questionnaire

1. Equipment designated to making or packing one given product type
2. Production areas arranged by machine type; one product code and function (making or packing) performed in each area
3. Narrow, specific job descriptions (line tender, maker 1 operator, maker 2 operator, etc.) to maximize output
4. Salaried employees make all the decisions ("thinkers")
5. Shop-floor workers follow instructions and are not expected to give feedback/suggestions ("doers")
6. Marketing, Engineering and Operations optimize their given area of a project before passing it on to another area
7. Always keep line running. If need be, reduce speed, but try to keep from having to shut it down completely.
8. Thorough inspection of outgoing product by Quality Assurance
9. Raw materials made in-house (in-house control of quality & delivery)
10. Large raw materials (RM) and work-in-progress (WIP) inventories to buffer against uncertainty in material deliveries, machine operation, and product demand
11. High productivity encouraged by tying pay to amount of material produced
12. Hierarchical organizational structure to assist communication of orders downward and information of results upward
13. Several management positions to provide the needed authority to get work assigned quickly and easily.
### Appendix D: Value Rankings of "Old Practices" (continued)

**Compiled Responses from Salaried Workers Involved in Pilot Group Effort**

(14 respondents -- 10 engineers, 1 engineering manager, 1 plant manager, 1 operations manager, 1 operations supervisor)

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<th>Score ± Standard Deviation</th>
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<td>Equipment designated to making or packing one given product type</td>
<td>1.9 ± 1.3</td>
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<td>Production areas arranged by machine type; one product code and function</td>
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<td>(making or packing) performed in each area</td>
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<td>Narrow, specific job descriptions (line tender, maker 1 operator, maker 2</td>
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<td>operator, etc.) to maximize output</td>
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<td>Salaried employees make all the decisions (&quot;thinkers&quot;)</td>
<td>2.8 ± 1.7</td>
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<td>Shop-floor workers follow instructions and are not expected to give</td>
<td>1.0 ± 0.0</td>
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<td>feedback/suggestions (&quot;doers&quot;)</td>
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<tr>
<td>6</td>
<td>Marketing, Engineering and Operations optimize their given area of a project</td>
<td>2.5 ± 1.6</td>
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<tr>
<td></td>
<td>before passing it on to another area</td>
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<td>7</td>
<td>Always keep line running. If need be, reduce speed, but try to keep from</td>
<td>3.3 ± 1.5</td>
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<td>having to shut it down completely</td>
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<td>8</td>
<td>Thorough inspection of outgoing product by Quality Assurance</td>
<td>2.4 ± 1.4</td>
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<td>Raw materials made in-house (in-house control of quality &amp; delivery)</td>
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<td>Large raw materials (RM) and work-in-progress (WIP) inventories to buffer</td>
<td>1.7 ± 1.3</td>
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<td>against uncertainty in material deliveries, machine operation, and product</td>
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<td>demand</td>
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<td>11</td>
<td>High productivity encouraged by tying pay to amount of material produced</td>
<td>2.1 ± 1.2</td>
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<tr>
<td>12</td>
<td>Hierarchical organizational structure to assist communication of orders</td>
<td>2.3 ± 1.3</td>
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<td>downward and information of results upward</td>
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<td>13</td>
<td>Several management positions to provide the needed authority to get work</td>
<td>1.9 ± 1.4</td>
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<td>assigned quickly and easily</td>
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Appendix D: Value Rankings of "Old Practices" (continued)

Compiled Responses from Union Workers Involved in Pilot Group Effort
(14 respondents - 12 operators, 2 machinists)

1. Equipment designated to making or packing one given product type 2.9 ± 1.5
2. Production areas arranged by machine type; one product code and function (making or packing) performed in each area 3.9 ± 0.9
3. Narrow, specific job descriptions (line tender, maker 1 operator, maker 2 operator, etc.) to maximize output 3.3 ± 1.3
4. Salaried employees make all the decisions ("thinkers") 2.2 ± 1.3
5. Shop-floor workers follow instructions and are not expected to give feedback/suggestions ("doers") 1.6 ± 0.8
6. Marketing, Engineering and Operations optimize their given area of a project before passing it on to another area 3.3 ± 1.3
7. Always keep line running. If need be, reduce speed, but try to keep from having to shut it down completely. 2.4 ± 1.9
8. Thorough inspection of outgoing product by Quality Assurance 4.6 ± 0.5
9. Raw materials made in-house (in-house control of quality & delivery) 4.1 ± 0.9
10. Large raw materials (RM) and work-in-progress (WIP) inventories to buffer against uncertainty in material deliveries, machine operation, and product demand 3.7 ± 0.8
11. High productivity encouraged by tying pay to amount of material produced 3.6 ± 1.1
12. Hierarchical organizational structure to assist communication of orders downward and information of results upward 2.7 ± 1.3
13. Several management positions to provide the needed authority to get work assigned quickly and easily 2.4 ± 1.1
Appendix D: Value Rankings of "Old Practices" (continued)

Compiled Responses from Supervisors in Main Production Area)
(2 respondents)

1. Equipment designated to making or packing one given product type 2.5 ± 0.7
2. Production areas arranged by machine type; one product code and function (making or packing) performed in each area 2.0 ± 0.0
3. Narrow, specific job descriptions (line tender, maker 1 operator, maker 2 operator, etc.) to maximize output 1.5 ± 0.7
4. Salaried employees make all the decisions ("thinkers") 2.5 ± 0.7
5. Shop-floor workers follow instructions and are not expected to give feedback/suggestions ("doers") 1.5 ± 0.7
6. Marketing, Engineering and Operations optimize their given area of a project before passing it on to another area 1.5 ± 0.7
7. Always keep line running. If need be, reduce speed, but try to keep from having to shut it down completely. 3.0 ± 0.0
8. Thorough inspection of outgoing product by Quality Assurance 4.0 ± 0.0
9. Raw materials made in-house (in-house control of quality & delivery) 2.5 ± 0.7
10. Large raw materials (RM) and work-in-progress (WIP) inventories to buffer against uncertainty in material deliveries, machine operation, and product demand 1.5 ± 0.7
11. High productivity encouraged by tying pay to amount of material produced 2.0 ± 1.4
12. Hierarchical organizational structure to assist communication of orders downward and information of results upward 2.0 ± 1.4
13. Several management positions to provide the needed authority to get work assigned quickly and easily 1.0 ± 0.0
Appendix D: Value Rankings of "Old Practices" (continued)

Compiled Responses from Union Workers in Main Production Area
(8 respondents)

1. Equipment designated to making or packing one given product type 4.2 ± 0.9
2. Production areas arranged by machine type; one product code and function (making or packing) performed in each area 4.2 ± 0.9
3. Narrow, specific job descriptions (line tender, maker 1 operator, maker 2 operator, etc.) to maximize output 3.7 ± 1.2
4. Salaried employees make all the decisions ("thinkers") 3.2 ± 1.2
5. Shop-floor workers follow instructions and are not expected to give feedback/suggestions ("doers") 2.7 ± 0.9
6. Marketing, Engineering and Operations optimize their given area of a project before passing it on to another area 4.0 ± 0.9
7. Always keep line running. If need be, reduce speed, but try to keep from having to shut it down completely. 4.2 ± 0.9
8. Thorough inspection of outgoing product by Quality Assurance 4.5 ± 0.5
9. Raw materials made in-house (in-house control of quality & delivery) 3.5 ± 0.9
10. Large raw materials (RM) and work-in-progress (WIP) inventories to buffer against uncertainty in material deliveries, machine operation, and product demand 3.5 ± 0.9
11. High productivity encouraged by tying pay to amount of material produced 3.5 ± 1.2
12. Hierarchical organizational structure to assist communication of orders downward and information of results upward 3.2 ± 0.9
13. Several management positions to provide the needed authority to get work assigned quickly and easily 3.0 ± 1.5
Appendix E: Influential Factors (Questionnaire and Responses)

Example Questionnaire

Please indicate how the listed factors would influence your behavior towards the listed new practices by using the symbols shown below:

++  strong influence to go along with new practice
+   moderate influence to go along with new practice
    no influence
-   moderate influence to protest new practice
--  strong influence to protest new practice

New Practice:  

Job Security:  Peers:  Self

- Flexible equipment and job definitions
- Supervisors can fill in on line
- Systematic problem solving techniques
- All employees contribute improvement ideas
  (Solicit input from union workers on improvement of equipment)
- Concurrent engineering -- work with other functional groups on improvement/development projects
- Vision provided by top management
- Operators responsible for quality
- Operators have authority to stop line when there is a problem
- All operators paid same flat rate
- Areas organized in work cells
- All raw materials outsourced
- Use kanban inventory control
- Three to four management layers (flatter organization)
- Line rationalization
Appendix E: Influential Factors (continued)

Compiled Responses from Salaried Workers Involved in Pilot Group Effort
(14 respondents -- 10 engineers, 1 engineering manager, 1 plant manager,
1 operations manager, 1 operations supervisor)

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Appendix E: Influential Factors (continued)

Compiled Responses from Union Workers Involved in Pilot Group Effort
(14 respondents - 12 operators, 2 machinists)

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Appendix E: Influential Factors (continued)

Compiled Responses from Supervisors in Main Production Area)
(2 respondents)

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Appendix E: Influential Factors (continued)

Compiled Responses from Union Workers in Main Production Area
(8 respondents)

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<td>• Concurrent engineering -- work with other functional groups on improvement/development projects</td>
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<td>• Vision provided by top management</td>
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<td>• Operators responsible for quality</td>
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<tr>
<td>• Operators have authority to stop line when there is a problem</td>
<td>+</td>
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<tr>
<td>• All operators paid same flat rate</td>
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<td>• Areas organized in work cells</td>
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<td>• All raw materials outsourced</td>
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<td>• Use kanban inventory control</td>
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<td>• Three to four management layers (flatter organization)</td>
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<td>• Line rationalization</td>
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Appendix F: Matrix Questionnaire

Please fill in the grids below as follows:

Assuming that the listed practices are acceptable, go down through each column and ask yourself:

Increasing this practice leads to more, less, or no change in the corresponding practices?

If more, interaction is reinforcing.
If less, interaction is opposing.
Use grid rankings below to fill in squares.

Ignore "Value Rankings" and "Influence Rankings" sections.

<table>
<thead>
<tr>
<th>Grid Rankings</th>
<th>Old Practices</th>
<th>New Practices</th>
<th>Energized Organization</th>
<th>Zero non-conformance to requirements</th>
<th>24-hour conversion</th>
<th>Elimination of non value costs</th>
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<td>Salaried employees make all decisions</td>
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<td>- Strongly opposing</td>
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<td>Keep line running no matter what</td>
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<tr>
<td></td>
<td>Thorough final inspection by QA</td>
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<td>Influence Ranking</td>
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Line rationalization
Appendix G: MOC Filled in with Accepted Interactions

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<td>All operators paid same flat rate</td>
<td>Few management layers (3-4)</td>
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<td>Stop line if not running at speed</td>
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<td>Few management layers (3-4)</td>
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Old Practices

- Designated equipment
- Areas separated by machine type
- Narrow job functions
- Salaried employees make all decisions
- Hourly workers carry them out
- Functional groups work independently
- Keep line running no matter what
- Thorough final inspection by QA
- Raw materials made in-house
- Large WIP and FG inventories
- Pay tied to amount produced
- Vertical communication flow
- Several management layers (6)
Appendix H: MOC Filled in by Salaried Workers in Pilot Group

**Grid Rankings**
- Strongly reinforcing
- Reinforcing
- Weak to no interaction
- Opposing
- Strongly opposing

**Value/Influence Rankings**
+2 Strong positive
+1 Positive
-1 Negative
-2 Strong negative

### Old Practices

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<td>+</td>
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### Value/Influence Rankings

- Strong positive
- Positive
- Negative
- Strong negative
Appendix I: MOC Filled in by Union Workers in Pilot Group

Grid Rankings
+ Strongly reinforcing
+ Reinforcing
Weak to no interaction
- Opposing
- Strongly opposing

Value/Influence Rankings
+2 Strong positive
+1 Positive
-1 Negative
-2 Strong negative

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24-hour conversion
Elimination of non-value costs
Energized Organization
Zero non-conformance to requirements

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Appendix J: MOC Filled in by Salaried Workers
in Main Plant

### Grid Rankings

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<td>Strongly opposing</td>
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### Value/Influence Rankings

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### Old Practices

- Designated equipment
- Areas separated by machine type
- Narrow job functions
- Salaried employees make all decisions
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- Functional groups work independently
- Keep line running no matter what
- Thorough final inspection by QA
- Raw materials made in-house
- Large WIP and FG inventories
- Pay tied to amount produced
- Vertical communication flow
- Several management layers (6)

### New Practices

- Flexible equipment, jobs
- Supervisors can fill in on line
- Systematic problem solving
- All employees contribute ideas
- Concurrent Engineering
- Operators responsible for quality
- Vision given from top
- Stop line if not running at speed
- All operators paid same flat rate
- All operators organized in cells
- Few inventories outsourced
- Low inventories using Kanban
- Few management layers (3-4)
- Lean rationalization

### Influences

- Self Satisfaction
- Peer Influence
- Job Security

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References


