

# IMPLEMENTATION OF LEAN MANUFACTURING AND ONE-PIECE FLOW AT ALLIED SIGNAL AEROSPACE

by

Steven R. Harman

B.S. Mechanical Engineering, Duke University, 1989  
M.B.A. University of San Diego, 1995

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

MASTER OF SCIENCE IN MANAGEMENT  
and  
MASTER OF SCIENCE IN MECHANICAL ENGINEERING

at the  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
June 1997

© Massachusetts Institute of Technology. All rights reserved.

Signature of Author .....  
Sloan School of Management  
Department of Mechanical Engineering

Certified by .....  
Stanley B. Gershwin, Thesis Supervisor  
Senior Research Scientist

Certified by .....  
Stephen C. Graves, Thesis Supervisor  
Professor of Management Science

Accepted by .....  
Ain A. Sonin, Chairman of the Graduate Committee  
Department of Mechanical Engineering

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

JUL 21 1997

LIBRARIES  
OF TECHNOLOGY



# **Implementation of Lean Manufacturing and One-Piece Flow at AlliedSignal Aerospace**

by  
Steven R. Harman

Submitted to the Department of Mechanical Engineering and  
the Sloan School of Management on May 9, 1997 in  
partial fulfillment of the requirements for the degrees of

Master of Science in Mechanical Engineering and  
Master of Science in Management

## **Abstract**

This thesis covers the implementation of lean manufacturing initiatives in a traditional manufacturing facility. Changes in the competitive environment in the Aerospace industry are forcing companies to adopt lean manufacturing to remain competitive. Specifically, this thesis covers the implementation of a one-piece flow production system. This production system, initially adopted from the Toyota Production System (TPS), brings along a whole set of new challenges when implemented in a low volume manufacturing facility.

The context for the thesis research was a sheet metal production center. Nevertheless, the methodology used in implementing the lean initiatives could easily be adapted to any other low volume environment. This thesis describes the initial production system, the improvements made, and some opportunities for further improvement. Most of the effort was focused on improving the flow of material, reducing waste, and improving the production scheduling methodology. Additionally, a method of estimating rough capacity of a mixed-model production cell is developed. Through these improvements, this facility will realize inventory reductions, lead time reductions, and cost reductions.

To obtain full advantage of lean production a number of organizational changes will still be required. This thesis covers a number of organizational barriers that still need to be overcome to truly eliminate all waste. These include more data-driven decision making tools, changes in the incentive system to encourage cross-training, and training.

Thesis supervisors:

Stephen Graves, Professor of Management Science  
Stanley Gershwin, Senior Research Scientist



## Acknowledgments

First I would like to acknowledge my parents and my brother for their constant support during the past two years.

I would also like to thank Steve Graves and Stan Gershwin, my advisors at MIT, for their guidance, support, and constant encouragement during the internship and the subsequent thesis writing experience.

At AlliedSignal, I want to thank Marc Hoffman, VP of Operations, for making the internship possible and Mark Thurman, Building Director, for allowing it to happen in his facility. I would also like to thank Jeff Helbling, my supervisor, for taking the time to teach me the ropes, and Paul Lamantia, Production Control Manager, for all the time he was willing to spend with me talking about material handling and for his trust in me to let me work on improvement efforts in his area. Finally, I would like to acknowledge all the people in the AlliedSignal Engines 404 Building (Static Components Production Center) for their help in this project, especially Phil Hardt, of Operational Excellence who spent a lot of time showing me how to get things implemented on the shop floor, and Kimberley Peterson, who just always seemed to have the answer to any question I had.

Finally, I gratefully acknowledge the support and resources made available to me through the Leaders for Manufacturing (LFM) Program. Along with this, I would also like to acknowledge all the outstanding individuals who make up this program and who collectively have made the last two years a great learning experience for me, not to mention a lot of fun.



# Table of Contents

<b>1. INTRODUCTION AND GENERAL BACKGROUND INFORMATION</b> .....	<b>9</b>
1.1 ALLIEDSIGNAL, INC. ....	9
1.2 ALLIEDSIGNAL ENGINES .....	9
1.3 INDUSTRY ANALYSIS .....	10
1.4 INTERNSHIP PROJECT .....	11
1.5 TERMS .....	12
1.6 THESIS OVERVIEW .....	14
<b>2. SITE INFORMATION AND OPPORTUNITIES FOR IMPROVEMENT</b> .....	<b>15</b>
2.1 PLANT BACKGROUND .....	15
2.1.1 <i>Production Processes</i> .....	15
2.1.2 <i>Products and Customers</i> .....	16
2.1.3 <i>Production Scheduling</i> .....	16
2.2 IMPROVEMENT GOALS .....	17
2.2.1 <i>Pro-Active Planning</i> .....	17
2.2.2 <i>On-Time Delivery</i> .....	18
2.2.3 <i>Inventory and Work-In-Process (WIP)</i> .....	18
2.2.4 <i>Lead Time</i> .....	19
<b>3. LEAN MANUFACTURING</b> .....	<b>21</b>
3.1 LEAN MANUFACTURING/TOYOTA PRODUCTION SYSTEM (TPS) .....	21
3.2 ONE-PIECE FLOW .....	22
3.3 GOALS OF ONE-PIECE FLOW .....	25
3.3.1 <i>WIP Reduction</i> .....	25
3.3.2 <i>Lead Time Reduction</i> .....	25
3.3.3 <i>Cost Reduction</i> .....	26
3.4 REQUIREMENTS .....	27
3.4.1 <i>Standard Processes</i> .....	27
3.4.2 <i>Sufficient Capacity</i> .....	27
3.4.3 <i>Level-Loaded Demand</i> .....	28
3.5 FRAMEWORK .....	29
<b>4. CAPACITY MODEL</b> .....	<b>31</b>
4.1 ASSUMPTIONS .....	31
4.2 CAPACITY MODEL .....	33
4.2.1 <i>Key Characteristics</i> .....	33
4.2.2 <i>One-Piece Flow Complexity</i> .....	33
4.2.3 <i>Capacity Model</i> .....	35
4.3 MODEL USES/APPLICATIONS .....	38
4.3.1 <i>Analysis</i> .....	38
4.3.2 <i>Planning</i> .....	38
4.4 MODEL LIMITATIONS .....	40
4.4.1 <i>Data</i> .....	40
4.4.2 <i>Model Assumptions</i> .....	41
<b>5. IMPROVEMENTS IN MATERIAL FLOW</b> .....	<b>45</b>
5.1 FLOW MANUFACTURING .....	45
5.1.1 <i>Methodology</i> .....	45
5.1.2 <i>Cell 3 Example</i> .....	47
5.1.3 <i>Expected Benefits</i> .....	48
5.2 SUPERMARKETS .....	48

5.2.1 Purpose .....	48
5.2.2 Design Methodology .....	49
5.2.3 Cell 3 Example .....	50
5.2.4 Results .....	52
5.3 POINT-OF-USE STORES .....	53
5.3.1 Description .....	53
5.3.2 Purpose .....	53
<b>6. IMPROVEMENTS IN PRODUCTION SCHEDULING - PULL SYSTEM.....</b>	<b>55</b>
6.1 PURPOSE .....	55
6.2 OPERATION .....	55
6.2.1 Detail Production Board .....	55
6.2.2 Signal Board .....	58
6.2.3 Pull Signal (Kanban) Card .....	61
6.3 EXPECTED RESULTS .....	62
6.4 FUTURE PLANS .....	63
<b>7. CONCLUSION/RECOMMENDATIONS.....</b>	<b>65</b>
7.1 CONCLUSION .....	65
7.1.1 Results .....	65
7.1.2 Learnings .....	66
7.2 RECOMMENDATIONS .....	67
7.3 CLOSING COMMENTS .....	68
<b>REFERENCES.....</b>	<b>69</b>

## Table of Figures

<b>FIGURE 2-1 TRADITIONAL LAYOUT (CELL 3).....</b>	<b>15</b>
<b>FIGURE 2-2 WEEKLY DEMAND FOR TYPICAL PART.....</b>	<b>17</b>
<b>FIGURE 3-1 TYPICAL FLOW LOOP .....</b>	<b>22</b>
<b>FIGURE 3-2 REINFORCING EFFECT OF WIP ON LEAD TIME .....</b>	<b>26</b>
<b>FIGURE 3-3 LEAN MANUFACTURING AND ONE-PIECE FLOW FRAMEWORK .....</b>	<b>29</b>
<b>FIGURE 4-1 ROUGH-CUT CAPACITY MODEL.....</b>	<b>35</b>
<b>FIGURE 4-2 CAPACITY DECISION TREE .....</b>	<b>39</b>
<b>FIGURE 5-1 CELL 3 AFTER RE-ORGANIZATION.....</b>	<b>47</b>
<b>FIGURE 5-2 SUPERMARKET DESIGN.....</b>	<b>49</b>
<b>FIGURE 5-3 SHELF SIZING.....</b>	<b>50</b>
<b>FIGURE 5-4 CELL 3 SUPERMARKETS AND MATERIAL FLOW .....</b>	<b>51</b>
<b>FIGURE 5-5 CELL 3 SUPERMARKET (1) .....</b>	<b>51</b>
<b>FIGURE 5-6 CELL 3 SUPERMARKET (2) .....</b>	<b>52</b>
<b>FIGURE 5-7 CELL 3 POU STORES.....</b>	<b>53</b>
<b>FIGURE 6-1 DETAIL PRODUCTION BOARD.....</b>	<b>56</b>
<b>FIGURE 6-2 CELL 3 DETAILED PRODUCTION BOARD.....</b>	<b>57</b>
<b>FIGURE 6-3 SIGNAL BOARD.....</b>	<b>58</b>
<b>FIGURE 6-4 CELL 3 SIGNAL BOARD .....</b>	<b>60</b>
<b>FIGURE 6-5 KANBAN CARD.....</b>	<b>61</b>



# **1. Introduction and General Background Information**

This thesis presents a methodology used to transform a manufacturing plant from traditional mass production to lean manufacturing and one-piece flow production. As the entire transformation of the manufacturing plant will take far longer than the duration of this internship project, this thesis will only cover a select number of facets of lean manufacturing that were being implemented at the time during which this internship project took place. Most of the work done during this internship project was performed as a member of a team, either a Kaizen team or the Lean Manufacturing System Support team. Therefore, this thesis represents the team's learnings and accomplishments, not just the author's. Though most of this thesis focuses on Cell 3 of the 404 Building (the Static Components Production Center), the same process was being implemented in the other cells in the 404 Building.

This chapter provides a brief overview of the manufacturing facility in which the internship project takes place, the products being manufactured, the goals of the internship project, and a brief overview of some of the terms used.

## **1.1 *AlliedSignal, Inc.***

This thesis covers an internship project at AlliedSignal Engines (AE) in Phoenix, AZ, a division of AlliedSignal's Aerospace sector. AlliedSignal is an advanced manufacturing company serving customers worldwide. It is divided into three sectors, Automotive, Aerospace, and Engineered Materials. As a whole, AlliedSignal had 1995 revenues of 14.3 Billion, with roughly 36% coming from Aerospace. Within the Aerospace sector, AE is by far the largest division.

## **1.2 *AlliedSignal Engines***

AlliedSignal Engines (AE) is the largest producer of small gas turbine engines. It produces a wide range of different products including Turbofan engines, Auxiliary Power Units (APU's), Turboprop engines, and Turboshift engines.

- The APU's are internal combustion engines that provide starting power for main engines, provide pneumatic power for environmental control systems, provide back-up electrical and

pneumatic power for in-flight operations, and electric and pneumatic power for ground operations. AE produces APU's in the range of 100-1,100 Shaft Horse Power (SHP) for use on regional, executive, narrow & wide body commercial transports.

- The Turbofan engines provide thrust for commercial and military aircraft (such as the Dassault Falcon, Learjet, and Cessna Citation). The engines range in output between 3,000 and 10,000 lbs of thrust.
- The Turboprop engines come in the range of 575 to 1,500 SHP. They are used on both commercial and military aircraft.
- The Turboshaft engines are produced in the range of 500 to 4,600 SHP. They are meant for commercial, military, rotorcraft, industrial, and maritime applications.

Of these products, the APU's and Turbofan engines are the highest volume items, each making up roughly a third of the total production volume.

AE serves three different types of customers, the Original Equipment Manufacturers (OEM's), the Repair and Overhaul (R&O) facility, and the Spares market. Overall, AE has a very large in-service fleet of engines, giving it a very strong after-market, and providing it with a strong global presence.

Within Phoenix, AE's production facilities are divided into different buildings. The 301 Building performs the final assembly of the engines. The 101/102 Building produces the rotating parts. The 103 Building is responsible for all the gears used inside of the engines. Finally, the 404 Building (also known as the Static Components Production Center) is responsible for all the non-rotating parts in the engines.

### **1.3 Industry Analysis**

The Aerospace industry is an extremely cyclical business. Currently, the industry is in the middle of a rather sharp up turn. Boeing and Airbus both recently announced 25-30% production rate increases for 1997-1998 [Chao, 1997]. Therefore, as a key supplier of APU's to all major aircraft companies, AlliedSignal Engines is currently also experiencing very strong growth.

This increased industry demand is also leading to more competition. New players such as United Technology Corporation's Pratt & Whitney Canada are entering the marketplace with new products. These new firms are coming in with compatible products at lower cost. Additionally, these new entrants are also advertising sharply reduced lead times.

#### **1.4 Internship Project**

The internship project covers the implementation of lean manufacturing in a traditional mass production facility and is composed of a number of smaller projects. All these different projects took place in the 404 Building, which housed the Static Components Production Center. As the name implies, this facility was responsible for the manufacturing of all the non-rotating parts.

This production facility was divided into 15 cells, which were simply conglomerations of machines and associated parts being produced in traditional job-shop batch production environment.

The specific projects were:

1. Assist in the implementation of a new one-piece flow production strategy through active participation on Kaizen teams. Additionally, develop a capacity model for each of the cells in the 404 Building to help in splitting up the cells into the various flow loops and help identify potential capacity problems in the future as the demand continues to increase. This model would also be used to analyze the effect of implementing the 'one-piece flow' production strategy on overall capacity.
2. Assist the Lean Manufacturing System Support team in identifying and implementing the required changes to the manufacturing support systems to support the one-piece flow production strategy. This would mainly be focused on eliminating as many of the non-value adding activities as possible.

Upon arrival at the site, the building had just had a change in senior management. The new management was charged with implementing lean manufacturing initiatives. Therefore, the building had just begun implementing a one-piece flow manufacturing strategy. This one-piece flow strategy (to be discussed in Section 3.2) was based on adapting the Toyota Production

System to a manufacturing environment, which encompassed treating the shop floor as an assembly line and releasing parts into the various flow lines at a certain interval, known as the takt time.

Most of the research performed during this project concentrated on one specific cell of the 404 Building, Cell 3. However, much of the analysis and recommendations are still directly applicable to most of the other production centers at AlliedSignal Engines.

### **1.5 Terms**

This thesis will be using a number of terms related to lean manufacturing and to AlliedSignal. Since every company uses some of these terms slightly differently, the following definitions are provided.

- **Cycle Time** - the processing time required to complete one part (not including the initial machine set-up time) on a given machine.
- **Set-Up Time** - the time from when the last good part of one type is produced until the time when the first new good product of the next type is produced on a given machine.
- **Manufacturing Lead Time** - the amount of time (usually in days) required to manufacture a given part. This time is measured from when the part is first released onto the shop floor until when the part is delivered to the warehouse.
- **Production Lead Time** - the total amount of time (usually in days) required to produce a given part. This time is measured from when the part is first ordered until when the part is delivered to the warehouse. For most parts, production lead time is manufacturing lead time plus 10 days (3 for order processing and 7 for ordering the parts).
- **Takt Time** - the inverse of the rate at which parts should be released onto the shop floor to match the production rate to the customer demand. This takt time (usually in minutes) is derived by dividing the total time available (to a loop or cell) to produce parts by the total number of parts that a given loop or cell needs to produce (demand). Mathematically, this can be expressed as:

$$Takt\ Time = \frac{Time\ Available}{Parts\ Required}$$

For example, if takt time for a given loop is 100 minutes, then every 100 minutes a piece of raw material is released into the loop and every 100 minutes a part should come out of the loop completed. If a given loop produces several different part types, the takt time might be different for each part type.

- Point-of-Use Stores (POU) and Supermarkets - storage locations for raw material on the shop floor instead of in a warehouse (this will be discussed in greater detail in Sections 5.2 & 5.3).
- One-Piece Flow - a new manufacturing strategy being implemented in which the factory floor is treated as an assembly line and parts both enter the cell and exit the cell at regular time intervals (takt time). While in the cell, no part is allowed to sit idle between machines (no buffer stock is allowed to build up between the machines). This will be discussed in further detail in Section 3.2).
- Flow Loop - an arrangement of machines in which parts flow from one machine to the next in a pre-determined (and standard) manner - much like an assembly line.
- Standard Work-in-Process (WIP) - the amount of WIP that is required to keep the flow loop running. In general, this will consist of one part for each automatic (CNC) machine and one part for each operator. This will allow each part in the loop to be either in an automatic machine being processed, or be in the hands of an operator, being processed on a manual machine.
- Just-in-Time (JIT) - the principle of producing just the right units in just the right quantities at just the right time.
- Production Work Order (PWO) - the work order that travels along with each batch of parts on which the operators sign off for completing individual operations.
- Manufacturing Operations and Tooling (MOT) - the blueprint for actually building the parts. This document lists all the operations that need to be performed on each part, where to

perform them, and what tooling is required to perform it (such as for example what CNC tape to use).

- Loadcenter - designation for a specific type of machine in a cell. For example 6ML designates a Manual Lathe in Cell 6. Currently, many loadcenters have multiple machines.

## **1.6 Thesis Overview**

Chapter 2 provides a quick overview of what the situation was at the start of this internship project and describes some of the problems facing the organization. Chapter 3 provides the necessary background information for the thesis. It covers the basic lean manufacturing principles, including a short discussion of the Toyota Production System (TPS). It also covers the basic purpose and rules of one-piece flow manufacturing. Chapter 4 discusses the capacity model developed for each of the cells, its inputs, its outputs, its purposes and applications, and its limitations. Chapter 5 describes the improvements in material flow implemented on the shop floor. It covers both the implementation of flow manufacturing and the improvements made to reduce non-value adding transportation time in the form of supermarkets and point-of-use stores. Chapter 6 describes the improvements made in the production scheduling system through the development of a consumption-based (or pull) scheduling system. Finally, Chapter 7 covers some of the results from the improvement actions, some conclusions, and some recommendations for future improvements.

## 2. Site Information and Opportunities for Improvement

This chapter provides a brief overview of what the manufacturing facility (both the entire building and Cell 3 specifically) was like at the start of the internship project. It also discusses the opportunities for improvement facing management at the start of the project.

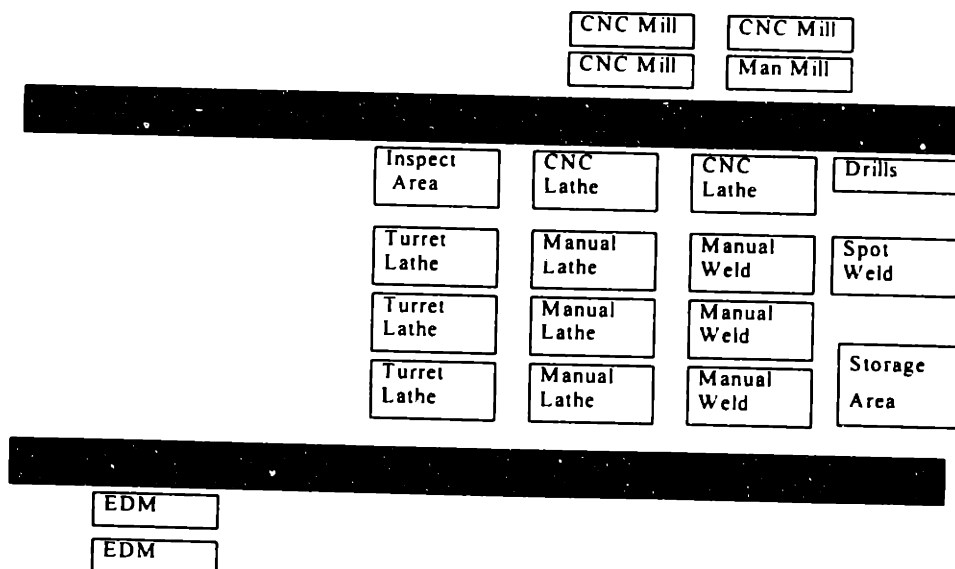
### 2.1 Plant Background

#### 2.1.1 Production Processes

The research for this project was performed mostly in Cell 3 of the Static Components Production Center of AlliedSignal Engines in Phoenix, AZ. The use of the word cell in this case is a little bit of a misnomer. The word cell is simply used to denote a group of machines, people, and products all located together. The word cell does not mean that this area is organized in the more conventional cellular manner, where products flow from one machine to another in a continuous manner [Schonberger, 1986].

Within this cell, manufacturing was done in a traditional mass production manner. The building was basically divided into miniature departments (cells) within which most of the machines were organized by machine type, with all the same type machines located next to each other (see Figure 2-1 for a typical layout before any equipment moves were begun). Cycle times on most

**Figure 2-1 Traditional Layout (Cell 3)**



of the machines were quite variable, ranging from 10 minutes to 10 hours.

The roughly 30-person work force (in this cell) was non-unionized, operating in 2 shifts. Most of the workers were organized by function, with workers becoming more and more specialized on a specific machine as their careers progress (versus becoming proficient on more machines).

### 2.1.2 Products and Customers

The cell manufactures fabricated plenums, compressor housings and combustors destined for both Auxiliary Power Units and regular propulsion engines. Though the parts in this cell may have similar names, the actual production processes were very different. A typical part usually starts the process by getting welded, then goes out of the cell for heat treat and Fluor Penetrant Inspection (FPI), comes back into the cell to get machined, and then gets inspected before getting shipped off to the warehouse.

The customer for all the cell's products are internal, with the parts either going to the assembly line for use in production engines, or to the Marketing, Sales and Service (MS&S) organization for use as a spare part.

### 2.1.3 Production Scheduling

Production scheduling is performed through the use of a MRP II system (MacPac). The customer demand gets entered into the system by the Master Planner and then individual part demand gets scheduled based upon the individual lead times of the various components. This individual demand then shows up on the 12-week report which shows the requirements for the next 12 weeks for each cell.

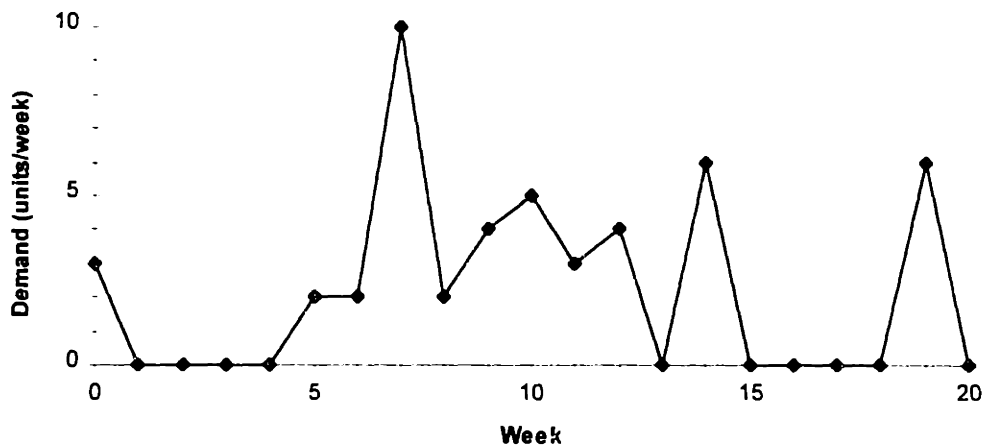
This 12-week report is what the cell builds to and uses for prioritizing its production. It is also what the cell is held accountable for. When the 12-week report tells the cell that a part should be started, the cell planner draws up all the required paperwork and initiates the Production Work Order (PWO). This PWO then gets routed to a number of different places to get a copy of the Manufacturing Operations and Tooling (MOT), a copy of the blueprint, and a list of the required raw material. Finally, all this paperwork gets routed to the warehouse (in the 402 building) to get the material issued and sent over to the cell so that actual production can start. This whole



process can take up to 10 days, 3 days for the planning process and 7 days for the actual paperwork generation and material delivery process.

Typical batch sizes are 2 to 4 weeks of demand. Demand for the various parts have great variability, both in terms of total demand and in terms of individual weekly demand. Individual part demand varies from 5 a week to 1 a year. Figure 2-2 shows a typical part's weekly demand.

**Figure 2-2 Weekly Demand for Typical Part**



## **2.2 Improvement Goals<sup>1</sup>**

A number of opportunities for improvements existed in the facility. These opportunities were not necessarily new, but with the increasing competitiveness of the market, they were becoming more important to “harvest”. Therefore, aggressive improvement goals had been established.

### **2.2.1 Pro-Active Planning**

A number of years before the start of this internship project, all time standards had been eliminated. Therefore, no accurate method of performing any type of capacity planning existed.

---

<sup>1</sup> The data in this section has been modified and therefore is not actual. It is to be used for reference only.

Much of the planning was performed by using the cell leader's "gut feeling", and waiting to see if the cell output matched the demand requirements.

Also, with the strong increase in demand due to the increase in airplane production, several capital expenditures were needed. Without a capacity model, no true cost justification could be performed (since actual machine utilization was unknown).

### 2.2.2 On-Time Delivery

Due to the strong growth in demand, cell production had not been able to keep up. The on-time delivery percentage of parts to the external customers for the building as a whole (as measured by the Customer Satisfaction Index -CSI) was underperforming expectations. This was causing problems in the assembly line. Due to parts not arriving on time, the assembly line typically could only operate a portion of the month, and engine orders were starting to be missed.

An aggressive end of the year goal of nearly 100% CSI had been established for the Static Components Production Center.

### 2.2.3 Inventory and Work-In-Process (WIP)

WIP was becoming a big problem. As demand kept increasing, more parts were being released onto the shop floor, with no place to go (since all the machines were already being used). This caused large pile-ups of WIP on the shop floor. In June of 1996, total WIP on the shop floor (as measured in days of supply) was 100 days, almost twice as large as the average lead time for the building.

Also, due to the long lead times on some of the parts, changing demands once the parts had already started production, caused large amount of the wrong parts to be manufactured and stored. During one visit to the warehouse for sub-assemblies, parts from 1987 were discovered.

Overall, aggressive goals of 50% reduction in WIP levels had been established for the Static Components Production Center.

#### 2.2.4 Lead Time

Time is becoming a strategic weapon in the business world. More and more companies are turning to increased customer responsiveness in the form of quicker service and reduced lead times as a form of competition. By being the most responsive to customer demand by delivering to customers not only what they want, but also when they want it, firms can charge premium prices and still maintain their competitive position as market leaders [Stalk and Hout, 1990].

In AlliedSignal's case, with the increasing number of market participants (as mentioned in Section 1.3), time was definitely becoming more and more important. Current lead times for engines were significantly longer than competitors. Therefore, significant attention needed to be focused on reducing these lead times.

For the Static Components Production Center, aggressive goals on lead time reduction had been established.



### **3. Lean Manufacturing**

This chapter provides a brief overview of lean manufacturing, the Toyota Production System (TPS) and one-piece flow. It also provides a brief framework of how the facility was hoping to use the lean manufacturing initiatives (such as JIT/One-Piece Flow) to address some of the opportunities for improvement presented in Section 2.2. Finally, the chapter concludes with some basic requirements that have to be fulfilled for the cells to be able to implement the one-piece flow production strategy.

#### **3.1 *Lean Manufacturing/Toyota Production System (TPS)***

Many definitions of lean manufacturing exist, but most of them come down to simply doing more with less resources. Lean manufacturing is also often referred to as the Toyota Production System (TPS) since Taiichi Ohno, working at Toyota is regarded as its inventor [Womack, Jones and Roos, 1990, Monden, 1993].

In mass-production, producers use narrowly skilled workers tending expensive, single-purpose machines to churn out standardized products in high volumes. Due to relatively high capital expenditures involved, many buffers are installed to assure smooth production. Also, in an attempt to minimize costs, product changeovers are minimized [Womack, Jones and Roos, 1990].

In contrast to mass production, a lean manufacturer utilizes teams of multi-skilled workers to operate highly flexible, increasingly automated machines to produce volumes of products in enormous variety [Womack, Jones and Roos, 1990].

The basis of the TPS is the absolute elimination of waste and the reduction of costs. The two main building blocks used to support this system are [Ohno, 1988, Shingo, 1989]:

- Just-in-time
- Autonomation - also known as automation with a human touch

Both of these building blocks have the ultimate goal of reducing waste in the production process. In a typical production process, a number of different wastes can be identified. These are [Ohno, 1988]:

- Waste of overproduction
- Waste of time on hand (waiting)
- Waste in transportation
- Waste of processing itself
- Waste of stock on hand (inventory)
- Waste of movement
- Waste of making defective products

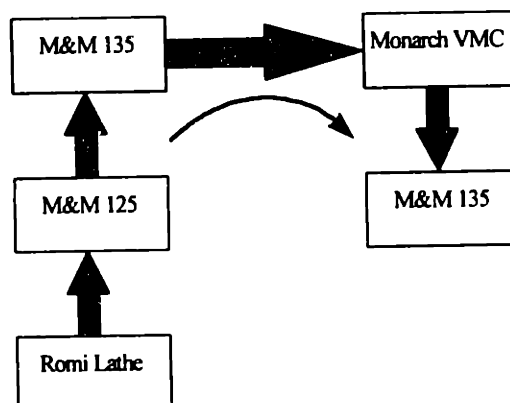
The TPS systematically reduces and eliminates these wastes, thus reducing production costs.

Finally, it is important to note that the TPS very much relies on the concept of continuous improvement. Management and workers are continuously striving to improve the way they do things and eliminate more waste.

### **3.2 One-Piece Flow**

One-piece flow (also often referred to as single-piece flow) is basically producing one piece at a time following the sequence and rules of the takt time [Hirano, 1988].

**Figure 3-1 Typical Flow Loop**



One-piece flow manufacturing is based on the TPS and entails treating the manufacturing floor as an assembly line. To do this, standardized process routings are developed such that all the parts follow the same path as they go through the manufacturing process (much like an assembly line). In an attempt to minimize the total distance traveled by the part (which is non value-adding and therefore a waste), the machines are all arranged in so-called flow loops (see Figure 3-1 for an example of a flow loop). Whenever possible, these flow loops are arranged such that the parts actually flow in a counter-clockwise direction, and follow a U-shape with the open end facing to one of the main aisles in the building.

Parts are released into the flow loop, visit all the machines in the prescribed order, and then exit the loop. The rate at which these parts are released and exit the flow loop is based on the takt time, meaning that every takt time, a part is released into the loop.

While in the flow loop, the parts are not allowed to build up between the machines (zero buffers between machines). As one part is completed, it is immediately transferred to the next machine (transfer lot size of one), where either the next operator or the same operator performs the next operation.

Since no buffers can build up between the machines, this turns the manufacturing process into a 'pull' system, where parts cannot move to the next machine until the machine is ready for it, or pulls it - hence incorporating the JIT principle of the TPS. This also implies that if any of the machines in the loop break down, the whole loop comes to a halt (again, much like an assembly line where the whole line stops when one station has a problem).

It is important to note that even though the transfer lot size is one, the actual lot size of parts does not necessarily equal one. Instead of each time releasing a different part into the loop, a number of the same parts can be released, one after the other. This minimizes the effect of large set-up times, as the machines can remain set-up for a given type of part.

Finally, as machines are re-arranged into the flow loops, individual jobs in a given loop are combined in such a manner that the total amount of time a worker is busy in a given cycle is less than the takt time (this time only includes that portion of the machine's cycle time that the operator actually has to be at the machine - such as the loading or unloading time). Therefore, a

given worker may perform one task on one machine, then walk over to the next machine and perform a task there and then walk back to the first machine, as long as the total time to do these jobs is less than the takt time.

For example, assume that the takt time for a given loop is 75 minutes (meaning that one part needs to be produced every 75 minutes) and the following times apply to the different processes involved in making the part (including walking to the next machine):

1. Process A: 20 minutes
2. Process B: 20 minutes
3. Process C: 25 minutes
4. Process D: 60 minutes
5. Process E: 10 minutes

In this case, one operator would be assigned to perform operations A, B and C, while a second operator performed operation D and E. In this case the total sum of the cycle times for each operator (including walking between the different machines) is less than the takt time for the loop, so the loop should be able to meet the demand. As demand increases, the loop's takt time will decrease (since the denominator - parts required - increases while the numerator - time available - remains constant). Assume that the new takt time is now 65 minutes. Now, two operators are no longer enough for the loop to meet demand. Therefore, an additional operator has to be added to the loop. In this case, the first operator would perform operations A and E, the second operator would perform Operation D, and the third operator would perform Operation B and C. Once again, the sum of the individual operator's cycle times is less than the loop's takt time and hence the loop should be able to meet demand. Overall, this allows a loop's capacity to be easily adjusted as the demand for the loop's parts changes. It also reduces the total number of operators required to operate the loop. In a traditional mass-production scenario, this loop would require 5 separate operators to man each of the different machines (regardless of demand). Now, by using multi-skilled operators and combining the different tasks, the same is accomplished using two or three operators. Hence, productivity should increase (assuming the machines never fail as will be discussed in Section 4.4.2).



### **3.3 Goals of One-Piece Flow**

The goals of one-piece flow manufacturing are threefold: (1) reduce the Work-in Process (WIP) in each of the cells; (2) reduce the manufacturing lead time; and (3) reduce the manufacturing costs by reducing waste.

#### **3.3.1 WIP Reduction**

Under traditional batch production, parts are released into a production area in a given batch. Then, this batch of parts moves as a group to the different machines where each of the parts undergoes some machining or other value-added activity. Since most machining centers can typically only process one part at a time, the other parts in the batch must wait while the one part is being processed. Therefore, the actual time that a part is being worked on is only a small portion (typically 5-10%) of the total time that it is on the shop floor. With the one-piece flow strategy, parts would no longer be allowed to wait around next to a machine (since no buffers are allowed to build up in between the machines). Therefore, the total amount of WIP in the cell will be reduced dramatically (often by as much as 50%). Some "standard WIP" will still be required to keep the loop operating. As mentioned in Section 1.5, this standard WIP depends on the number of automatic machines and the number of operators in each loop. Typically, one piece of WIP must be present for each CNC machine and one piece for each operator. Additionally, a certain amount of standard WIP must exist if the parts must exit the loop for outside processes (such as inspection and heat treat). The number of parts required to buffer these outside processes depends on the batch size and lead time of these outside processes.

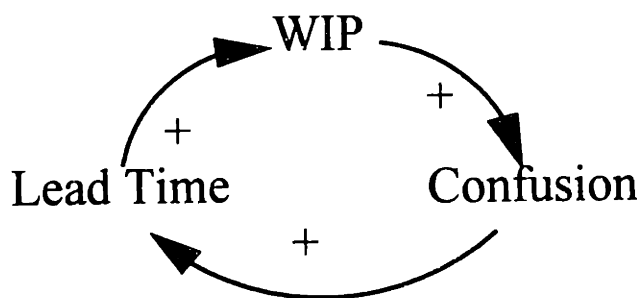
#### **3.3.2 Lead Time Reduction**

Along with the reduction in WIP (as argued above) comes a reduction in manufacturing lead time. Production lead time should decrease for two reasons. The main reason is that since the parts no longer have to wait for the rest of the batch to be worked on, the total time each part spends on the shop floor is drastically reduced.

The second, more qualitative reason is that as the WIP on the shop floor decreases, there should be a reinforcing effect as the confusion (as to what parts to work on next) decreases. Figure 3-2

shows this effect graphically. As the amount of parts present on the shop floor increases, the amount of confusion as to what to work on increases. This then results in the wrong parts being worked on, which then results in increased manufacturing lead times, which then in turn causes even more WIP to be released onto the shop floor. This cycle continually reinforces itself until action is taken. Therefore, by eliminating a lot of the WIP and by placing all the machines in flow loops, much of the confusion can be eliminated, thus reducing the lead times. Some of this confusion could of course also be eliminated with clear, simple rules.

**Figure 3-2 Reinforcing Effect of WIP on Lead Time**



Similar to the WIP reduction goals, overall lead time reductions on the order of 50% (compared to the starting condition) are targeted by implementing the one-piece flow.

### 3.3.3 Cost Reduction

By having less WIP on the shop floor and by having more standard routings of parts, the number of defects will decrease. Since the time between when a bad part leaves one machine and starts being processed on the next is drastically reduced, the number of subsequent bad parts is reduced, as the defect is discovered quicker. Therefore, the cost of poor quality (COPQ) should go down.

Also, by more standard routings of parts and by having operators assigned to loops instead of machines, operators will have more ownership of the product. This will make it much easier to determine where the defects are occurring and therefore, determine the root cause of problems.

By combining the different tasks so as to minimize each worker's idle time, some workers can be taken out of the loop (and assigned to other jobs), thereby increasing overall productivity.

Some minor capital equipment might need to be purchased to set up the different flow loops and allow the parts to flow. But, since these machines are usually small, dedicated machines, these expenditures will be minor compared to the cost savings they provide.

Overall, elimination of all these wastes (defects, over-production, inventory, motion, transportation, waiting) should reduce the total manufacturing cost of the parts.

### **3.4 Requirements**

To make one-piece flow work, a number of requirements have to be fulfilled. The main requirements include:

#### **3.4.1 Standard Processes**

All or most of the parts assigned to a loop must follow the same standard process routing. Without this standard routing, the machines cannot be arranged in the desired flow loop, which then will confuse the routing of the different parts, as no buffers are allowed to build up between the machines. All parts do not necessarily have to undergo processing on each machine, but no so-called loop-backs are allowed. This means that the different parts in a cell should be grouped together by the type of processing they receive as opposed to the more traditional practice of grouping parts by application or function (i.e. grouping all the plenums together even though all the plenums do not get manufactured the same way).

#### **3.4.2 Sufficient Capacity**

As mentioned in Section 3.2, to ensure that sufficient capacity exists in each loop, the cycle time of all the operations in a given loop must be less than the takt time for that loop. This ensures that the loop is able to deliver the parts at the desired rate. If this is not the case, a closer look at the weighted-average cycle time is required to determine if sufficient capacity exists. When doing this, the cycle time of the bottleneck machine is weighted by the volume of parts that go to that machine. This weighted cycle time is then compared to the takt time to determine if sufficient capacity exists. In this case, however, the loop does not have sufficient capacity to use pure one-piece flow (no buffers), but can be made to work by allowing a buffer to build up (and

subsequently be worked off) in front of the bottleneck machine. This will allow the machine to continuously be working, even when the rest of the loop is working on parts that do not go to the bottleneck machine. The capacity model described in Section 4 helps determine if the loop has enough capacity to do pure one-piece flow or if certain bottleneck machines need to be buffered out.

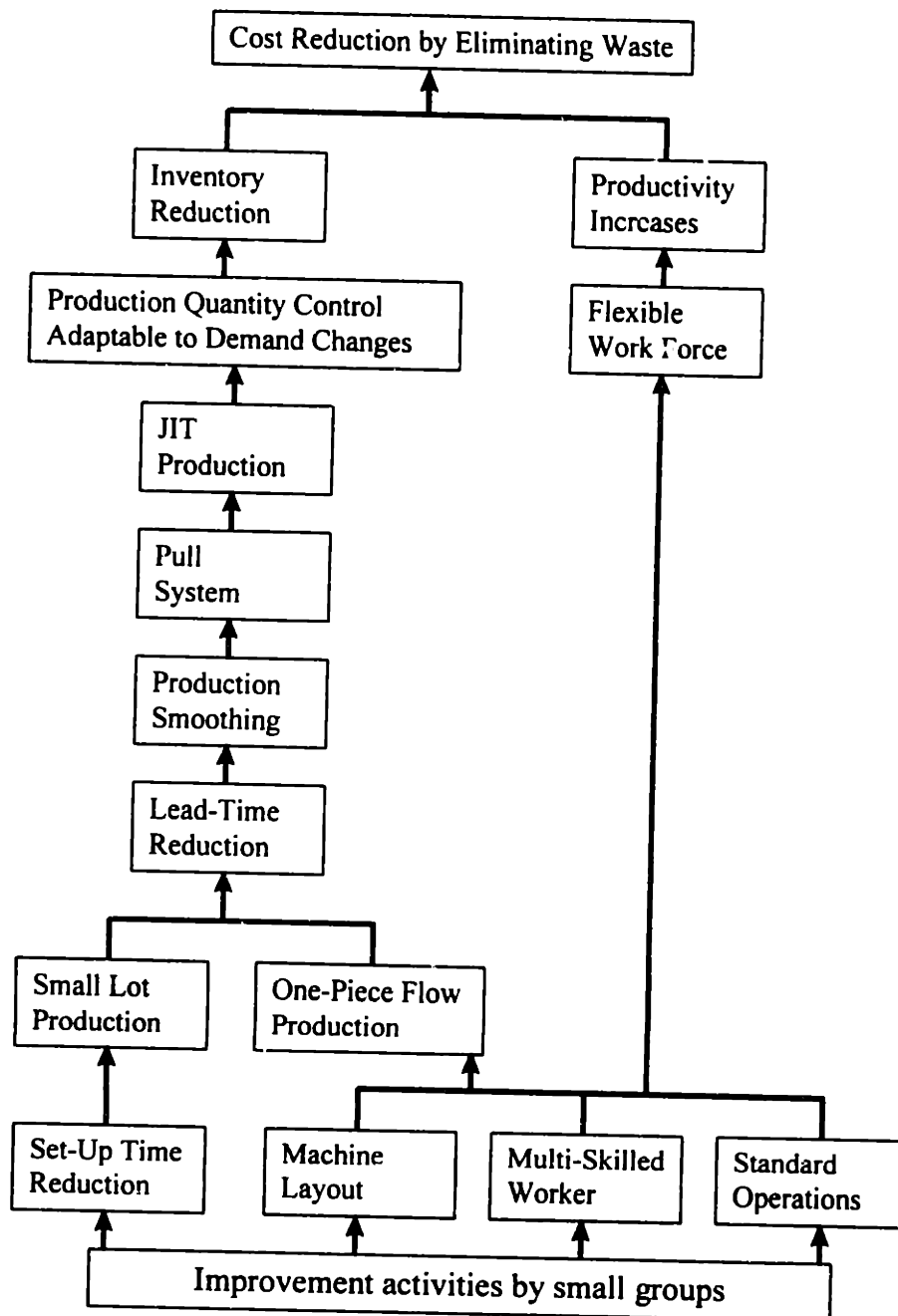
### 3.4.3 Level-Loaded Demand

Similar to an assembly line, one-piece flow is based on working at a constant rate. In theory, the number of different machines and the number of operators is based on being able to meet a predetermined rate (this rate is simply equal to the inverse of the takt time). Since many of the machines are automatic machines, for a loop to be efficient as far as capacity is concerned, the weighted average cycle time of the heaviest loaded machine must be close to, but not greater than takt time. Also, since machine capacity is not easily added or eliminated once the flow loops are established, the rate for the loop must be maintained relatively constant (to avoid either over-capacity or under-utilization of the loop). Hence, achieving a relatively level production schedule (production linearity) is essential. This allows the maximum benefit to be gained from the one-piece flow manufacturing strategy as well as from some of the other lean concepts, such as the supermarkets discussed in Section 5 and the consumption based production scheduling discussed in Section 6.

### 3.5 Framework

Figure 3-3 shows how the whole system described above fits together to reduce lead time, inventory, and costs [adapted from Monden, 1993].

**Figure 3-3 Lean Manufacturing and One-Piece Flow Framework**





## 4. Capacity Model

This chapter provides a brief overview of the rough-cut capacity model developed to aid in the implementation of one-piece flow on the production floor. It also covers the assumptions made, the model's inputs, the outputs, and the model's uses or applications. It then ends with a brief discussion of the limitations of the model imposed by the various assumptions.

### 4.1 Assumptions

To develop a rough-cut capacity model for each of the different manufacturing cells in the building, a number of assumptions had to be made. These included:

- *No Rework.* Rework can add a lot of variability into a cell's capacity. As no definitive data were available for process yields, the assumption of 100% yield was made. An additional premise for making this assumption was that if you plan for rework, you will come to expect it. Therefore, you do not want to plan rework into capacity. Instead, you want to work on eliminating the causes of rework.
- *Constant Part Routing.* This assumption covers two points. The first point is that the parts actually get their processing done by the loadcenter (machine) called out on the MOT and not some alternative loadcenter in another building (though the MOT might sometimes allow this to occur). The second point is that the parts actually get their processing performed in the order in which the MOT prescribes (as opposed to doing some of the processing out of order - which in some cases might be permissible per the MOT). This assumption was made since the capacity model was meant to determine the capacity of the flow loops, not the entire building.
- *Constant Processing Times.* Several years ago, all time standards were eliminated. Therefore, to develop a capacity model, average historical processing times (as logged in by the operators over the past year) were used. Since at least a portion of the total processing time is manual operation, there will be some variability present in these times. For simplicity, this variability was ignored. Some of the limitations on this assumption will be covered in Section 4.4.1.

- *100% Machine Availability*. Three main reasons existed for making this assumption. The first is that no good data existed concerning machine reliability and down-time. The second reason was that this model was developed to determine how close to the maximum theoretical capacity each of the loadcenters and loops were operating. This maximum would be with all machines being operational 100% of the time. Finally, similar to with rework, if you plan machine down-time into your capacity, you come to expect it. Therefore, instead of planning for down-time, you want to try to eliminate the causes of the down-time (or at least minimize the down-time once a failure occurs).
- *Level Loaded Production*. Large swings in individual product demand have major effects on capacity since they can tie up one specific machine for long periods of time, thus blocking all other machines. Therefore, an important facet of one-piece flow is level-loaded production. Since the processing cycle times for each of the parts flowing through a given loop have large variability, this assumption was very important and had large consequences. In level-loading, each product was assumed to be run once a week. The higher demand items will most likely follow this assumption, while the low volume items will most likely be run less frequently. Since much of the actual daily production scheduling was done by the cell planner with input from the cell leader, this assumption could actually be relatively accurate if correct scheduling discipline is adhered to.
- *Negligible Set-Up Times*. In keeping with the goals of the TPS and to minimize the complexity of the model, set-up times were assumed to be negligible. This assumption may be somewhat flawed in the beginning, but throughout the building set-up times were being reduced to near negligible times (compared to cycle times) through focused Kaizen set-up time reduction activities. Therefore, over time, this assumption will become less important. Also, as production will still occur in batches, this assumption should not introduce much error.



## **4.2 Capacity Model**

### **4.2.1 Key Characteristics**

The main goal of the capacity model was that it would be useful and applicable in the one-piece flow environment that AlliedSignal was trying to implement.

In an attempt to maximize the probability that the model would actually be used, two key characteristics were sought. These were:

- *Self-updating.* Each of the flow loops processes numerous different part numbers. Each of these part numbers is scheduled out for the next 12 weeks. Therefore, each week when the new demand data is published, this must be input into the model. Inputting this data manually for each part number would be very time-consuming and error prone. Therefore, for the model to be useful, it needs to be self-updating. The goal is that each week when the production schedule is updated for the past week's deliveries and changes in engine build schedules, the model automatically incorporates these changes without requiring any manual intervention.
- *Simple.* For a tool to be truly useful, it must be simple and easy to use. Therefore, much effort was devoted to making the model as simple as possible while at the same time still being relatively accurate. Keeping it simple makes it easier to explain and understand, which greatly increases its probability of being used.

### **4.2.2 One-Piece Flow Complexity**

Much literature exists for how to determine the capacity of a given assembly line or a high volume, dedicated flow loop for one specific part or family of similar parts. But, unfortunately, little literature exists for how to do this in AlliedSignal's case. Three factors make the development of even a "rough-cut" capacity model that would be applicable in AlliedSignal's one-piece flow environment difficult. These are:

- *Low Volume Environment.* The easiest environment for developing a capacity model is where all the machines in a given flow loop are dedicated to one specific part. In this case, the capacity of the loop is simply the capacity of the bottleneck (limiting) machine adjusted

for machine reliability and yield. Since in AlliedSignal's case the typical volumes for each of the parts are relatively low compared to the capacity of the specific machines required to process the parts, the establishment of dedicated flow lines for each individual part is not feasible. Therefore, parts have to be grouped together based on similar processing requirements. This drastically increases the complexity of the model, especially as the process routing for all these different parts is not always exactly the same.

- *One-Piece Flow Rules.* In pure one-piece flow, no buffers are allowed to exist between machines. Consequently, if all the parts in a loop do not follow the exact same process routing, large amounts of capacity can be wasted. For example, part A visits machines 1, 2, 3 and 4 while part B only visits machines 2, 3, and 4. Since no buffers are allowed to exist in between machines, all parts have to be assumed to go to all machines. Taking this into account adds complexity to the model.
- *Cycle Time Variability.* Cycle time variability increases complexity in two ways. The first is that as individual cycle times of the different parts on a given machine start to vary, total part demand can no longer simply be multiplied by cycle time and compared to the available machining time to determine loop capacity. As mentioned in Section 3.4.2, instead, the weighted average of the cycle times (where the weighting is based on individual part demand) must be computed and compared to the loop's takt time to see whether or not the loop has sufficient capacity (the loop might have sufficient capacity by allowing buffers to build up in front of the bottleneck machines). The second way in which the cycle time variability increases complexity has to do with the one-piece flow rules. As mentioned before, in pure one-piece flow no buffers are allowed to develop between machines. Therefore, the maximum rate at which parts can be assumed to move from machine to machine is based on the bottleneck operation for that part. As long as the same machine is always the bottleneck operation for each part that is processed in the loop, this is not difficult to deal with (since there is again only one loadcenter to look at). In this case, the capacity of the flow loop is simply determined by looking at the weighted average cycle time of the limiting loadcenter and comparing it to the loop's takt time. Now, as the variability of cycle times on individual machines increases between parts (meaning that a different machine is

the bottleneck for different parts), the complexity of the model increases since it is no longer obvious which loadcenter to look at.

### 4.2.3 Capacity Model

Figure 4-1 shows a generic example of the rough-cut capacity model developed during the internship project. A separate model was developed for each of the flow lines established in the building. This model was basically a simple Excel-based spreadsheet that looked at each of the different loops, determined the total processing time needed to satisfy demand, and then compared this to the total available time (taking the number of machines per loadcenter into account) to determine utilization. In this case, utilization was defined as:

$$Utilization = \frac{\sum (Individual Processing Times) \times (Individual Part Demand in Period)}{Available Processing Time in Period}$$

**Figure 4-1 Rough-Cut Capacity Model**

Loadcenter Machines Part #	Machine A 2		Machine B 1		Machine C 1		Machine D 2		Bottleneck Loadcenter	12 Week Quantity	Weekly Quantity	Total Minutes
	Operation	Cycle Time	Operation	Cycle Time	Operation	Cycle Time	Operation	Cycle Time				
Part 1	Total= 285 10 164 20 121	Total= 234 30 234	Total= 0	Total= 134 40 134	234	56	4.7	1092				
Part 2	Total= 211 10 211	Total= 223 20 102 30 121	Total= 198 40 198	Total= 230 50 230	223	58	4.8	1078				
Part 3	Total= 239 10 239	Total= 0	Total= 125 20 125	Total= 182 30 126 40 56	125	73	6.1	760				
Part 4	Total= 290 10 290	Total= 200 20 111 30 89	Total= 100 40 100	Total= 110 50 110	200	56	4.7	933				
Part 5	Total= 230 10 230	Total= 67 20 67	Total= 153 30 121 40 32	Total= 99 50 99	153	58	4.8	740				
Total Time Utilization		8269 70%	Total Time Utilization	3427 76%	Total Time Utilization	2924 65%	Total Time Utilization	2936 43%	Total Min(week)= 4803			
Time Available:		Days/Week= 5	days					Total Parts= 301				
		Min/Day= 900	min					Takt Time= 178				
		Total= 4500	min/week									

Loop 102%

#### 4.2.3.1 Model Inputs

The following inputs into the model are required:

- *Parts*. Each of the part numbers assigned to the respective flow loop have to be included in the model to allow the self-updating function of the model to work.
- *Individual Part Demands*. In this case 12-week quantities for each of the part numbers are used. This input is automatically obtained from the 12-week report (which is linked to the MRP system) through a look-up function in Excel.
- *Quantity of Machines*. In some cases more than one machine is used to perform a certain process. This basically doubles the capacity of that individual loadcenter. Therefore, for each of the loadcenters in the loop, the number of actual machines must be taken into account and entered in the model.
- *Loadcenters*. Each of the different loadcenters that the parts visit as they flow through the loop are included in the model.
- *Available Time*. In order to determine how close to capacity each of the loadcenters and the loop as whole is operating, the total processing time must be compared to the total available time. Since different loops operate different numbers of shifts, total available time must be calculated separately for each loop. In this case, the processing time available per shift is assumed to be 450 minutes/shift. This is based on an 8 hour shift, minus two 10 minute breaks and one 10 minute clean-up period at the end of the shift.
- *Processing Times*. Specific processing times for each of the MOT operations at each of the loadcenters is listed. Since no time standards exist, these times are a mixture of historical average times, time studies, and best guess estimates. All times are in minutes unless specified otherwise.

#### 4.2.3.2 Model Outputs

As can be seen in Figure 4-1, the model has three main outputs. These are:

- *Individual Loadcenter Utilization.* For each of the loadcenters, the individual utilization is determined. This is determined by multiplying each of the part demands (assumed to be level-loaded over 12 weeks) by the total processing cycle time (on a given loadcenter) divided by the number of machines in the loadcenter. This determines the total processing time for each machine in that loadcenter in a given week. This total processing time is then divided by the total available time for the loadcenter to determine individual machine utilization.
- *Loop Utilization.* The total utilization for the loop is determined by looking at each individual part type and determining how much time the loop is tied up processing this part type each week. Doing this requires a number of steps. First, due to the rule imposed by one-piece flow of having no buffers between machines, each part must be assumed to go to each loadcenter. Therefore, the so-called bottleneck loadcenter (and associated cycle time) is determined for each part. This bottleneck cycle time is the minimum time that must be allowed between releases of parts into the loop (to prevent parts from piling up between loadcenters). As with the individual utilizations, the number of machines in each loadcenter is taken into account when determining the bottleneck loadcenter. Once the bottleneck loadcenter is identified, the loop is assumed to be tied up with this part for a specific time (determined by multiplying the level-loaded weekly quantity by the bottleneck cycle time). Finally, the loop utilization is determined by dividing the total loop processing time (determined by adding up the individual times) by the total available processing time for the loop.
- *Loop Takt Time.* Individual loop takt times are calculated to help in production planning and scheduling. For instances where all parts are similar with similar processing times on all loadcenters, this takt time can be used for releasing material into the loops. As mentioned above, when processing times are not similar, separate loop takt times for each part type must be determined manually by looking at the bottleneck cycle time.

### **4.3 Model Uses/Applications**

Even though the model is only a very rough model based on a number of assumptions, it still provides valuable information. In fact, by the time the internship project ended, a number of different people in the facility had copies of the models and were using them. Most potential applications of the model can be divided into two categories: analysis or planning.

#### **4.3.1 Analysis**

Having a better understanding of capacity (even if only approximate) can provide valuable information when performing a number of different types of analysis. These include:

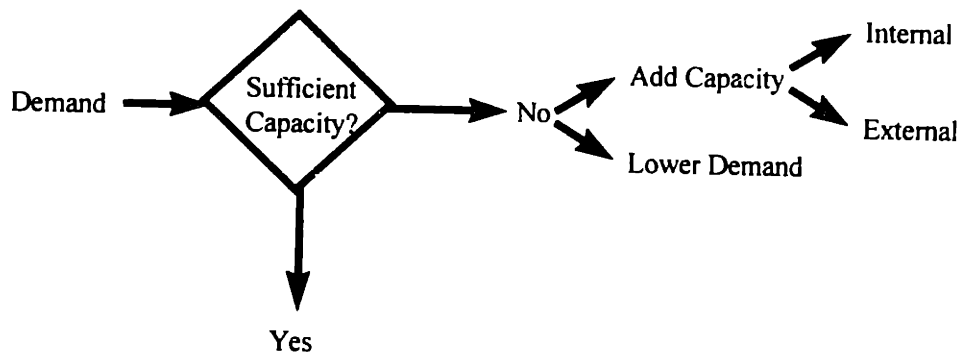
- *Bottleneck Analysis.* As mentioned before, the capacity model clearly shows which loadcenter has the highest utilization. This allows management to better focus set-up time and cycle time reduction efforts on those loadcenters that are closest to maximum capacity.
- *Capital Investment Justification.* As mentioned before, engine demand is growing very rapidly and hence, many machines are rapidly approaching maximum capacity. Therefore, a number of capital expenditures in the form of increased machining capacity will soon be required. Use of the capacity model to demonstrate current levels of machine utilization facilitates justification (thus speeding up the justification process) and also helps ensure that the correct investment decisions are made.
- *One-Piece Flow Analysis.* As demonstrated before, pure one-piece flow can cause a lot of capacity to be wasted if there is large variability in cycle times. For example, Figure 4-1 shows a scenario where the loop itself exceeds rated capacity (loop utilization is 102%) while the highest individual loadcenter utilization is only 76%. If cycle times can be better balanced through re-distribution of tasks between loadcenters, the loop can be brought back within rated capacity. The model is useful in helping determine which operations need to be split up or reduced in order to better balance the line.

#### **4.3.2 Planning**

- *Pro-Active Capacity Planning.* As demand continues to grow, pro-active planning will increase in importance. Without a capacity model, it is hard to determine if sufficient

capacity exists to meet projected demand. Due to the long lead times involved in procuring extra capacity, simply reacting to increases in the weekly production schedule is not acceptable. Instead, longer term capacity planning is required. The capacity model can be used for this. Instead of using the current 12-week production schedule for demand data, next quarter's numbers can be used. Doing this allows each cell to look out into the future and determine whether or not capacity will become an issue. Figure 4-2 shows graphically how the model could be used for capacity planning.

**Figure 4-2 Capacity Decision Tree**



- *Make/Buy Decision Making.* As demand continues to grow it will eventually exceed capacity. As Figure 4-2 shows, there are two methods of adding capacity, internal and external. If the increase in demand is expected to last for long periods of time, then adding internal capacity is the correct thing to do. But, as long as this growth is expected to only be temporary in nature, capital expenditures to upgrade capacity are not justifiable. In that case, adding external capacity through temporary outsourcing of production might be a better solution. But, since all parts do not follow the same process routing, deciding on which parts to out-source is not an easy thing. When making this decision, those parts that tie up the bottleneck loadcenter must be outsourced (in order to gain the maximum benefit from the outsourcing decision). To do this, you need to be able to run multiple scenarios and analyze the results on total loop capacity. The capacity model allows this to be done. Additionally,

being able to analyze the result of an outsourcing decision on loop capacity allows a better pricing decision (of the outsourcing) to be made.

- *One-Piece Flow Implementation.* As the one-piece flow manufacturing is being implemented, traditional clusters of machines are being split up into flow loops and arranged in such a manner that parts flow from one machine to the next. In keeping with the goal of the TPS of eliminating all waste, it is important to know exactly how much capacity of each type of machine is needed in each loop to meet demand. This allows the unused capacity of a loop to be minimized. Therefore, before any loops are formed, it is important to first develop a simple capacity model for that loop and look at individual machine utilizations. If any loadcenter utilization is above a pre-determined level (in this case arbitrarily set at 75-80%), then an additional machine must be added to this loadcenter. Doing this allows the formation of the loops to be more based on facts than on the “gut feeling” of how many machines of each type are needed in a loop. This eliminates wasted capacity. Also, over the course of time, as processes become more standardized, it might become necessary to move certain parts between loops to better fit the flow. Having a better understanding of capacity allows “what-if” scenarios to be run to determine the effect on loop capacity of adding/removing parts from a given loop.

#### **4.4 Model Limitations**

It is important to note that this model is meant to be a rough cut capacity model. Some definite tradeoffs had to be made between keeping it simple and user friendly and making it accurate. Hence, when interpreting the output of the model, it is extremely important to understand the assumptions on which the model is based and consequently, the model’s limitations. These limitations can be attributed to the data used in the model and the actual assumptions used in developing the model. Each one of these is discussed in further detail below.

##### **4.4.1 Data**

As mentioned in Section 4.1, all time standards had been eliminated a number of years ago. Therefore, accurate processing times for all the different operations were hard to come by. Due



to the sheer number of different operations and the relatively long cycle times of each, performing detailed time studies of each operation was not feasible during the time period of the internship project. Instead, as a first approximation, historical processing times (as measured when operators scan in and out of specific jobs) were used. In an attempt to minimize measurement errors, this time data was averaged over the last year.

It is important to realize that these times are going to be inaccurate. As operators take breaks, they stay scanned in on a given job. As operators run more than one machine at a time, they can only be scanned in on one of them. As operators go off to team meetings, they often stay scanned in on the job at hand. As operations are changed to facilitate processing, the average times will still reflect the older processes and times. All these things will cause the historical data to be flawed and thus the output of the model to be inaccurate.

However, in an attempt to see how flawed the data was, two quick tests of the models and time data were performed whenever building a model for a loop. The first one was to look at which loadcenter the model showed as having the highest utilization and then comparing this to what the operators thought based on experience. In almost all cases, the highest utilized loadcenters (as shown by the model) were also the ones generally acknowledged by all people involved as being the highest loaded machines, thus backing up the model. The second one was that any time any time-studies were performed, these times were compared to the historical times listed in the model. Generally, all times fell within 15% of what the historical time showed. Therefore, both tests imply that at least as a first approximation, these rough-cut models could be useful. But, in order to stay useful, they need to be continuously updated as more time studies are performed and as processing operations are modified.

#### 4.4.2 Model Assumptions

As mentioned in Section 4.1, a number of assumptions had to be made in developing the capacity model. Some of these assumptions were due to lack of data and some were made to minimize the complexity of the model. All these assumptions reduce the overall accuracy of the output. Some of the assumptions can be easy to plan around. For instance, if yield is known to be 95%,

then simply limiting loop utilization to 95% minimizes the effect of the assumption. Some of the limitations imposed by the others are not as obvious.

Due to the one-piece flow rules, one assumption in particular can create a lot of inaccuracy in the model. This is the 100% machine availability assumption. Since one-piece flow does not allow buffers to exist, individual machine reliability will have large effects on loop capacity. Now, in essence, any machine can stop flow in the loop (as there is no inventory to de-couple the various machines from each other), and the loop must therefore be treated as a group of connected machines. This causes small disruptions to get magnified as they flow through the loop since there is no inventory to dampen them out.

The following example shows how individual machine unreliability gets magnified by the loop. Assume that each of the machines in a loop with  $k$  machines has a mean time to fail (MTTF) of  $1/p$  and a mean time to repair (MTTR) of  $1/r$ . Also, assume that only operation dependent failures are taken into account. Then, the overall efficiency of the flow loop ( $E_{ODF}$ ) can be shown to be given by [Gershwin, 1994]:

$$E_{ODF} = \frac{1}{1 + \sum_{i=1}^k \frac{p_i}{r_i}}$$

So, for example, if in this case the isolated efficiency of each machine is 99% (MTTF=100 hours and MTTR=1 hour), no buffers are allowed to exist between machines, and there are 20 machines in the loop ( $k=20$ ), then the loop's overall efficiency drops down to 83% (even though all the machines are 99% efficient). So, for large loops with relatively unreliable machines, the loop's overall efficiency will be significantly reduced due to the lack of buffers between machines.

Similarly, looking at time dependent failures, a similar relationship can be shown to exist. Again, small disruptions can cause large effects on capacity due to the lack of buffers to de-couple the various machines and thus prevent the disruptions from propagating from machine to machine.

The capacity model does not take this into account and simply assumes perfect reliability for two reasons. These are: (1) lack of available data; and (2) the fact that all parts do not get processed on each machine. The first reason could be remedied by obtaining more data. Dealing with the second reason however, would make any potential model extremely complex (since endless combinations are possible as part mix changes).

Ultimately, it was decided that any individual machine utilization would simply be limited to 75-80% to cover these inherent inaccuracies in the model.



## **5. Improvements in Material Flow**

Many of the benefits of lean manufacturing are derived from the elimination of waste. This chapter provides a brief overview of some of the improvements implemented to allow the parts to better flow as they are processed and thus eliminate waste. This chapter also includes the basic methodology followed in developing these changes, which helped eliminate much non-value adding transportation time and waiting time, and reduced the parts on hand (WIP). As part of this flow manufacturing implementation (one-piece flow), this chapter also covers the supermarkets and point-of-use stores that were implemented to reduce transportation time, wasted motion, and waste of over-processing.

### **5.1 Flow Manufacturing**

#### **5.1.1 Methodology**

The first step in implementing the one-piece flow manufacturing was to create a better flow of material on the shop. To do this, most of the machines were re-organized into so-called “flow-loops” (this term is used instead of the more traditional term “cell” - used in most literature - since the term cell was already used to describe the existing condition). This re-organization consisted of splitting the larger cells into multiple dedicated loops. By the end of the implementation, the 15 original cells were expected to end up in 42 flow loops.

This splitting up was done through the use of Kaizen<sup>2</sup> teams following a clearly established methodology. These Kaizens were typically one-week events in which a cross-functional team worked together to develop and implement change. These teams were made up of hourly workers from the cell, process engineers, design engineers, production supervisors, and general support people (such as maintenance people, facilities people, buyers, planners, etc.). Each of the Kaizen teams also had an external consultant assigned to them.

---

<sup>2</sup> This was just one application for which Kaizen teams were used. Kaizen teams were also used in the more traditional sense of performing continuous improvement on the shop floor, such as cycle-time reduction efforts and set-up time reduction efforts.

The basic steps followed in splitting up the cells were:

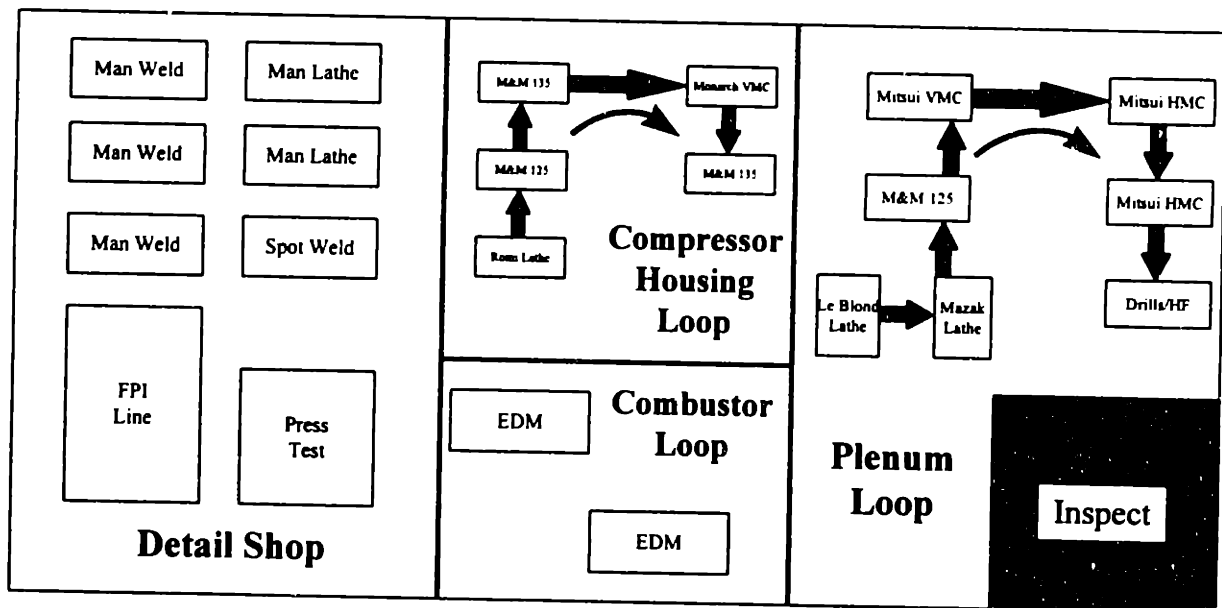
- *Develop Standard Process.* The goal of this step was to develop one process (sequence of steps) that all the parts assigned to a loop could follow. This would allow all the machines to be re-organized according to this standard process. To do this, first all the parts initially assigned to the cell were split up and assigned to individual loops based on projected loop capacity, processing requirements, or machine size requirements. Next, “process mapping” was performed. This is a process in which the different processes that a part undergoes are mapped out using post-it notes. This allows easy re-shuffling of the different steps for each part as commonality is sought between the various parts. Usually, it was not possible to develop one standard process that would fit all parts. But, since a small number of parts usually made up 70-80% of a loop’s volume, a process was developed that would at least fit these parts. All the other parts were then treated as exceptions and assigned for future review.
- *Develop Capacity Model.* Once the different types of machines required in a flow loop were determined (such as to allow the parts to follow the standard process), the number of each machine required to meet anticipated capacity needed to be determined. This was done using the rough-cut capacity model developed in Section 4 (where the model was available) or by performing takt time versus cycle time analysis for those loops where the model had not yet been developed.
- *Develop Paper Model.* Once the required equipment was determined, the actual flow loop was developed. This was first performed using a small-scale paper layout of the facility. Using this layout, the different machines were cut out and then moved around to try out different possibilities. Once a layout was developed that would meet all the different constraints (such as available space, ceiling height, and crane availability) full-size paper cutouts were made up and used to simulate the entire flow loop in an old abandoned hangar. In doing this, all the workers from the cell were brought in to get their input. Once consensus was achieved, the layout was finalized by putting it on a CAD drawing for the movers to use when actually re-arranging the machines.

- *Process Changes.* The next step was to actually make all the required changes on the MOTs to allow the parts to actually follow the standardized process routing developed at the start. This included re-arranging steps, moving steps from one machine to another (for example from a manual lathe to a CNC lathe), and ordering the required CNC programs and fixtures (if necessary).
- *Implementation.* The final step was to actually implement the changes. This included moving the machines around and cross-training the workers.

### 5.1.2 Cell 3 Example

An example of a transition from traditional mass-production to flow-manufacturing that occurred during the internship project is Cell 3. At the start of the internship project, this cell was arranged in a traditional sense (see Figure 2-1), with similar machines located next to each other instead of in dedicated flow loops. Using the above methodology, this cell was split up into four

**Figure 5-1 Cell 3 After Re-Organization**



separate sections. Three of these sections were flow loops and one of them remained a job shop, since no real flow existed due to the nature of the product. In this case, the Detail Shop fed the other three loops. Figure 5-1 shows the different loops that were developed.

### 5.1.3 Expected Benefits

The expected benefits from the example shown in Section 5.1.2 are plentiful. Table 5-1 lists the projected results:

**Table 5-1 Projected Results of One-Piece Flow in Cell 3**

Measure	Projected Improvement
Space (SQFT)	20% Reduction
Inventory	35% Reduction
Part travel distance	50% Reduction
Lead time	30% Reduction

## 5.2 Supermarkets

### 5.2.1 Purpose

Similar to the flow manufacturing described in Section 5.1, the purpose of the supermarkets was to eliminate waste and improve the flow of parts. It does this in two ways:

- *Reduction in Distance Traveled.* By storing the raw material and sub-assemblies inside the cell (where they are actually used), costly transportation time is saved. Additionally, total distance traveled by the parts (as they go from raw material to sub-assembly to final-assembly of the engine) is reduced, thus reducing lead time.
- *Increased Visibility of Over-Production.* By storing the intermediate sub-assemblies inside the cell, it becomes very easy to spot over-production. For example, assume that a final assembly requires one inner and one outer sub-assembly. Now, if in the past 10 inner sub-assemblies have already been produced, but no outer sub-assemblies exist, this becomes immediately visible to all people involved if the parts are located on the shop floor. If, however, the parts are simply stored in a warehouse, this would never become visible. By having this visible, no costly capacity will be wasted making inner sub-assemblies until at

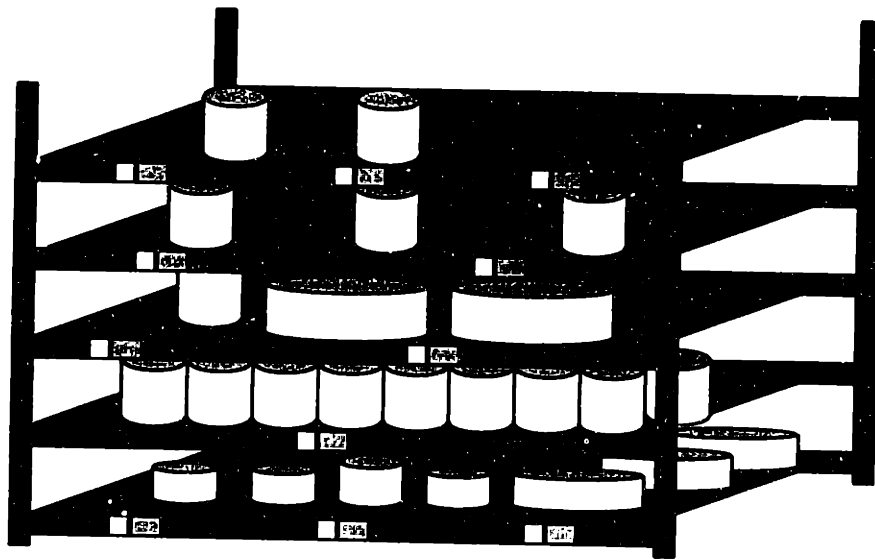


least 10 outer sub-assemblies have been produced (no matter what the 12-week report calls out). Additionally, having the parts on the shop floor facilitates the implementation of a consumption-based production scheduling system which also minimizes over-production. This is described in further detail in Section 6.

### 5.2.2 Design Methodology

The actual supermarkets are simple racks located within the cell. Each rack has dedicated spaces for individual parts. Additionally, a signal board is located in front of each part number, to trigger replenishment and control total WIP (this will be discussed later in Section 6). Figure 5-2 shows a typical supermarket design.

**Figure 5-2 Supermarket Design**



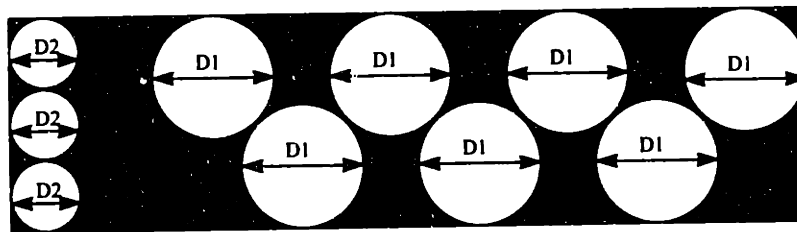
To determine the size and number of shelves required, the following approach is used:

1. A simple spreadsheet is developed. This spreadsheet lists all the parts that are either needed by the loops (raw material) or are produced by the loops (sub-assemblies), their associated level-loaded demand, the lead time, and the number of total parts that will be allowed to exist as either WIP on the shop floor or as WIP in the supermarket (the method to calculate this WIP will be covered later in Section 6.2.2).

2. Since not all the parts will be in the supermarket at one time (some of the parts will be on the shop floor as WIP if the correct lead time and demand are used), the shelves are sized to hold a portion of the total possible parts. This includes the expected cycle stock, the safety-stock and a little buffer to compensate for variability in either demand or lead time.
3. Once the quantity desired of each part is determined, the part is measured and the required shelf space is determined. When doing this, it is important to try to minimize the total space needed by combining the different parts on a given shelf (though all the parts for a given part number should be on the same shelf). Figure 5-3 shows this graphically.

**Figure 5-3 Shelf Sizing**

**Shelf - Top View**

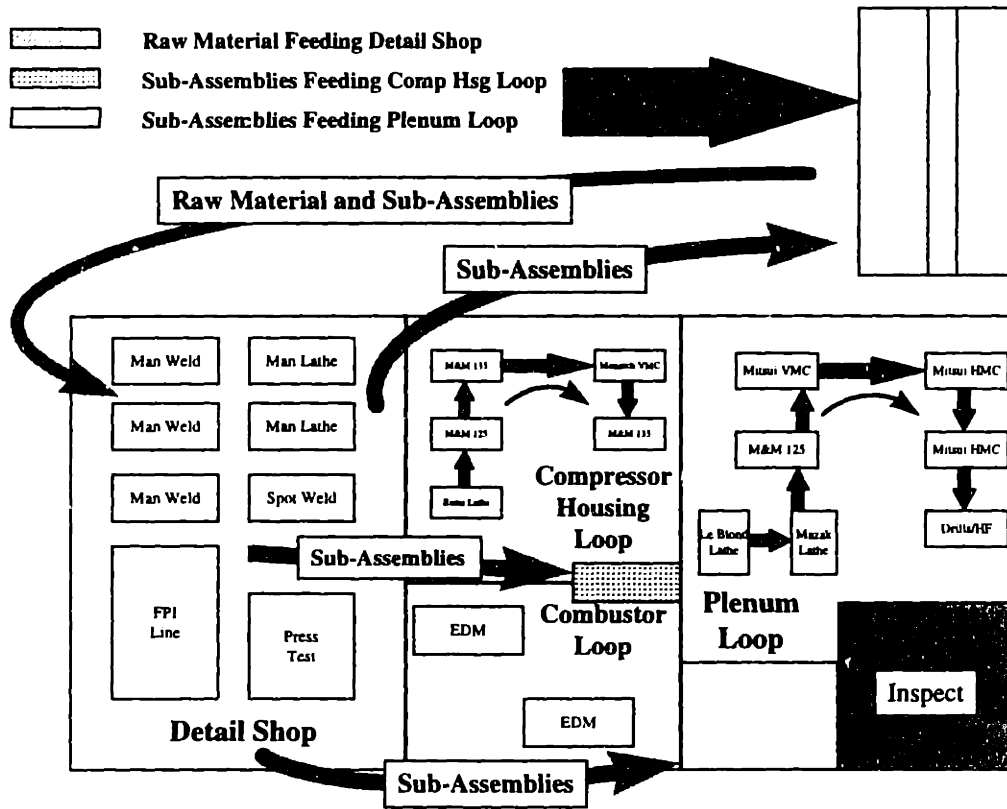


### 5.2.3 Cell 3 Example

During the course of the internship project, the supermarket approach was implemented in Cell 3. In this case, three supermarkets were used to couple the batch-process Detail Shop to the one-piece flow machining loops (see Figure 5-4).

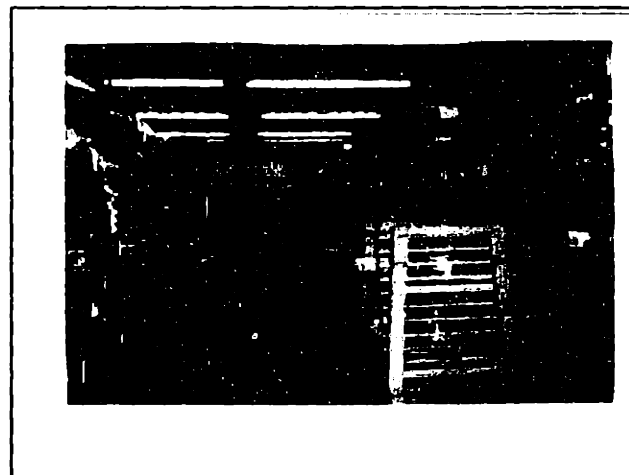
These supermarkets contained: (1) finished fabricated details; (2) in-process parent Plenums ready to enter the machining loop; and (3) in-process Compressor Housings ready to enter the machining loop.

**Figure 5-4 Cell 3 Supermarkets and Material Flow**

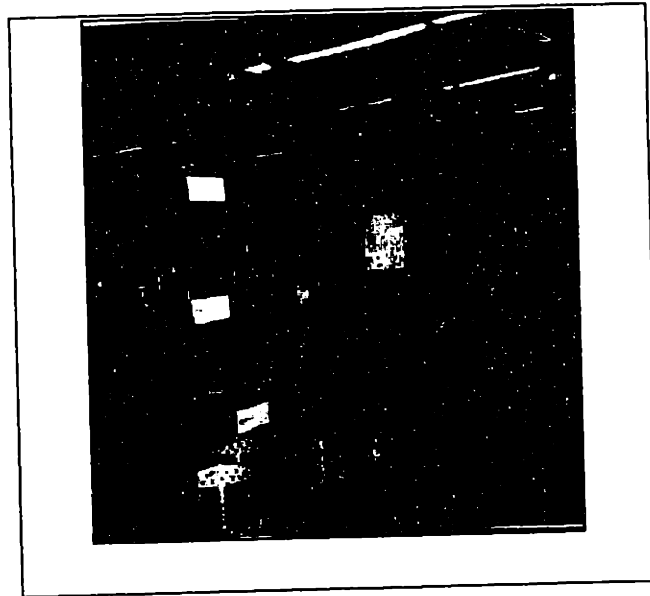


The loop end-item (finished assemblies) supermarkets were located at the beginning of their associated loops, while the fabricated detail supermarket was located next to the cell, together with all the purchased raw materials. Figure 5-5 and Figure 5-6 show the actual supermarket constructed to house the fabricated details and the raw material.

**Figure 5-5 Cell 3 Supermarket (1)**



**Figure 5-6 Cell 3 Supermarket (2)**



#### 5.2.4 Results

As predicted in Section 5.2.1, the two main benefits that resulted from building the supermarkets in Cell 3 were:

- *Increased Visibility.* By having a spreadsheet model for total inventory in the cell (as needed to determine the sizing of the supermarket), the effects of batch size, lead time, and safety-stock on total WIP became very visible. This allowed better trade-offs to be made between lost capacity (due to set-up time) and total WIP as the lot sizes were determined. Also, the effects on WIP of future lead time reduction efforts can now easily be quantified.
- *Reduced Overall Lead Time.* Before the supermarket, it took anywhere from one to seven days for raw material (or sub-assemblies) to be ordered and delivered to the shop floor, as the warehouse was located  $\frac{1}{4}$  mile from the 404 Building. By having the supermarkets, this was reduced down to 1 hour. For multiple-level items, this reduction applied to each level built in the cell.

### **5.3 Point-of-Use Stores**

#### **5.3.1 Description**

In addition to the Supermarkets mentioned in 5.2, one additional improvement activity was developed to facilitate flow manufacturing. This was a Point-of-Use (POU) Stores. Similar to supermarkets, the POU Stores were locations to store parts on the shop floor. In this case, the locations were next to (or as close to as possible to) where the parts were actually used. These POU Stores contained the small, low dollar-value items (so-called C-items) that fit into small drawers. Figure 5-7 shows the POU stores developed in Cell 3.

**Figure 5-7 Cell 3 POU Stores**



#### **5.3.2 Purpose**

Due to their small size, these parts were easily misplaced if simply put on the carts along with all the other raw material at the beginning of the process. This then often required the operator to stop production and locate a replacement part. By locating these parts in a POU Stores next to the operators, the parts are not obtained until right before the parts are needed. This minimizes the number of parts misplaced, and thus the wasted time of looking for the parts.



## **6. Improvements in Production Scheduling - Pull System**

This chapter provides a brief overview of the consumption-based production system that was developed. The chapter first discusses the purpose of this Kanban system and then gives a brief description of how the system operates and what the expected benefits are. Finally, the chapter ends by discussing some possible future plans that tie into the production scheduling system developed.

### **6.1 Purpose**

The purpose of the Kanban system is threefold:

- *Inventory Control.* By controlling the number of Kanban cards that are allowed to be in the system, the total number of parts either in the supermarket or on the shop floor is controlled. This total number is based on demand, lead time, lot-size, and variability.
- *Increased Visibility and Prioritization.* A Kanban system facilitates production scheduling by ensuring that only parts with an actual demand are worked on. This prevents over-production.
- *Inventory Bleed-Off.* Use of the Kanban system facilitates bleeding-off the existing inventory through the use of different colored cards (red “excess” cards) that do not trigger any events.

### **6.2 Operation**

The Kanban system developed consisted of three basic building blocks: (1) Detail Production Board; (2) Signal Board; and (3) Kanban Card. Each one of these will be described in further detail.

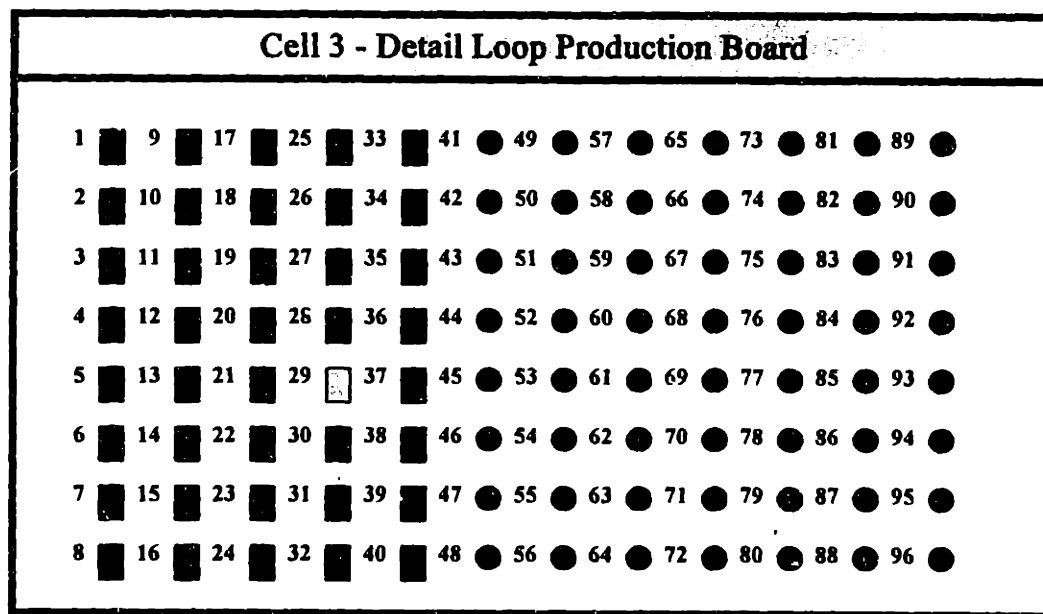
#### **6.2.1 Detail Production Board**

The purpose of the Detail Production Board is two-fold: (1) to provide the cell with a visual means of seeing what and how many jobs are currently released to the Detail Loop; and (2) to provide the cell with a means of prioritizing and scheduling different jobs within the Detail Shop.

The main goal behind the actual design of the board is to ensure that once hung, cards will not have to be moved until the parts are complete and moved back to their respective supermarkets (to minimize the effort of keeping the board updated). Therefore, instead of having moving cards, the board has moving holes (hole flow vs card flow). In this case, the hole is the location (hook) where the next cards are hung. Figure 6-1 shows the Detail Production Board.

Besides the regular signal cards used to represent the various parts made in the cell, there are three additional colored cards used on this board, namely: (1) a green card signifying which of the jobs currently in the queue to start next; (2) a black card signifying the last job added to the queue; and (3) red cards signifying "hot" jobs needing special attention (the number of red cards is purposely limited to prevent all jobs from becoming "hot").

**Figure 6-1 Detail Production Board**



■ - Signal Card   □ - Next Job (green)   ● - Last Added (black)   ● - Hot Job (red)

Basic operation of the board is as follows:

1. When a pull signal (along with PWO) arrives from the supermarket signal boards, the cards are hung on the next available hook. All cards for the batch are hung on the same hook behind the black (last added) card. Then, the black card is moved to the next hook

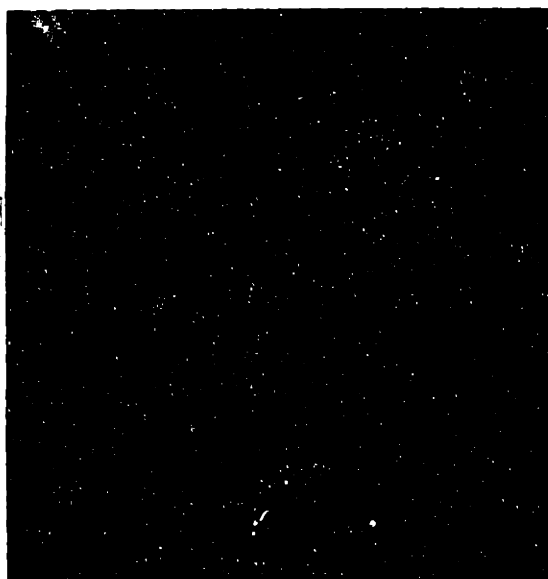


(sequentially). Once the next hook reaches the end of the board - 96-, it starts back in the beginning - 1.

2. When the Detail Shop is ready for the next job, the operator looks at the board for the next job to be started, pulls the PWO, and starts the job. At the same time, the green signal card is moved to the next job in the queue.
3. As the Detail Shop finishes a job, the parts are moved to the appropriate supermarket, and the signal cards are removed from the board and hung back on the signal boards in front of the parts.
4. If a job becomes “hot” while in the Detail Shop, one of the red “hot” cards is placed over the front-most batch of this part in queue. If this batch is already being worked, nothing else happens. If the next batch has not yet been started, the signal cards are moved from their respective place in the queue to the front of the line (where the green card is hanging), covered with the green card, and all the subsequent cards are moved down one spot. This makes the “hot” parts the next job started.

To ensure that there is always an open hook to hang cards on, the board must have more hooks than the maximum number of jobs that will be allowed to be released to the Detail Shop and be

**Figure 6-2 Cell 3 Detailed Production Board**



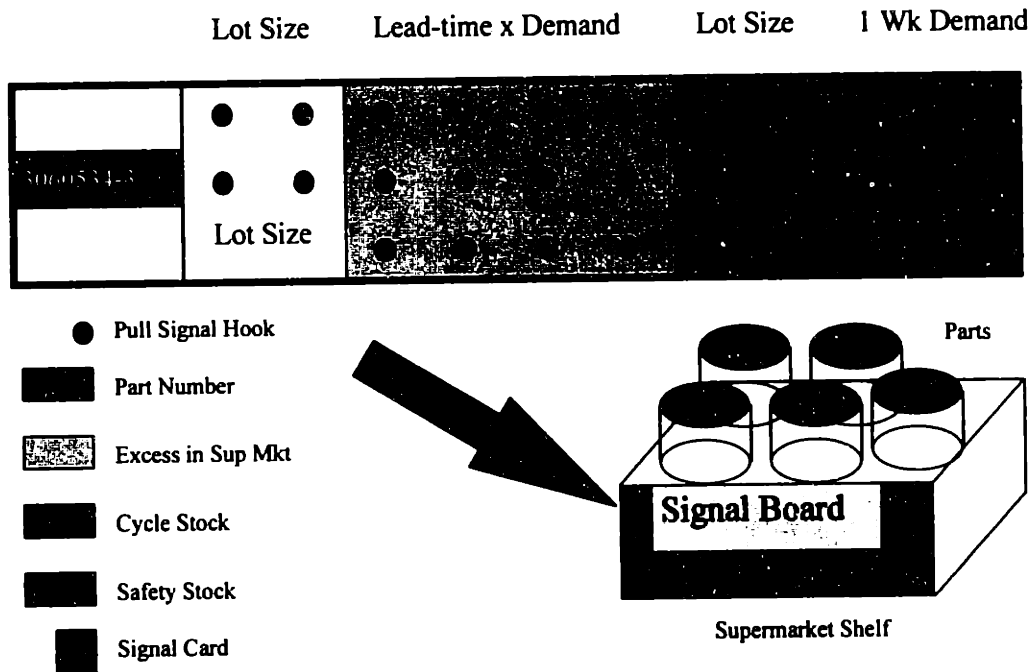
in process or waiting in queue.

To be a useful visual tool, the board is located inside the Detail Shop, in such a manner, that it is clearly visible to the operators. Figure 6-2 shows the actual Detail Production board installed on the shop floor in Cell 3.

### 6.2.2 Signal Board

The main purpose of the signal board (shown in Figure 6-3) is to provide trigger points for when to re-order more parts (based on actual consumption) and to limit the total amount of Work-In-Process (WIP) that can be present in either the supermarket or the Detail Shop. Additionally, the

**Figure 6-3 Signal Board**



signal boards are also meant to increase visibility of a cell's performance relative to plan.

To facilitate movement of the Kanban cards (pull signal), the boards are mounted in the supermarket, to the shelves, in front of their associated parts. In addition, the mounting of the boards is such that they can be easily moved, as the total space taken up by the supermarket shrinks (due to lead time reduction efforts).

The signal board has five basic areas. These are: (1) part number; (2) pre-determined lot size that will be used as the parts are manufactured in the Detail Shop; (3) yellow zone, signifying excess WIP in the supermarket; (4) green zone, signifying the expected cycle stock; and (5) red zone, signifying the safety-stock.

The number of hooks in each of the zones is determined as follows: (1) the yellow zone is based on traditional re-order times for each lot (lead time x demand) - care must be taken to ensure that the time units for both demand and lead time are the same; (2) the green zone is based on the desired lot size in the Detail Shop (based on set-up time considerations, outside-process batch requirements, etc.); and (3) the red zone is simply the desired safety-stock, such as for example one week of demand. In all these calculations, the final numbers are always rounded up.

The total number of hooks in the three colored zones is equal to the maximum number of parts that can be in WIP (either in the supermarket or in the Detail Shop) at any point in time.

Therefore, by controlling the number of cards, the total WIP in the cell is controlled.

Red "excess" cards are used to denote excessive WIP (for a particular part number). These cards do not trigger replenishment, and are removed from existence as their associated parts are consumed.

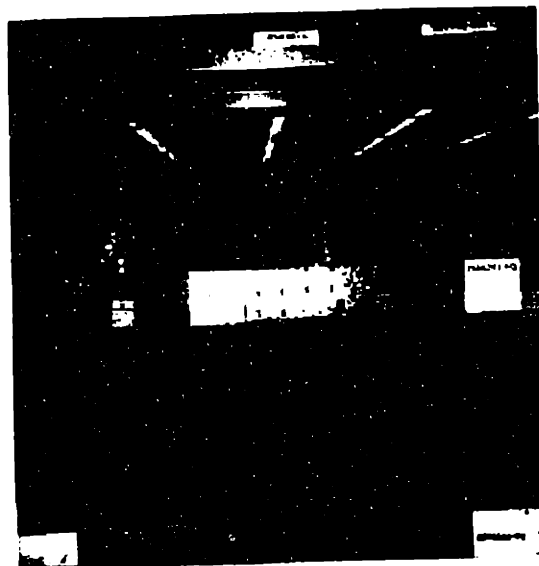
Basic operation of the signal board is as follows:

1. When a part in the supermarket is pulled (either a final assembly or finished detail), a Kanban card is moved from either the yellow/green/red zone (in that order) to a hook in the "lot size" box (unless there is excess inventory, as indicated by a red "excess" card, in which case the card is simply removed from the hook and nothing else happens).
2. If all the "lot size" hooks are not yet filled, nothing else happens. If however, this next card fills up all the hooks, a trigger point is reached.
3. Once a trigger point is reached, the cards are removed from the "lot size" box, and a Production Work Order (PWO) is cut. Thus, the signal for more parts to be produced is now based on actual consumption. For parts going to the finished detail supermarket, a single PWO for the whole batch is cut. For parts going to the loop supermarkets, individual PWOs are cut for each part (since the parts will be pulled in lots of one from these supermarkets).

4. Once the PWO is cut, the cards are hung on the next available hook on the Detail Production Board (as described in the procedures for this board).
5. When the parts are completed, the parts are placed on the shelves in the supermarket, and the cards are hung back on the hooks on the associated signal board.

An actual signal board built and installed in Cell 3 is shown in Figure 6-4. Looking at this, it becomes apparent how these signal boards can increase visibility of the cell's performance as far as lead time is concerned. Two specific conditions are worth mentioning:

**Figure 6-4 Cell 3 Signal Board**



- *Yellow Zone.* If the signal board continuously has cards hanging in the yellow zone, this would imply that there are too many parts in the supermarket. This could be caused by actual demand being lower than anticipated, or lead time being smaller than previously assumed (i.e. the parts are getting through the Detail Shop faster). Consequently, both the number of hooks in the yellow zone and the number of cards for that part would have to be reduced (by equal amounts). To do this, both a card and a hook would be removed from a the yellow zone. The card would be replaced by a red "excess" card, which would then be removed as the excess parts are consumed.

- *Red Zone.* If the hooks in the red zone are continuously empty, this indicates that there are insufficient parts in the supermarket (for that particular part number). This could be due to actual demand being higher than expected, or lead time being longer than previously assumed. To remedy this, the number of hooks in the yellow zone must be re-calculated, and new hooks/cards added. The hooks are added to the yellow zone, while the cards are immediately hung in the “lot size” box.

To prevent stock-outs from occurring or from building up excessive WIP, it is important to regularly verify that the number of cards hanging in front of a shelf is equal to the number of parts sitting on the shelf. If there are any discrepancies, action must be taken to correct the situation immediately (by moving any extra cards to the “lot size” box). Additionally, to ensure that the right number of cards are in the system, it is important to re-calculate the number of cards needed on a regular basis, in particular, when demand or lead time changes occur.

### 6.2.3 Pull Signal (Kanban) Card

Figure 6-5 shows a typical pull-system or Kanban card. Individual signal (Kanban) cards are used to represent each part.

**Figure 6-5 Kanban Card**

○

**3060316-3**

Loop:            Com Hsg

Pull Signal: 1

Lot Size:        \_\_\_\_\_

As mentioned before, by controlling the total number of cards for each part, the total possible WIP is controlled (since parts can only be released to the shop floor if pull cards signal them to be released).

Different background colors represent different part end-destinations. For Cell 3, possible colors are: (1) magenta for parts going to the Plenum Loop supermarket; (2) light blue for parts going to the Compressor Housing Loop supermarket; (3) orange for parts going to the finished-detail supermarket; and (4) red for “excess” parts. All Kanban cards are 2” x 2”, and have the following information on them: (1) part number; (2) destination (loop); and (3) pull signal number.

When lead time is reduced or demand decreases, the total number of cards must be adjusted (based on the afore-mentioned formulas). Any excess cards are then exchanged for a red “excess” card. This card also represents a single part, but unlike a regular signal card, it does not trigger production. Once the part is consumed, the card exits the system. This thus provides a means for bleeding off any excess inventory already on the shop floor.

### **6.3 Expected Results**

At the end of the internship project, this production scheduling system had just been completed and was about to be implemented. Therefore, no actual results are yet available. However, the expected results of using a pull system versus the traditional push system are [Monden, 1993]:

- *Elimination of Unnecessary Inventory and WIP.* By only scheduling production for what has actually been consumed, costly capacity is not wasted making parts that are not needed. This reduces the overall WIP on the shop floor and reduces the end-item inventory.
- *Shortening of Lead Times.* By ensuring that only those parts that have a demand are produced, production prioritization becomes easier. This reduces the overall confusion on the shop floor and thus ensures that the right parts are being worked on. Ultimately, this shortens the overall lead times (as mentioned in 3.3.2 and shown in Figure 3-2).
- *Prompt Adaptability to Changes in Demand.* By using a system that is based on the level-loaded demand, the system will easily adapt as demand changes. The only thing necessary is to re-calculate the total number of signal cards for each part number.

One additional advantage of the system developed here over a traditional Kanban system is that it is color coded. This was done to make the cell’s performance more visual. If the cards are

constantly being pulled out of the red zone (which is the safety-stock zone), then there are not enough cards in the system. This can be either due to the cell not meeting the expected lead time on that part or due to the demand for that part being higher than initially projected. On the other hand, if the cards are constantly being pulled out of the yellow zone, then too many cards (or parts) are in the system. This can be due to the actual lead time being shorter than expected or demand being lower than projected. In either one of these cases, the total number of cards needs to be adjusted. With a traditional Kanban system, this would not have been as visible.

Finally, it is important to note that before many of these results are achieved, one important prerequisite needs to be fulfilled. This is smoothing of product demand or level-loading. To get the most benefit from the Kanban system, the production schedule must be level-loaded. The more level, the better the scheduling will work, and the less inventory will be needed (safety-stock).

#### **6.4 Future Plans**

A number of expansions to the pull-system developed for production scheduling in individual cells have already been planned. These are:

- *Link Individual Loops to the Assembly Line.* This would encompass developing a pull system that links each of the loops to the assembly line (building on the loop's individual pull-system). Before this can be implemented, each of the individual cells needs to get their production scheduling system implemented and running. Implementing this would basically turn the whole site into one big Just-In-Time factory, reducing total engine lead times and minimizing the total amount of inventory in the supply chain within AlliedSignal.
- *Pull-System for Buying.* This would entail using the same sort of system as used for the production scheduling system, but instead of sending the cards to the Detail Production Board after a work-order is cut, the cards are sent to an "On-Order Board" after a fax is sent to the supplier. This fax would be the signal to ship more parts to the cell (a production schedule covering the next couple of months would already have been sent to give each of the suppliers warning on roughly when the parts would be required). Similar to the production scheduling system, the transportation lead time and the desired order-size would determine how many cards need to be in the system for each part. For this to work, buy-in

would first have to be obtained from the key-suppliers, as well as the buyers involved for these parts. Ultimately, this would then reduce the total inventory in the entire supply chain.



## **7. Conclusion/Recommendations**

This chapter first provides a brief summary of the results of some of the projects worked on during the internship project, along with some of the key learnings. Then, a number of recommendations are presented on how things might be further improved in the future (in keeping with the spirit of continuous improvement).

### **7.1 Conclusion**

#### **7.1.1 Results**

In their quest to implement Lean Manufacturing, AlliedSignal was basically following the method mentioned by Womack and Jones in their recent book *Lean Thinking* [Womack & Jones, 1996]. This consisted of:

- Specify value (as seen by the customer).
- Identify the entire value stream for the product.
- Make the value-creating steps flow.
- Let customers pull products instead of pushing them.
- Strive for perfection (through continuous improvement).

According to Womack and Jones when doing this, based on global benchmarking, the following rules of thumb can be used for projecting the benefits of switching from traditional batch production to continuous flow with effective pull by customers:

- 100% increase in labor productivity.
- 90% reduction in production lead times.
- 90% reduction of inventories in the system.
- 50% reduction in defects.

Using June as the baseline (since this is when this internship project started) the actual improvements obtained in the 404 Building (Static Components Production Center) are:

- Customer Satisfaction Index (CSI): 18% increase
- Planned lead time: 25% decrease
- Past due pieces: 27% decrease
- WIP: 36% decrease
- Productivity: 10% decrease
- Defects per unit (DPU): 30% decrease

With the exception of the productivity, these results are in line with those expected from lean manufacturing. The initial decrease in productivity can be partially explained by the fact that many of the workers were tied up in re-organizing all the machines and forming the loops. The productivity should start improving as the re-organization is complete.

### 7.1.2 Learnings

This internship project provided many great learning opportunities. Two of the main learnings were: (1) you have to use a systems approach to making change to maximize the benefit; and (2) one-piece flow can have bad effects on capacity if not implemented correctly.

When making all these changes to the production system, it is important to realize that a production system is very complex with many supporting activities. Therefore, when making changes, the entire value-creating system must be looked at, not just the shop floor. For example, just implementing a one-piece flow production system on the shop floor is not good enough. Instead, all the support systems (such as the PWO system and the production scheduling system) also need to be looked at and “leaned” out (i.e. all the waste removed). Only then will the maximum benefit be reaped from implementing lean manufacturing.

Next, the impact that one-piece flow can have on capacity cannot be over-emphasized. Without making all the required changes to cycle times and machine reliability, the large increases in productivity anticipated will probably never be achieved. Specifically, there is usually a reason why inventory exists. Inventory is a buffer used to reduce disruptions by reducing the propagation and influence of one machine’s failure on another machine. Therefore, without first

eliminating this reason (i.e. increasing the reliability of the various machines), simply reducing inventory will cause the factory to operate at less than optimum capability [Manufacturing News, 1996].

## **7.2 Recommendations**

In keeping with the spirit of continuous improvement, a number of observations and recommendations are made to improve further in the future. These are:

- *Incentives.* A large part of the success of the one-piece flow production strategy depends on workers becoming more multi-skilled. To promote this, the incentive structure for the workers must be better aligned with this goal. Currently, there is very little incentive for the workers to actually cross-train. In fact, there is incentive against it. In the past, the aerospace business has been very cyclical, with large lay-offs resulting in the down periods. As this is still fresh in a lot of the workers' minds, the workers might naturally want to protect their job security. By not encouraging or helping others cross-train on their jobs, they remain essential to the company, thus increasing their job security. Therefore, for the one-piece flow to be successful, the incentive system needs to be adjusted.
- *Training.* The manner in which the lean manufacturing is being implemented on the shop floor is through Kaizen teams. A small team of people (albeit cross-functional) go about trying to change the way things are done on the shop floor. Not surprisingly, these people often run into a lot of resistance on the shop floor. Since a lot of the other people on the shop floor do not truly understand what is being done or why, they naturally tend to resist. People often do not fear change, just the insecurity of not knowing what the end result will be or how they will fit into it. Therefore, more wide-spread training for all personnel involved, not just the Kaizen team, would be beneficial.
- *Fact-Based Decision-Making.* Lean manufacturing is about eliminating all waste. To do this, you have to know where the waste is. Initially, this might be very obvious, but as more of the low-hanging fruit is harvested, this will become less obvious. Therefore, to continue to improve, the need will arise for more fact-based decision-making. Only by having a better understanding of what the outcome of a process should be, or how much resources a process

really needs, can you see whether or not you have waste. Examples of this include time standards and WIP models. Only by knowing how much time a process should take can you see how you are performing. Similarly, only by knowing how much WIP should be in a system (based on all the parameters) can you see whether or not you have too much in the system. Without these fact-based decision-making tools, you can only guess at where the waste is.

- *Better Data.* Along with the need for more fact-based decision-making tools, comes the need for better and more timely data. In order to build capacity models, you need time data. In order to determine what the correct lead time is, you need to know how long it has been taking to build the product. This data collection needs to be done automatically if possible, and fed into the decision-making tools mentioned above. One possible way of doing this would be to switch to more data-based capacity or WIP models, where the model continuously draws time and cost data out of a data base. This makes changing the data and updating the models much easier.
- *Accountability.* Not all of the problems mentioned in Section 2.2 can be attributed to the current production system. Some of them are simply due to a lack of accountability. Without basic accountability, even the new one-piece flow strategy will be totally ineffective. This accountability actually becomes more important as the process is leaned out and the traditional buffers are removed.

### **7.3 Closing Comments**

So far, the results of all the improvement activities have been impressive. Some of these improvements can probably be attributed to more attention to detail, but others can only be explained by systematic change. However, all the expected results have not yet been achieved. As mentioned at the beginning of the thesis, this whole transformation to lean manufacturing is expected to take up to two years. As long as the building is able to continue its current rate of improvement, it should have no problem being able to achieve true world class status by the time the whole transformation is complete.

## References

- Gershwin, Stanley. *Manufacturing Systems Engineering*. PTR Prentice Hall. 1994.
- Manufacturing News. *Just-In-Time May Not Be Working As Planned*. Manufacturing News. March 15, 1996.
- Ohno, Taiichi. *Toyota Production System: Beyond Large-Scale Production*. Productivity Press. 1988.
- Monden, Yasuhiro. *Toyota Production System: An Integrated Approach to Just-in-Time*. Industrial Engineering and Management Press. 1993.
- Chao, Pierre. *Morgan Stanley US Investment Research*. Morgan Stanley Global Research. 30 Jan, 1997.
- Schonberger, Richard. *World Class Manufacturing: The Lessons of Simplicity Applied*. The Free Press. 1986.
- Shingo, Shigeo. *A Study of the Toyota Production System from an Industrial Engineering Viewpoint*. Productivity Press. 1989.
- Stalk, George Jr. and Thomas Hout. *Competing Against Time: How Time-Based Competition is Reshaping Global Markets*. The Free Press. 1990.
- TBM Consulting Group. *Shopfloor Kaizen Breakthrough*. TBM Consulting Group. 1994
- Womack, James, Daniel Jones and Daniel Roos. *The Machine that Changed the World: The Story of Lean Production*. Harper Perennial. 1990
- Womack, James and Daniel Jones. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon & Schuster. 1996.

